Indian Agriculture after Independence

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Indian Agriculture after Independence

Agriculture is the foundation of civilization, culture and heritage of India. About half of the Indian population derive their livelihood and income from agriculture and allied activities. On the occasion of 75th year of India's independence, the *Azadi Ka Amrit Mahotsav*, the success of National Agricultural Research, Education and Extension System in achieving national food security and farmers' prosperity is worth remembering. During the last 75 years, the country marched from a ship-to-mouth to self-sufficient to food exporting nation. The book '**Indian Agriculture after Independence**' portrays the uniqueness, diversity, vastness, history, achievements and aspirations of Indian agriculture. It chronologically depicts various science-backed agri-revolutions (Green, White, Blue, Yellow, Golden, Silver, Brown, Grey, etc.) and milestones, which transformed Indian agriculture. Seventeen chapters of the book provide overviews of the achievements and aspirations in crop, horticulture, animal science, fisheries, natural resource management, engineering, education, extension, policy, collaborations and leadership in agricultural research and development in the pre- and post-independent India.

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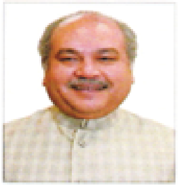

संदेश

हमने अपने देश के लोकतंत्र को दृढ़ निश्चय से पोषित और पल्लवित किया है तथा अभूतपूर्व प्रगति भी की है। स्वतंत्रता के बाद, हम "आज़ादी का अमृत महोत्सव" के रूप में आज़ादी के 75 वें वर्ष का आयोजन कर रहे हैं। यह देश और इसके सुयोग्य नागरिकों, जिन्होंने इसके लिए बहुत योगदान किया है, के लिए बहुत गर्व और सौभाग्य का अवसर है। प्रत्येक समारोह भोजन और पोषण से तथा हमारे जीवन में खुशी लाने से जुड़ा होता है। भारत की आज़ादी की वर्षगांठ का अवसर आज़ादी के बाद की अवधि में भारतीय कृषि की यात्रा का पुर्नअवलोकन, आकलन, वर्णन और प्रलेखन करने का एक शानदार और प्रसन्नता का अवसर है।

भारतीय कृषि जिसकी शुरुआत लगभग 11000 वर्ष पहले हुई, ने सदियों के दौरान महत्वपूर्ण प्रगति के कई आयाम तय किए हैं। भारतीय कृषि विश्व की सतत् उत्पादन प्रणालियों में से एक है, जोकि अपनी विविधता और विभिन्नता के लिए जानी जाती है। विज्ञान आधारित कृषि विकास ने भारत को 1950 के दशक तक खाद्यान्न अल्पता वाले देश से 2010 तक खाद्यान्न निर्यात करने वाला देश बना दिया है। हमारा खाद्यान्न उत्पादन जो वर्ष 1950 में 50 मिलियन टन था, वर्ष 2022 में बढ़कर 316 मिलियन टन से अधिक हो गया है। आज, भारत विश्व में दूध, दलहन और जूट का सबसे बड़ा उत्पादक है और धान, गेहूँ, कपास, फलों और सब्जियों का दूसरा सबसे बड़ा उत्पादक है। हम मसालों, मछली, मुर्गीपालन, पशुपालन और बाग़ान फसलों के अग्रणी उत्पादक भी हैं। तथापि, भारतीय कृषि बढ़ती आबादी, सिकुड़ रहे प्राकृतिक संसाधन आधार और गंभीर होते जलवायु परिवर्तन की पृष्ठभूमि में बढ़ती उत्पादकता, लाभात्मकता, बदलाव की अनेक चुनौतियों का सामना कर रही है।

"स्वतंत्रता के बाद भारतीय कृषि" नामक पुस्तक भारतीय कृषि की विशिष्टता, विविधता, विशालता, इतिहास, उपलब्धियों और आकांक्षाओं; विशेषकर आज़ादी के बाद की उपलब्धियों को दर्शाती है। यह हरित, श्वेत, नीली और अन्य कृषि क्रांतियों सहित क्रमानुसार उपलब्धियों को दर्शाती है; जिनके कारण, भारत खाद्यान्न के आयात करने वाले देश से आज खाद्यान्न निर्यातक देश के रूप में बदल गया है। यह उदयीमान विज्ञान एवं प्रौद्योगिकियों का इस्तेमाल करके आय, साम्यता, टिकाऊपन, जलवायु अनुकूलता और अपने मानवीय पक्ष को सुधारने के लिए भारतीय कृषि की आकांक्षाओं को भी प्रस्तुत करती है।

मैं, पुरातन काल से भारतीय कृषि की यात्रा और आज़ादी के बाद की विशेष उपलब्धियों को रेखांकित करने वाली इस पुस्तक के प्रकाशन के लिए भारतीय कृषि अनुसंधान परिषद को बधाई देता हूँ। यह पुस्तक विद्यार्थियों, शिक्षाविदों, अनुसंधानकर्ताओं, नीतिनिर्धारकों और कृषि क्षेत्र में कार्य करने वाली सार्वजनिक एजेंसियों के लिए उपयोगी होगी।

(नरेन्द्र सिंह तोमर)

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Prime Minister Shri Lal Bhahdur Shastri interacting with a farmer

त्रिलोचन महापात्र, पीएच.डी.
सचिव एवं महानिदेशक
TRILOCHAN MOHAPATRA, Ph.D.
SECRETARY & DIRECTOR GENERAL

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FOREWORD

Commemoration of 75th year of India's Independence 'Azadi Ka Amrit Mahotsav' is the moment of great pride, joy and honour. India is among the few fortunate democratic countries in the world, which is celebrating the Platinum Jubilee of its Independence. Agriculture is one amongst the few sectors that made progressive growth after independence and marched well with the need of the country. Success in agriculture since Independence has been the backbone of India's success. The successful transformational narration of independent India, therefore, is incomplete without the narration of the agricultural transformation from 'ship to mouth' to 'self-sufficiency and export'. The agricultural imperative and achievements of India has been appreciated globally. The book 'Indian Agriculture after Independence' narrates the journey of agriculture in the last 75 years of post-independent India.

The progress of Indian agriculture has been quite impressive despite several limiting factors such as uncertainties of weather, declining soil health, increasing atmospheric temperature and emergence of virulent pest and pathogens. The transformation from an acutely food-scarce to food-exporting country could be realized with the concerted efforts by ICAR as frontal organization through development and dissemination of technology, building human capital and establishing the rural farm centres to serve the farmers. In this book, we presented this challenging but successful journey of Indian agriculture.

The book captures the uniqueness of Indian agriculture and depicts the various revolutions in staple food, livestock and fisheries making India a food scarce country to food surplus and food exporting nation. The book also presents the aspirations of Indian agriculture for improving income, equity, sustainability, climate resilience and its human face using the emerging technologies.

I compliment the editors and authors for bringing out this publication that shall be useful for students, academicians, researches, policymakers and public agencies to take the task of agricultural development. The book will serve a treatise of milestones, achievements, impacts and lessons of Indian agriculture during the last 75 years to guide the future path.

Trilochan Mohapatra

Prime Minister Smt. Indira Gandhi visiting IARI, New Delhi

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Agriculture is the foundation of the civilization, culture and heritage of India. Agriculture in India is a complex mosaic of distinct agro-ecosystems, differentiated by climatic, soil, vegetation and other natural features. About half of the Indians derive their livelihood from agriculture and allied activities. It is one of the oldest systems of the world characterized by its diversity and heterogeneity, unorganized and stressed on account of natural and anthropogenic vagaries from 'seed to market'. Historically, stressed natural resources due to unfavourable weather, monsoon and natural calamities resulted in crop failures leading to food shortage that made serious impacts on the civilization. Post-Independence, the Indian agriculture transformed from a food-scarce to food-exporting country primarily due to science led innovations that caused multifold increase in the agricultural production from 135 million tons in 1950/51 to over 1300 million tons in 2021/22 in spite of increasing abiotic and biotic stresses and depleting alongwith deteriorating natural resources.

The book 'Indian Agriculture after Independence' portrays the uniqueness, diversity, vastness and history; and captures the aspirations of Indian agriculture to develop a road-map for agri-food system matching with the 4th Industrial Revolution and the global commitments on food security, nutrition and sustainability. The first chapter provides an overview of Indian agriculture with its achievements and aspirations. The following three chapters detail out the crop and animal husbandry and natural resource management in the pre-independent India starting from the Vedic to British period. The subsequent chapters present the achievements of Indian agriculture after independence in the areas of field crops, horticulture, livestock and poultry, fisheries and aquaculture, crop and animal health, mechanization and post-harvest processing, natural resources management, agricultural education and extension, as well as policy, investment, collaboration and organizational leadership.

The book is an outcome of a sincere exercise by about 60 leading scientists and science-leaders of ICAR, from a range of disciplines. In the course of preparing the book, the authors and editors have received help and support from different individuals. We are extremely grateful to each one of them. Our sincere gratitude to the distinguished reviewers namely Dr. RB Singh, Dr. SP Ghosh, Dr. JC Katyal, Dr. Mruthyunjaya, Dr. MP Yadav, Dr. SL Mehta, Dr. P Das, Dr. VM Mayande and Dr. AG Ponnaiah for their constructive suggestions and guidance. The editors take this opportunity to express their gratitude to

all the authors for developing the chapters in a comprehensive and time-bound manner. We sincerely thank Hon'ble Minister of Agriculture and Farmers' Welfare, and Hon'ble Ministers of State of Agriculture and Farmers' Welfare, Govt. of India and Secretary, DARE & DG, ICAR for their guidance and support in bringing out this publication. We are thankful to the ICAR-Directorate of Knowledge Management in Agriculture, New Delhi for its support in formating, developing the cover page and printing of the book.

We hope that the publication would be useful to the students, researchers, teachers, policy makers, planners, administrators and the farmers.

Editors

CONTENT

Abbreviations

ABI	Agri-Business Incubation
ABNJ	Areas Beyond National Jurisdiction
ACABC	Agri-Clinic and Abri-business Centre
ACARE	Advanced Centre for Agricultural Research and Education
ADSS	Autonomous Decision Support Systems
AHRD	Agricultural Human Resource Development
AI	Artificial Intelligence
AICARP	All India Coordinated Agronomic Research Project
AICMIP	All India Co-ordinated Millets Improvement Project
AICPIP	All India Coordinated Pulse Improvement Project
AICRIP	All India Coordinated Rice Improvement Project
AICRP	All India Coordinated Research Project
AICRPO	All India Coordinated Research Project on Oilseeds
AICVIP	All India Coordinated Vegetable Improvement Project
AICWIP	All India Coordinated Wheat Improvement Project
AIEEA	All India Entrance Examinations for Admission
AINP	All India Network Project
AMR	Anti-microbial Resistance
ANASTU	Afghan National Agricultural Sciences and Technology University
APAARI	Asia-Pacific Association of Agriculture Research Institutions
APC	Agro-Processing Centers
APCAEM	Asian and Pacific Centre for Agricultural Engineering and Machinery
APMC	Agricultural Produce Market Committee
APMR	Agriculture Produce Marketing Regulation
ARS	Agricultural Research Services
ARYA	Attracting and Retaining Youth in Agriculture
ASEAN	Association of South East Nations
ASRB	Agricultural Scientists Recruitment Board
ATIC	Agricultural Technology Information Centre
ATMA	Agricultural Technology Management Agency
AVRDC	Asian Vegetable Research & Development Centre
AWS	Automatic Weather Stations
BARC	Bangladesh Agricultural Research Council
BBF	Broad Bed and Furrow
BBRC	Bioscience Biotechnology Research Communications
BGA	Blue Green Algae
BI	Bioversity International
BIMSTEC	Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation
BIRAC	Biotechnology Industry Research Assistance Council
BIS	Bureau of Indian Standards
BISA	Borlaug Institute for South Asia

BMC	Broodstock Multiplication Centres
BMGF	Bill & Melinda Gates Foundation
BPD	Business Planning and Development
BRDs	By-catch Reduction Devices
BRICS	Brazil, Russia, India, China and South Africa
BSAA	Belarusian State Agricultural Academy
BSMA	Broad Subject Matter Area
CAAS	Chinese Academy of Agricultural Sciences
CABI	Centre for Agriculture & Biosciences International
CACP	Commission for Agricultural Costs & Prices
CAFRI	Central Agroforestry Research Institute
CAGR	Compound Annual Growth Rate
CAS	Centre of Advanced Studies
CAZRI	Central Arid Zone Research Institute
CBP	Capacity Building Program
CCAFS	Climate Change, Agriculture and Food Security
CCARI	Central Coastal Agriculture Research Institute
CCIS	Comprehensive Crop Insurance Scheme
CDP	Community Development Programme
CGIAR	Consultative Group for International Agricultural Research
CHC	Custom Hiring Centre
CIAE	Central Institute of Agricultural Engineering
CIAH	Central Institute for Arid Horticulture
CIAT	International Centre for Tropical Agriculture
CIB	Central Insecticides Board
CIBA	Central Institute of Brackishwater Aquaculture
CIDA	Canadian International Development Agency
CIFA	Central Institute of Freshwater Aquaculture
CIFE	Central Institute of Fisheries Education
CIFRI	Central Inland Fisheries Research Institute
CIFT	Central Institute of Fisheries Technology
CIMMYT	International Maize and Wheat Improvement Centre
CIP	International Potato Centre
CIRAD	Centre for International Research on Agricultural Development
CIRCOT	Central Institute for Research on Cotton Technology
CISH	Central Institute for Subtropical Horticulture
CMFRI	Central Marine Fisheries Research Institute
CPCRI	Central Plantation Crops Research Institute
CPE	Cumulative pan evaporation
CRIDA	Central Research Institute for Dryland Agriculture
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CRM	Crop Residue Management
CROPSAP	Crop Pest Surveillance and Advisory Project
CSCA	Central Staff College for Agriculture
CSIR	Council of Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSISA	Cereal Systems Initiative South Asia
CSMCRI	Central Salt and Marine Chemicals Research Institute

CSS	Central Sector Scheme
CSSRI	Central Soil Salinity Research Institute
CWC	Central Warehousing Corporation
DACP	District Agricultural Contingency Plans
DAFW	Department of Agriculture & Farmers Welfare
DARE	Department of Agricultural Research & Education
DARS	Desert Afforestation Research Station
DBT	Department of Biotechnology
DCFR	Directorate of Coldwater Fisheries Research
DDG	Deputy Director-General
DDPSC	Donald Danforth Plant Science Center
DFID	Department for International Development
DISA	District-level Institute of Scientific Agriculture
DOR	Directorate of Oilseeds Research (now Indian Institute of Oilseeds Research)
DPPQS	Directorate of Plant Protection Quarantine and Storage
DSR	Direct seeded rice
DWR	Directorate of Wheat Research
e-NAM	e-National Agriculture Market
EAFM	Ecosystem Approach to Fisheries Management
EC	Electrical Conductivity
EEZ	Exclusive Economic Zone
EIA	Environmental impact assessment
EIAR	Ethiopian Institute of Agriculture Research
ELKS	Enhancing livelihoods through livestock knowledge systems
EPNs	Entomopathogenic Nematodes
ETP	Effluent Treatment Ponds
ETP	Endangered Threatened and Protected
EUS	Epizootic Ulcerative Syndrome
FAO	Food and Agriculture Organization
FAW	Fall armyworm
FCI	Food Corporation of India
FFS	Farmer Field School
FISH	Fluorescence *in situ* hybridization
FLRP	Food Legumes Research Platform
FPC	Farmers Producers Company
FPO	Farmer Producers Organizations
FSI	Fishery Survey of India
GAP	Good Agricultural Practices
GBPUAT	Govind Ballabh Pant University of Agriculture and Technology
GCF	Gross Capital Formation
GDP	Gross Domestic Product
GEAC	Genetic Engineering Appraisal Committee
GEBV	Genomic Estimated Breeding Value
GER	Gross Enrolment Ratio
GTV	Goat Tissue Virus
GUI	Graphic User Interface
GVA	Gross Value Added
HCIO	Herbarium Cryptogamae India Orientalis

HPR	Host Plant Resistance
HPV	Hepatopancreatic parovirus
HSI	Hyperspectral imaging
HYVP	High Yielding Varieties Programme
IAN	Indian Agriculture Network
IAP	India Agricultural Programme
IARI	Indian Agricultural Research Institute
IBSA	India, Brazil and South Africa
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICFRE	Indian Council of Forestry Research & Education
ICGEB	International Centre for Genetic Engineering and Biotechnology
ICIMOD	International Centre for Integrated Mountain Development
ICMR	Indian Council of Medical Research
ICRAF	World Agro-Forestry Centre
ICRISAT	International Crop Research Institute for the Semi Arid Tropics
ICT	Information and Communication Technology
IDA	International Depositary Authority
IDLAM	Integrated District Level Adaptation and Mitigation
IDWR	Indian Daily Weather Report
IEC	Information, Education and Communication
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
IFS	Integrated Farming System
IHHNV	Infectious hypodermal and haematopoietic necrosis virus
IIFSR	Indian Institute of Farming Systems Research
IINRG	Indian Institute of Natural Resin and Gums
IISR	Indian Institute of Sugarcane Research
IISS	Indian Institute of Soil Science
IIWM	Indian Institute of Water Management
ILRI	International Livestock Research Institute
IMD	India Meteorological Department
IMNV	Infectious myonecrosis virus
IMTA	Integrated Multi-trophic Aquaculture
IMTECH	Institute of Microbial Technology
INFAAR	Indian Network of Fishery and Animals Antimicrobial Resistance
INRAE	National Research Institute for Agriculture, Food and Environment
IOFS	Integrated organic farming system
IPM	Integrated Pest Management
IR	International Relations
IRDP	Integrated Rural Development Programme
IRRI	International Rice Research Institute
ISHS	International Society for Horticulture Sciences
ISRO	Indian Space Research Organization
ISTA	International Seed Testing Association
ITCC	Indian Type Culture Collection
ITD	Innovations in Technology Dissemination
IVLP	Institution Village Linkage Programme

IVRI	Indian Veterinary Research Institute
IW	Irrigation Water
IWM	Integrated weed management
IWMI	International Water Management Institute
JFE-SSD	Juvenile Fish Excluder cum Shrimp Sorting Device
JIRCAS	Japan International Research Center for Agricultural Sciences
JTRL	Jute Technological Research Institute
KCC	Kisan Credit Card
KSHAMATA	Knowledge System for Homestead Agriculture Management in Tribal Areas
KTI	Kunitz Trypsin Inhibitor
KVK	Krishi Vigyan Kendra
LCA	Life Cycle Analysis
LGP	Length of Growing Periods
LTFE	Long-term Fertilizer Experiments
MACS	Mutually-Aided Cooperative Society
MBV	Monodon baculosvirus
MCA	Ministry of Corporate Affairs
MCE	Multi-Criteria Evaluation
MERU	Multidisciplinary Education and Research University
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MIDH	Mission for Integrated Development of Horticulture
MoFPI	Ministry of Food Processing Industries
MOVCD	Mission on Organic Value Chain Development
MOVCD-NER	Mission Organic Value Chain Development for North Eastern Region
MPEDA	Marine Products Export Development Authority
MRL	Maximum residue limits
MSME	Medium, Small, Micro Enterprises
MSNP	Micro and Secondary Nutrients and Pollutant
MSP	Minimum Support Price
MSRS	Multistage Stratified Random Sampling
MSU	Michigan State University
MSY	Maximum Sustainable Yield
NAARM	National Academy of Agricultural Research Management
NAAS	National Academy of Agricultural Sciences
NABARD	National Bank for Agriculture & Rural Development
NAC	Norms and Accreditation Committee
NACA	Network of Aquaculture Centres in Asia-Pacific
NAEAB	National Agricultural Education Accreditation Board
NAHEP	National Agricultural Higher Education Project
NAIF	National Agriculture Innovation Fund
NAIMCC	National Agriculturally Important Microbial Culture Collection
NAIP	National Agricultural Innovation Project
NARES	National Agricultural Research and Education System
NARI	Nutri-Sensitive Agricultural Resources & Innovations
NARO	National Agricultural Research Organization
NARP	National Agricultural Research Project
NARS	National Agricultural Research System
NASF	National Agricultural Science Fund

NATP	National Agricultural Technology Project
NBAIR	National Bureau of Agricultural Insect Resources
NBFGR	National Bureau of Fish Genetic Resources
NBPGR	National Bureau of Plant Genetic Resources
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NCA	National Commission on Agriculture
NCDC	National Cooperative Development Corporation
NCIPM	National Research Centre for Integrated Pest Management
NCPA	National Committee on use of Plastics in Agriculture
NCPAH	National Committee on Plasticulture Applications in Horticulture
NEH	North Eastern Hill
NFBSFARA	National Agricultural Innovation Project and the National Fund for Basic, Strategic and Frontier Application Research in Agriculture
NFDB	National Fisheries Development Board
NFFBB	National Freshwater Fish Brood Bank
NHAEP	National Higher Agricultural Education Project
NHB	National Horticulture Board
NHG	National Hybridization Garden
NIASM	National Institute of Abiotic Stress Management
NIBSM	National Institute of Biotic Stress Management
NICRA	National Innovation on Climate Resilient Agriculture
NIDHI	National Initiative for Developing and Harnessing Innovations
NILERD	National Institute of Labour Economics Research and Development
NIM	National Insect Museum
NIOT	National Institute of Ocean Technology
NIPB	National Institute for Plant Biotechnology
NIRJAFT	National Institute of Research on Jute and Allied Fibres Technology
NMCG	National Mission for Clean Ganga
NMSA	National Mission for Sustainable Agriculture
NPC	National Pusa Collection
NPOF	Network Project on Organic Farming
NPV	Nuclear Polyhedrosis Viruses
NRFC	National Repository of Fish Cell lines
NRG	Natural resins and gums
NRLMP	National Rural Livelihood Mission
NRM	Natural Resource Management
NSPAAD	National Surveillance Programme for Aquatic Animal Diseases
NTC	National Training Centre
NWDPRA	National Watershed Development Programme for Rainfed Areas
ODL	Open and Distance Learning
OGL	Open General Licensing
ORP	Operational Research Programme
OSU	OHIO State University
PACS	Primary Agricultural Cooperative Society
PAW	Parthenium Awareness Week
PDCSR	Project Directorate for Cropping Systems Research
PDF	Post-doctoral Fellowship
PDS	Public Distribution System

PEASEM	Plastic Engineering in Agricultural & Environment Management
PGPR	Plant Growth Promoting Rhizobacteria
PGS	Post Graduate Scholarship
PHET	Post-harvest Engineering and Technology
PIRRCOM	Project on Intensification of Regional Research in Cotton, Oilseeds, and Maize
PKVY	Paramparaghata Krishi Vikas Yojana
PM-KISAN	Pradhan Mantri Kisan Samman Nidhi
PME	Priority Setting Monitoring & Evaluation
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PMFME	Prime Minister Formalization of Micro Food Processing Enterprises
PPVFR	Protection of Plant Variety and Farmers Rights
PRECIS	Providing Regional Climates for Impacts Studies
PSSB	Professional Standard Setting Body
PYE	Potential Yield Estimation
QPM	Quality Protein Maize
RAWE	Rural Agricultural Work Experience
RAWEP	Rural Agricultural Work Experience Program
RCRC	Rapid Rural Community Response
RGCA	Rajiv Gandhi Centre for Aquaculture
RKVY	Rashtriya Krishi Vikas Yojana
RMS	Rabi Marketing Season
SAA	Seychelles Agricultural Agency
SAARC	South Asian Association for Regional Cooperation
SAC	Space Application Centre
SAU	State Agricultural University
SBIRI	Small Business Innovation Research Initiative
SCH	Single Cross Hybrid
SFAC	Small Farmers Agribusiness Consortium
SLCARP	Sri Lanka Council for Agricultural Research and Policy
SNP	Single Nucleotide Polymorphism
SOC	Soil Organic Carbon
SOP	Standard Operating Procedure
SPLAT	Specialized Pheromone and Lure Application Technology
SRI	System of Rice Intensification
SSD	Sub-surface drainage
SSS	Seed Support System
SST	Sea Surface Temperature
STCR	Soil Test Crop Response
TBI	Technology Business Incubation
TMIS	Training Management Information System
TMO	Technology Mission on Oilseeds
TMOP	Technology Mission on Oilseeds & Pulses
TNA	Training Need Assessment
TRIPS	Trade-Related Intellectual Property Rights
UCPH	University of Copenhagen
UN	United Nations
UN-CAPSA	United Nation's Centre for Alleviation of Poverty through Sustainable Agriculture

UNDP	United Nation Development Programme
UPAYA	Unleashing Potential in Agriculture for Young Agri-preneures
USA	United States of America
USAID	United States Agency for International Development
USDA	United State Department of Agriculture
VATICA	Value Addition and Technology Incubation Centre in Agriculture
VCRMC	Village Climate Resilience Management Committee
VHF	Vacuum Hermetic Fumigation
VNN	Viral Nervous Necrosis
WDCM	World Data Centre for Microorganisms
WFC	World Fish Centre
WFCC	World Federation for Culture Collections
WIPO	World Intellectual Property Organization
WSN	Wireless Sensor Networks
WTC-ER	Water Technology Center for Eastern Region

Prime Minister Pt. Jawaharlal Nehru examining growth of the wheat plant

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Chapter

Indian Agriculture: Achievements and Aspirations

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Summary

Indian agriculture, which began around 11,000 years before present (BP) with the domestication of animals and early cultivation of plants, has made significant progress over the millennia. This found place in the ancient scripts of Vedas, Upanishadas, Ramayana and Mahabharata. Agriculture in India has been a complex mosaic of distinct agro-ecosystems, differentiated by climatic, soil, vegetation and other natural features, often heterogeneous, unorganized and subjected to vagaries from 'seed to market'. Historically, food shortage in pre-independent India caused serious impacts as agriculture was monsoon-dependent and unfavourable rains and natural calamities resulted in crop failures. The planning process in the independent India, therefore identified agriculture as the most prioritized sector and emphasized that '*everything can wait but agriculture*'. In spite of the odds of uncertain weather, declining soil health, increasing atmospheric temperature and emergence of virulent pest and pathogens, which are continuing post-independence, Indian agriculture achieved several landmarks primarily due to science-led agricultural development. The most signifying milestone has been food security that brought confidence and raised the country's stature globally. We must not forget the ill memories of '*ship to mouth'* till 1950s. It is the toiling work of millions of our farmers, scientists and the planners that transformed India from a food deficit country to a food surplus and net food exporter nation. The food grain production, which was merely 51 million tons (Mt) in 1950/51 increased over 6 times to over 314 Mt in 2022. The country has also become the largest producer of milk, pulses and jute and second largest producer of rice, wheat, cotton, fruits and vegetables in the world. India is also one of the leading producers of spices, fish, poultry, livestock and plantation crops. However, Indian agriculture continues to battle several intimidating challenges of increasing productivity, profitability and resilience at the backdrop of increasing population, depleting natural resource base, aggravating climate change and reducing farm income. We are now reimagining the Indian agriculture and prioritized for enhancing farmers income (200%), reducing fertilizer use (25%) and water use (20%), increasing use of renewable energy (50%), reducing greenhouse gas emission intensity (45%) and rehabilitating degraded land of 26 million ha (Mha). India, being a signatory and prominent member of the United Nations, has several international commitments such as Panchamrit and carbon neutrality, land degradation neutrality, biodiversity conservation, regional agricultural development and Sustainable Development Goals (SDGs). Fortunately, advances in science have opened new avenues for addressing the challenges and fulfilling the priorities and

commitments. A multi-pronged strategy with integration, diversification, intensification, customisation, farm mechanization, value addition and market access are the way forward to realise the full potentials of Indian farming with focus on profitable commercialization and export, ecosystem approach, sustainable agri-food system involving smart farmers and farming, post-harvest value addition and entrepreneurship engaging youth and women. Indian Council of Agricultural Research (ICAR) and the National Agricultural Research, Education and Extension System (NAREES), are determined to harness the advances of science and technology to infuse pull and push in agriculture for an all-round welfare of the society.

1. Introduction

Agriculture is the foundation of livelihood, civilization, culture and heritage of India. With a population of 1.39 billion, India is the world's second most populous country, and is projected to become most populous by 2027-30, leaving China behind. It is the 7th largest country geographically in the world with 328 Mha area. India has about 160 Mha of arable land, second largest after the United States of America and experiences all the 15 prominent climates with 46 out of 60 soil-types that exist on the earth. About 50% of its total geographical area is cultivated which ranks it among the top user of the land for agriculture. In the more geographically suitable Indo-Gangetic Plain (IGP) and the deltas of the eastern coast, the proportion of cultivated to total geographical area often exceeds 90%. Indian agriculture, one of the oldest systems of the world; is diverse, heterogeneous, unorganized and often subjected to vagaries at various phases from 'seed to market'. It is the critical sector of economy for the sustainable and inclusive economic growth of the country. The sector engages 49.6% of the workforce, often seasonally, under-employed, under-paid and accounts for about 17% share in India's Gross Domestic Product (GDP).

Indian agriculture began as early as 11,000 BP with the domestication of animals and early cultivation of plants as evidenced in the ancient literature. The Bhagavad Gita, Rig Veda and Atharva Veda contain details on agriculture like crop, cultivation, manuring, classification of herbs and different varieties of plants. In ancient India farmers used to start the agricultural practices such as ploughing, sowing, reaping and harvesting on auspicious days as these were linked with religious customs. The Rig Veda proclaimed that '*May the ploughshares till our land properly; may the ploughmen go happily with the oxen'*. Maharshi Bhrugu, son of Maharshi Varun, observed, "*Food is the Brahma. Never speak ill about food. Never reject the food. Take an oath to produce plenty of food*". *Krishi-Parashara* with two hundred and forty-three verses is the theory of agriculture expounded in manner so as to benefit the farmers. Similarly, *Vrikshayurveda* discusses the science of plant life such as procuring, preserving and treating of seeds before planting; selection of soil and nourishment; and plant protection from internal and external diseases.

Since the beginning of civilization, Indian agriculture has made significant progress. However, there has been several periods in Indian history, when food shortage made serious impacts on civilization. In the pre-Independent India, agriculture has been heavily dependent on climate. Unfavourable monsoon, particularly southwest monsoon causes droughts and crop failure. Such droughts, sometimes in consecutive years led to famines. Famines in India resulted in more than 30 million deaths over the course of the 18th, 19th and early 20th centuries (Table 1).

Table 1. Famines in pre-independent India

Name of the Famine	Year	No. of victims (million)
1. Bengal Famine	1769-70	2-10
2. Chalisa Famine	1783-84	11
3. Doji Bara Famine	1791-92	11
4. Agra Famine	1837-38	0.8
5. Upper Doab Famine	1860-61	2
6. Orrisa Famine	1865-67	4-5
7. Rajasthan Famine	1868-70	1.5
8. Bihar Famine	1873-74	2.5
9. Southern India Famine	1876-78	6-10
10. Indian Famine	1896-97	12-16
11. Indian Famine	1899-1900	3-10
12. Great Bengal Famine	1943	2-3

Source: Adopted from IGI (1907)

The famous quote of India's first Prime Minister Pandit Jawaharlal Nehru that '*everything can wait but agriculture*' and Mahatma Gandhi's observation that '*there are people in the world so hungry, that God can not appear to them except in the form of bread*' signifies the importance of agriculture and the priority given to it after independence. The beginning happened with 'Grow More Food, Campaign in 1947 which later moved with scientific vigour, planners' rigour and millions of farmers' hard work. In the co-existence of uncertainties of weather and declining soil health, increasing atmospheric temperature and emergence of more virulent pests and pathogens, the science-led agricultural development transformed India from an acutely food-scarce and food shortage to food sufficient to food surplus and food exporting country. The overall food grain production increased from 51 Mt in 1950-51 to over 314 Mt in 2021-22. The production of food grains increased over 6 times, horticultural crops by 11 times, fish by 18 times, milk by 10 times and eggs by 53 times since 1950-51, thus making a visible impact on the national food and nutritional security (Pathak and Ayyappan 2020). India is today the largest producer of milk, pulses and jute and second largest producer of rice, wheat, cotton, fruits and vegetables in the world on account of active efforts and contributions of agricultural scientists. It is also one of the leading producers of spices, fish, poultry, livestock and plantation crops.

The accomplishments are numerous so are the newer challenges. The burgeoning population, changing economies have raised the demand for diversified quality food while the primary production resource base is not only depleting but also deteriorating. The cost of applied inputs, machines and labour has increased that adversely impacted the profitability. Consequently, farming at times no longer remains an attractive income option and preferred profession. Added to it, growth rate in productivity of many crops has become stagnant and further compounded by the challenges of climate change. About 49% of country's net cultivated area is rainfed and exposed to biotic and abiotic stresses. Even the areas in the command of those irrigation systems falling exclusively in the rainfed catchments also experience water stress in the event of deficient monsoon. Flood, especially in eastern part of the country, has been a regular feature which is now experienced in the driest regions due to change in rainfall pattern. In addition, frost in north-west, heat waves in central and northern parts and cyclone in eastern coast, the frequency of which have increased in recent years, cause havoc.

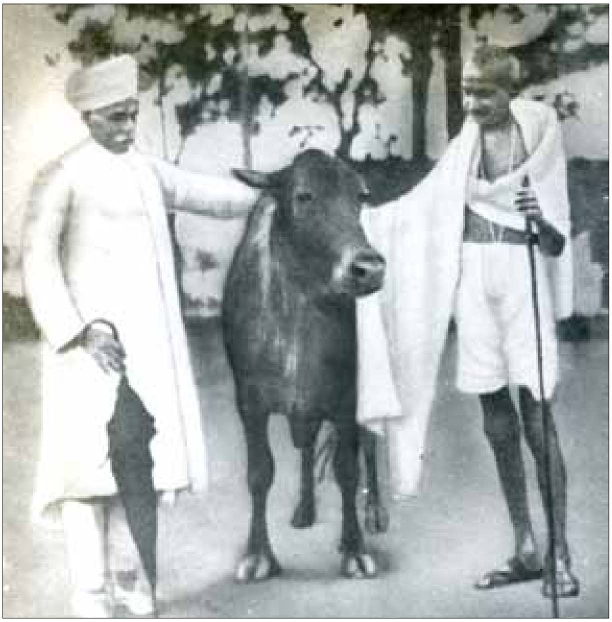
However, amongst the few sectors that made impressive progress during past 75 years of India' independence, agriculture is confidently the one. This has been proven time and again when all the sectors fall short, agriculture came as saviour. The recent performance during global pandemic COVID-19 is the best testimony. In this chapter, we discuss about the enormity, uniqueness and diversity of Indian agriculture; major milestones achieved; contributions of research and development in these achievements and the emerging challenges to make Indian agriculture productive, profitable and sustainable.

2. Unique, vast and diversified agriculture in India

Indian agriculture is as diverse as the country itself. It encompasses different agro-ecosystems based on commonality of climatic, soil, geological, vegetational and other natural features, which decide the diversity of habitats, variety of crops and livestock that has been developed over the millennia. India is one among the earliest regions on earth, where settled agriculture began about 11,000 years ago. The Indian region is one of the world's 8 centres of origin of crop plants. About 166 crop species and 320 wild relatives of crops have originated here. Genetic diversity within each species is also tremendous. For example, one species of rice has diversified into at least 50,000 distinct varieties, and one species of mango into over 1,000 varieties ranging from the size of a peanut to a small pumpkin. India also has the world's largest diversity of livestock. All the world's eight buffalo breeds are found here. More than mere physical adaptation, a host of economic, cultural, religious, and survival factors have played a role in this diversification. Several varieties of rice and other crops, for example, were grown in many parts of India just for their use during festivals, marriages or other auspicious occasions; several others were grown for their taste, colour or smell; and others for their pesticidal or soil-fertilization characteristics.

India is a unique and diverse country. It's climate varies from humid and dry tropical in the south to temperate alpine in the north. It is the home to vast agro-ecological diversity with 4 out of the 34 global biodiversity hotspots and 15 World Wide Fund for Nature (WWF) of global 200 eco-regions within the country. With only 2.4% of the world's land area, the country harbours around 8% of all recorded species, including over 45,000 plant and 91,000 animal species (Britannica, UK).

As the climate varies across the regions, so is the water availability in the country. The supply of water for agriculture is highly seasonal and depends mostly on the southwest monsoon, and partly on the northeast monsoon in a few southern states. The water availability for irrigation also varies greatly. For example, in the IGP region, because of the perennial rivers flowing from the Himalayas and recharged groundwater, adequate water for irrigation is available. However, the groundwater is depleting rapidly raising concerns about future crop productivity and sustainability. Contrast is true for peninsular India, where highly seasonal rainfall regime, lack of perennial water streams and hard rock formations limits the groundwater aquifers recharge adequately. India possesses large areas of highly fertile alluvial soils such as in the IGP, and relatively productive black soils of the Deccan plateau and the red-to-yellow lateritic soils. Most of the remainder of the soils are low in fertility. Overall, organic carbon content of Indian soils is less than 0.5%, which unfortunately is going down.



Mahatama Gandhi with Pt. Madan Mohan Malaviya at NDRI, Bangalore

The cropping is rather diverse in the country with about 60 crops grown in some states. The number may be even higher if localized cultivated crops are accounted for. In the order of area and production, rice is the foremost cereal crop of kharif season and wheat of rabi season. Other important cereals are maize, sorghum, pearl millet and finger millet. Another important category of food crop is pulses dominated by chickpea. These are the important source of plant protein for most Indians. The oilseeds that provide edible oil is another important group of crops. Amongst the 9 oilseed crops, soybean, rapeseed and mustard and groundnut are the important ones. The food and non-food crops that are used by industries to process and produce finished products include sugarcane, cotton, jute, mesta, tobacco, tea, etc. Tomato, onion and potato (TOP); and other green vegetables such as brinjal, okra and squashes as well as fruits such as mango, banana, mandarin orange, papaya and melons are non-staple crops. Various spices such as chilies, turmeric and ginger are cultivated for domestic as well export purposes with a long history and acknowledgement worldwide.

Animal husbandry is an integral part of India's agricultural system. Animal genetic resources are nation's traditional strength and provide a good option to manage agriculture sector in more profitable and sustainable manner. India has the largest bovine population of the world. Mixed farming of crops and livestock is the predominant farming system in India. Total livestock population is 536 million in India with 36% constituted by cattle and 20% by buffaloes. Total milk production in India was 210 Mt in the year 2021-22 with per capita milk availability of nearly 400 g day^{-1}. The major portion of the milk produced in India is contributed by small and marginal farmers. ICAR has characterized the livestock population of India in their natural home tracts and registered 197 breeds. This includes 50 breeds of cattle, 17 breeds of buffaloes, 34 breeds of goats, 44 breeds of sheep, 9 breeds of camel, 7 breeds of horses, 19 breeds of chicken and 3 breeds of dog.

Fishing is practiced along the entire length of India's coastline and in the, reservoirs and lakes. The marine and inland fisheries are contributing production of 3.8 Mt and 1.3 Mt, respectively. Major marine fishes include sardine and mackerel whereas the freshwater catches are dominated by carps. Aquaculture of fish and shrimp is becoming increasingly significant, which at present contributes over 9.0 Mt.

3. Agricultural research in India

Agriculture is possibly the oldest sector in the country to have research as its core segment. There are evidences of research and development in agriculture in the ancient as well medieval period of Indian history. A detailed account of such agricultural developments in crop husbandry, animal husbandry and natural resources management in the pre-independent India has been presented in chapters 2, 3 and 4, respectively of this book.

Systematic research in the country started with the establishment of Imperial Council of Agricultural Research (1929) in Delhi, which is known today as Indian Council of Agricultural Research (ICAR). This is the apex body with its headquarters at New Delhi for coordinating, guiding and managing research and education in agriculture including animal sciences and fisheries. The Council is an autonomous organisation under the governance of Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmers Welfare, Government of India. Established on 16 July 1929 as a registered society under the Societies Registration Act (1860) in pursuance of the report of the Royal Commission on Agriculture, ICAR now has 113 research institutes, 74 agricultural universities, 4 deemed-to-be-universities, 3 central universities and 731 Krishi Vigyan Kendras spread across the country. With these, ICAR leads one of the largest National Agricultural Research and Education System (NARES) in the world. India has one of the largest agricultural research human resource capitals in the world with approximately 30,000 scientists and more than 100,000 technical & supporting personnel in the NARES. ICAR footprints are also extended to the neighbouring countries and several international, national and regional research organizations and universities are engaged with ICAR in agricultural research and development. Additionally, private and non-Governmental organizations and farmers themselves have done significant agricultural research in their own fields.

4. Landmark achievements in Indian agriculture

In the year 1950-51 for which the data of agricultural production of majority of the commodities are available by the authorized sources, we have been producing about 135 Mt from agriculture and allied sectors. In 2021-22, total production of food and non-food items was about 1300 Mt. This achievement is one amongst the very few noticeable landmarks in the history of Independent India. There has been multi-fold increase in the production of all the commodities, in spite the net sown area remaining almost constant at about 140 Mha. The country has witnessed a rainbow revolution in the agricultural commodities (Fig. 1).

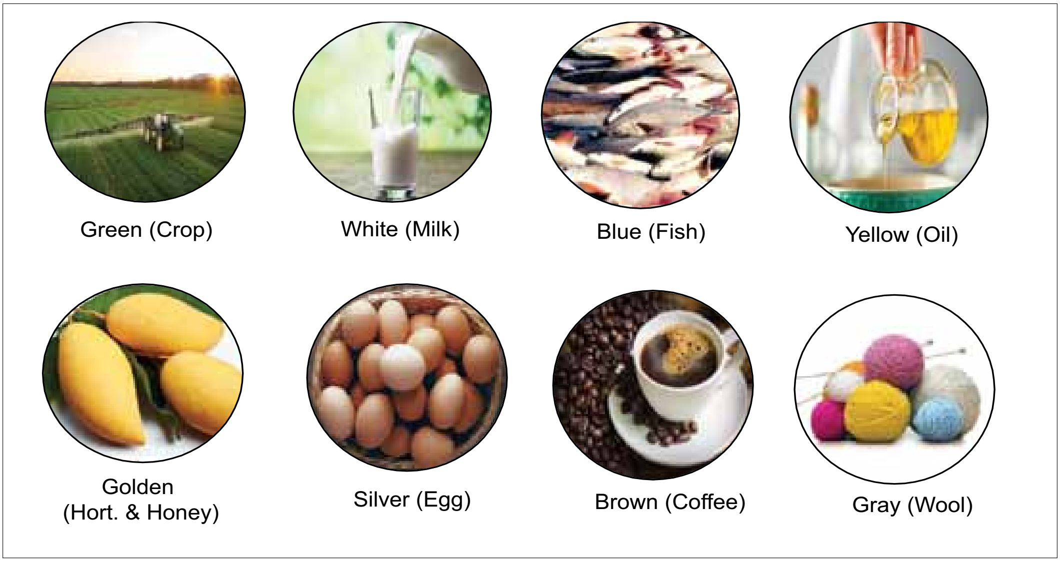


Fig. 1. Revolutions in Indian agriculture

India now is one of the largest agri-producers globally, ranking within the top 5 countries. These have enabled not only self-sufficiency in food, but also export of agri-commodities worth US$ 50 billion. Production of most of the agricultural commodities has increased by 6 to 68 times with only 1.3 times increase in area (Table 2). Thus, the country, which was food scarce till 1950, transformed itself into food shortage by 1960, food sufficient by 2000, food secured by 2010 and food surplus by 2010 onwards (Fig. 2). During the on-going COVID-19 pandemic situation also, food production systems have been meeting the demands, with innovative interventions across the value chain. There are also indications that the greenhouse gas (GHG) emission intensity in agriculture is reducing and fertilizer use efficiency is improving in recent years (Pathak and Ayyappan 2020). A blend of science, technology, extension and policy has contributed in this journey of transforming the country from food scarce to food surplus nation. The milestone achievements of Indian agriculture are briefly presented in the subsequent sections and in Table 3 (Pre-Independence) and Table 4 (Post-Independence).

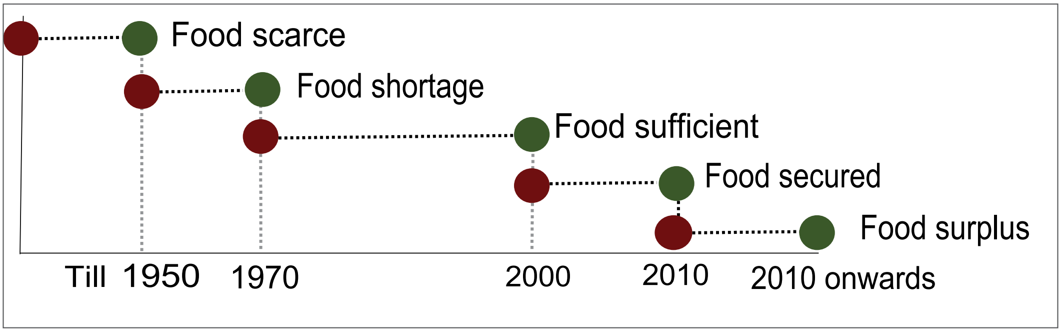


Fig. 2. Transformation of India from food scarce to food surplus nation

Table 2. Production of agricultural commodities and cultivated area in the country in 1950-51 and 2021-22

Commodity	1950-51	2021-22	Times increase
Food grains (Mt)	51	314	6.2
Vegetables & fruits (Mt)	25	333	13.3
Milk (Mt)	17	210	12.4
Egg (billion)	1.8	122	67.8
Fish (Mt)	0.8	14.2	17.8
Net sown area (Mha)	130	140	1.1
Gross sown area (Mha)	150	198	1.3

Table 3. Milestones of agricultural development in pre-independent India

Year	Milestone
9000 BC	Domestication of sheep and goat.
8000 BC	Domestication of cattle.
5000 BC	Domestication of dog, elephant and fowl.
4000 BC	Domestication of water buffalo.
2300 BC	First report of rice cultivation found in Lothal, Gujarat.
2300-1600 BC	Cultivation of wheat, barley, mustard, chickpea, cotton, date, lotus, coconut, pomegranate, lemon and melon in the Harappan civilization.
2000-1500 BC	Rig Veda discussed classification of seasons, burst of monsoon, weather systems and different types of clouds in Rig Veda. The Upanishadas discussed cloud, rain and seasonal cycles due to earth's movement around the Sun.
1725 BC	Growing of jowar in Ahar, Rajasthan.
1500-1000 BC	Cultivation of green gram, black gram and lentil in Tamil Nadu. Humped cattle breeding initiated.
1100-800 BC	Growing of bajra in Rangpur, Gujarat. Atharva Veda discusses ailments of animals, herbal medicines and cure of diseases.

Year	Milestone
322-185 BC	Categorization of soils.
321-296 BC	Kautilya's *Arthasastra* discussed meteorological aspects of agriculture.
100 BC-100 AD	Dam on rive Cauvery constructed by Karikala Chola in Tamil Nadu.
300	First veterinary hospital of the world by King Ashoka.
100	Kalidasa's Meghdoot mentioned dates of onset of monsoon and its path over central India.
200	*Manusmriti* described the Sun as the source of all energy, construction of Grand Anicut masonry weir, an ancient irrigation works on the River Cauvery.
505-587	Varāhamihira's Brihat Samhita discussed planetary movements, eclipses, rainfall and clouds.
1000	Bahur Tank, near Pondicherry; Gangaikonda Cholapuram and Bhojpur lake were constructed.
1400	Anantaraja Sagar of Porumamilla Tank in Cudapah, Andhra Pradesh built by prince Bhaskara of the 1st Vijayanagara Dynasty. Early Western Yamuna Canal built by Ferozshah Tughlak.
1510	Portuguese travellers introduced groundnut, tobacco, potato, chilli and *Amaranth* to India.
1555	Grafting technique was introduced by the Portuguese travellers in Goa.
1562	Mughal emperor Babur introduced scented Persian rose to India.
1555-1605	Abul Fazal's Ain-i-Akbari mentions sack-cloth of jute from Rangpur, Bengal.
1605-27	Production of *'itr'*, the extract of essential oils from the rose petals.
1636	Halley published a treatise on Indian summer monsoon.
1700	Early bari Doab or Hasli Canal on river Ravi built during the rule of Mughal Emperor Shahjehan. Early Eastern Yamuna canal built by Mohammed Shah.
1793	First meteorological unit, one of the oldest stations of the world, started in Madras by J. Goldingham.
1794	Established first Horse Stud in Pusa.
1809	Establishment of Camel Breeding Farm in Hisar, Haryana.
1815	Cattle and horse breeding started in the Government Cattle Farm, Hisar.
1852	Radhanath, first Indian superintendent of Government observatory, recorded systemic weather observation for the first time.
1868	Agricultural School at Saidapet, Chennai was established. Cattle plague Commission was formed.
1874	H.F. Blanford, first Imperial Meteorological Reporter to the Government of India, initiated the systems of long-range forecast in India.
1875	First headquarters of IMD started at Alipore, Kolkata.
1878	First solar observation in India was recorded at Dehradun.
1878	Publication of the Indian Daily Weather Report (IDWR) and first weather charts from Shimla.

Year	Milestone
1882	First veterinary college was established at Lahore.
1883	J.W. Leather started permanent manurial experiments at Kanpur and Coimbatore.
1886	First operational long-range forecast for south-west monsoon rain was issued by IMD. India became the first country to start systematic development in long-range forecast.
1889	First military dairy farm was established at Allahabad. Creation of Civil Veterinary Departments in the provinces. Establishment of Imperial Bacteriological Laboratory in Pune.
1899	Construction of Pravara River canals.
1901-05	Inspector General of Agriculture was appointed. College of Agriculture was established at Coimbatore, Kanpur, Sabour, Nagpur and Lyallpur.
1902	Anti-Anthrax Serum was developed. Indian Civil Veterinary Department was established.
1905	Indian Agricultural Research Institute was established at Pusa, Bihar. Upper air measurement of winds started by tracking balloons with theodolites.
1906	J.W. Leather devised an indigenous method of characterizing Indian soils. Indian Agriculture Service was constituted.
1907	Construction of Godavari Canal Project.
1908	Black Quarter Vaccine and Polyvalent HS Vaccine developed.
1911	Construction of Krishnaraja sagar Project in Mysore.
1915	Polson dairy, the first large scale milk processing plant in India, was established at Mumbai. Construction of Sarda Canal Project in Uttar Pradesh.
1921	Construction of Cauvery Mettur Project in Madras and Sutlej Valley Canals Project. Indian Central Cotton Committee constituted.
1922	Construction of Gang or Bikaner canal. J.N. Mukherjee gave the concept of diffused double layer, neutralization of the charge of colloids and nature of soil acidity.
1923	Imperial Institute of Animal Husbandry & Dairying was started in Bangalore.
1924	Sir Gilbert Walker discovered “walker circulation” and “southern Oscillation”. Construction of Nizamsagar Project in Andhra Pradesh.
1925	Use of Artificial Insemination (AI) for the cattle started in Military Dairy Farms.
1926	Royal Commission on Agriculture (Linlithgow Commission) was appointed.
1927	Goat Tissue Virus (GTV) Rinderpest Vaccine was developed.
1928	Establishment of Pune Headquarters of IMD and first all India weather summary and forecast was issued from Pune.
1929	Government set up the Imperial Council of Agricultural Research (now ICAR).
1933	Manufacturing of Symon’s rain gauge, cup anemometer and windvane started by IMD.
1935	Indore composting for organic farming initiated by Albert Howard. A.N. Puri developed methods for measurement of exchangeable bases, lime and gypsum requirement.
1936	P.K. De first time discussed the role of *cyanobacteria* in soil fertility.
1937	Construction of Haveli Project/Trimmu Barrage.

Year	Milestone
1940	C.N. Acharya developed biogas plant and methods of composting. Development of Ranikhet Disease Vaccine. Collection centres and distribution network were set up for linking the rural milk producers in Bombay with the urban consumers.
1942	R.N. Singh showed the role of blue green algae for supplying N in rice soils.
1943	Viswanath and Ukil at IARI prepared a Soil Map of India. Radiosonde Observations commenced.
1944	S.K. Banerjee became first Indian Director General of IMD. Based on data up to 1940 (a) 5-day normal pressure, humidity and temperature and (b) aviation climatological tables were published by IMD.
1946	Cooperative movement started in dairying with the establishment of the Kaira District Cooperative Milk Producers Union (AMUL) in Gujarat. Climatological charts of India and neighbourhood was published by IMD for meteorologists and Airmen.

4.1. Field crops

It was during the mid-1960s that Indian agriculture witnessed one of its momentous milestones - the Green Revolution. Subsequent decades witnessed revolutions in production of sugar, oilseed, pulses and other crops, thus making a visible impact on the national food security. The term "Green Revolution" was coined by William Gaud of USAID in 1968, and the same year, the Government of India commemorated it by issuing a postal stamp (Fig. 3). The introduction, development and widespread adoption of semi-dwarf, photo-insensitive, input-responsive and high yielding varieties of wheat and rice brought an unprecedented transformation in the national agricultural economy and food security. Technology was the driver of the Green Revolution as about 80% of the production gains were attributed to yield enhancements. The intensified efforts in oilseed crop research post Technology Mission on Oilseeds (TMO) in 1986 resulted in Yellow Revolution with a quantum jump in edible oil production from 10.8 Mt (1985-86) to 24.7 Mt (1998-99). Just in a decade period from 1985 to 1996, area under oilseed cultivation increased from 19.0 to 26.0 Mha. To achieve similar boost in pulses production, they were brought under TMO in 1991. The continued efforts for about three decades in pulses brought 'Pulse Revolution' by providing near self-sufficiency in pulses in the late 2010s (Yadav et al. 2019). The production of pulses, which remained almost constant at 14-15 Mt till 2014-15, jumped to 25.72 Mt (2020-21). India also witnessed Sugar Revolution with sugarcane production increased from 57.05 Mt (1950-51) to 405.42 Mt (2019-20). In independent India, 115 improved varieties have been developed which helped in the steady increase of sugarcane production with improved sugar recovery. ICAR has released more than 6000 varieties for cereals, oilseeds, pulses, fibre crops, forage crops, sugar crops and other crops. This list includes 55 varieties developed through marker-assisted selection to fulfil the various requirement of the farmers. In recent years (2014-21), 1575 high yielding varieties of field crops were released, more than 1300 varieties of which are climate resilient. Specific traits such as drought and sub-mergence tolerance, disease resistance and improved nutrition quality have been introgressed in 47 varieties of field crops using genomic tools like marker assisted selection. During this period, 87 crop varieties either bio-fortified with higher levels of Fe, Zn, protein or pro-vitamin A were developed. ICAR, the nodal agency for coordination of Breeder Seed production, has played a catalytic role in transforming the seed chain in the country by increasing the production of breeder seed of new varieties, pushing the varietal as well as seed replacement rate in pulses, oilseeds and cereals substantially over time. One important milestone of ICAR is the development of internationally consumer preferred and trade favoured Basmati rice, for its cooking and eating quality. About 90% of Basmati rice trade in global market is shared by India with export earnings of Rs. 32,806 crores in 2018-19. The Council has developed genomic resources of 16 commodities and successfully used genome editing in mega rice cultivar MUT1010, Pusa 44 and Pusa Basmati 1. The details of the achievements in the field crop sector are presented in Chapter 5.

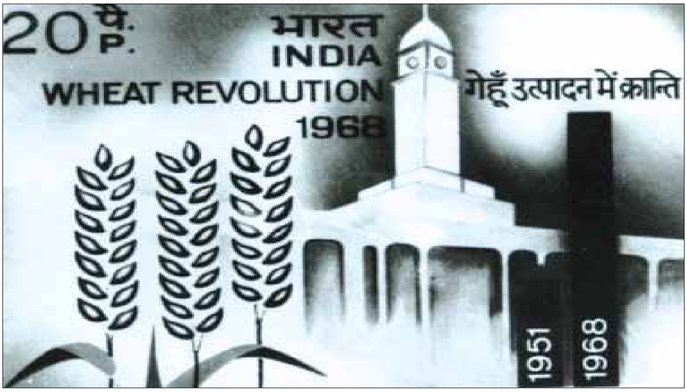


Fig. 3. Postal stamp to commemorate the Green Revolution

4.2. Horticulture

Improved varieties and hybrids of horticultural crops have played pivotal role in augmenting fruits and vegetables production for nutrition and augmenting income. ICAR has released 1,596 high yielding varieties and hybrids of horticultural crops (fruits, vegetables, ornamental plants, plantation and spices, medicinal and aromatic plants and mushrooms), which has made tremendous contributions in record production of 333 Mt (2021-22) from this sector. To boost the exports, good agricultural practices (GAP) and quality standards have been developed for apple, mango, grape, banana, orange, guava, litchi, papaya, pineapple, sapota, onion, potato, tomato, pea and cauliflower. The sea route transport protocols for banana and mango have been standardized to reduce the transportation cost in export. Improved techniques for production of disease-free quality planting material have been developed for citrus, banana, guava, potato, cassava and sweet potato. Micro propagation techniques have been standardized for various fruits, spices and other vegetative propagated plants and has been widely utilized for rapid and mass multiplication of various species. India is blessed with floral diversity, and Uttarakhand, Sikkim and Arunachal Pradesh are identified as cradle of flowering plants. Hybrids in vegetables have revolutionized vegetable production in the country, making it the second largest vegetable producer in the world, and increasing the nutritional security. Highly productive hybrids have been developed in coconut, mango, ber, aonla and other fruits. India is the world leader in mango and in development and production of hybrid mango varieties. A series of hybrids with high productivity, attractive fruit size, colour, aroma and quality, regular bearing and suitable for varying orcharding designs and intensities have fortified country's leadership in the mango world. *In vitro* culture technique has revolutionized banana yield and production in the country. Today, 45% of banana area in the country is planted to tissue-cultured plantlets. India is the largest producer of pomegranate in the word with nearly 86% of present area under Bhagwa variety (205 thousand ha). Pomegranate export earnings increased from Rs. 21 crores (2003-04) to Rs. 688 crores (2021-22). Grape is one of the important export-oriented fruit crops of India. With the adoption of dogridge rootstock for raising grape crops, the productivity and profitability have increased significantly. Large-scale propagation and popularization of Kamalam (dragon fruit) has resulted in speedy adoption of this exotic fruit. Horticulture revolution hinges on the availability of quality planting material, which has been enhanced several folds in recent years. The detail achievements in the horticulture sector are presented in Chapter 6.

4.3. Animal husbandry

Livestock sector has witnessed all round growth after Independence. During the 1950s and 1960s, India was a milk deficit nation and was importing milk/milk powder. With the launching of Operation Flood in 1970, one of the largest rural development programmes of the world, the milk production grew steadily at 6.4%, well above the global annual growth rate of 2.2%. The per capita availability of milk in the country has increased to about 400 g day^{-1} at present, which is much higher than world average of about 300 g day^{-1}. Genetic improvement of livestock species has been carried out to increase milk yield, body growth and reproductive performance. Several breeds of cattle, goat, sheep, camel and poultry have been conserved in their original habitats as well as in the form of embryo, semen and DNA. Production of cloned buffalo calves has been carried out from dead progeny-tested buffalo bull and wild buffalo through inter-species cloning. Vaccines and diagnostics including H5N2 DIVA marker vaccine against avian influenza virus, sheep pox vaccine, VLP-based IBD vaccine for poultry, swine fever live attenuated vaccine, equine influenza vaccine for respiratory viral infections and brucella vaccine and thermo-tolerant type 'O' FMD vaccine have been developed for effective control of livestock diseases. For balanced animal nutrition, several feed formulations have been developed. ICAR has handled several dreaded livestock diseases due to diagnostics and vaccines developed at different institutes. A major contribution has been the eradication of Rinderpest disease, which was declared eradicated in 2011 from the country, making it the first animal disease to be eliminated in the history of mankind. Poultry is one of the fastest growing sub-sectors of agriculture with around 8% growth rate per annum, making India one of the world's largest producers of egg and broiler meat. Currently, emphasis is given for the conservation and improvement of indigenous breeds. In 2020, for the first time in India, a gazette notification of 197 registered indigenous breeds were done and in 2021, three breeds of dogs were registered.

Detail achievements in livestock and poultry sectors are presented in Chapter 7 and in animal health in Chapter 10.

4.4. Fisheries

The Blue Revolution has enhanced fish production making India the second largest fish producing country in the world. A genetically improved rohu called 'Jayanti Rohu' with 17% higher growth realization per generation was developed through systematic selective breeding and being cultivated commercially. Species diversification of freshwater aquaculture for over two dozens of important fish species such as carps, catfishes, other miscellaneous species and freshwater prawns has been successful including packages of practices of their breeding and seed production. Marine cage-culture has been used for farming high value fish species and provided technical support to install cages along the Indian coasts. Several value-added fish products, products of aquaculture importance and nutraceuticals from sea weeds have been developed. Induced breeding of carp in controlled condition through hypophysation has been developed. Technology of composite fish culture achieved a five-fold increase in the national productivity of pond-culture carp from 0.6 t ha^{-1} yr^{1} to 3.5 t ha^{-1} yr^{-1}. Currently, India stands second in aquaculture production in the world. Detail achievements in fisheries and aquaculture sector are presented in Chapter 8.

Table 4. Milestones of Indian agriculture after independence

Year	Milestone
1947	• Initiation of 'Grow More Food' campaign.
1948	• First University Education Commission of India formulated to review the higher education in the country. • First multipurpose river valley project (Damodar Valley Corporation, Jharkhand) constructed. • Etawah Pilot and Nilokheri projects initiated for agricultural extension.
1949	• Wonder cane of India Co 740 developed.
1950	• Discovered hilsa spawning grounds in Hooghly estuary, West Bengal.
1951	• Ford Foundation signed an agreement of US $1.2 million with Govt. of India to train research personnel. • Classical biological control of cottony cushion scale, *Icerya purchasi* through predatory *Rodolia cardinalis*. • Anthrax spore vaccine developed.
1952	• Community Development Project (CDP) for agricultural extension initiated.
1953	• National Extension Service inaugurated.
1954	• World's first all rust resistant cultivar of wheat NP 809 released. • First Jute varieties JRC 212, JRC 321 and JRO 632 developed. • National Rinderpest Eradication Programme (NREP) launched.

Year	Milestone
1955	• Report of first Indo-American Team proposed for establishing Land-grant style university. • First major irrigation project (Bhavani Sagar Dam, Tamil Nadu) constructed. • Induced breeding of *Esomus danricus* achieved using catla pituitary gland extract.
1956	• Enterotoxaemia adjuvant vaccine developed.
1957	• Initiation of the first All-India Co-ordinated Research Project on Maize. • First Marine Fisheries Census carried out. • First success was achieved in induced breeding of *Cirrhinus reba,* followed by induced breeding of three Indian major carps. • Crop thresher developed.
1958	• Accorded status of Deemed University to IARI. • Coorg Honey Dew, 1st gynodioecious variety of papaya released. • National Agricultural Co-operative Marketing Federation established.
1960	• First State Agricultural University on land grant pattern established at Pantnagar, Uttarakhand. • Release of first pigeon pea variety Khargone 2. • Release of first chickpea variety Annegeri 1.
1961	• Release of double cross maize hybrids: Ganga 1, Ganga 101, Ranjit and Deccan. • Commercial ginning machine manufactured.
1962	• Successful breeding of Chinese carps (grass carp and silver carp). • Discovery of antifeedant properties of neem against desert locust.
1964	• CSH 1, first sorghum hybrid developed. • National Demonstration for extension initiated.
1965	• Commission for Agricultural Costs & Prices (CACP) and Food Corporation of India (FCI) established. • Release of C306 wheat variety with good chapatti making quality.
1966	• Introduction of miracle variety IR8. • Minimum Support Price (MSP) system started for wheat. • Seeds Act enacted. • High Yielding Variety Programme (HYVP) initiated. • First Model Act for uniformity across agricultural universities formulated. • Release of semi dwarf wheat varieties: Lerma Rojo, Sonora 64, Kalyan Sona, Sonalika, Chotti Lerma and Safed Lerma.
1967	• Targeted yield concept developed for fertilizer recommendation. • First masonry dam (Nagarjuna Sagar Dam, Telangana) constructed.
1968	• Release of first indigenously developed semi-dwarf high yielding rice variety, Jaya.
1969	• 14 major commercial private banks nationalized. • Concept of 'Integrated Control of Pest' propounded.

Year	Milestone
1970	• Developed gypsum technology for reclamation of sodic soils. • Prepared soil fertility maps. • Patents Act passed to regulate the laws related to patenting. • Combine harvester developed.
1971	• Amrapalli mango variety released by IARI, New Delhi.
1972	• Mallika, 1st regular bearing mango variety released by IARI, New Delhi.
1973	• Creation of Department of Agricultural Research and Education (DARE). • Quality protein maize composite variety, Shakti released. • Sheep pox culture vaccine (RF strain) developed.
1974	• Opening of first Krishi Vigyan Kendra (KVK) at Puducherry. • Training and Visit (T&V) System initiated.
1975	• Establishment of Agricultural Research Service (ARS) and Agricultural Scientists' Recruitment Board (ASRB). • Use of neem oil as a nitrification inhibitor to enhance nitrogen use efficiency. • The first forage cowpea variety Kohinoor released. • Standardization of induced maturation, breeding and larval rearing of penaeid shrimp.
1976	• Landmark variety of early pigeon pea 'UPAS 120' released. • First Kabuli variety of chickpea 'L 144" was released.
1977	• Introduction of low-density polyethylene plastic in irrigation system.
1978	• The first oat variety "Kent" notified. • Forage sorghum variety "MP Chari" released.
1979	• Launching of Lab-to-Land Programme and the National Agricultural Research Project (NARP). • Developed Bovine *Theileria* schizont vaccine.
1981	• Release of Lok 1, mega wheat variety with superior grain quality.
1982	• National Bank for Agriculture and Rural Development (NABARD) established. • Release of HD 2329, a high yielding mega wheat variety.
1984	• National Horticulture Board (NHB) set up.
1985	• Fertilizer Control Order (FCO) issued. • Comprehensive Crop Insurance Scheme (CCIS) introduced. • Adoption of 'Integrated Pest Management' (IPM) as national policy.
1987	• First embryo transfer calf in India born.
1988	• Launch of SAFAL – organized retail network for fruits and vegetables.
1989	• Development of first semi-dwarf basmati variety 'Pusa Basmati 1'. • ICAR was bestowed with the King Baudouin Award.
1990	• Establishment of the National Academy of Agricultural Sciences (NAAS). • Agro-Ecological Region map of India prepared.
1991	• Zero-till drill developed.
1994	• Prepared national groundwater quality map for irrigation purpose. • Release of first hybrid rice (APHR 1) in India.

Year	Milestone
1995	• Initiation of Institution-Village Linkage Programme (IVLP).
1996	• Establishment of National Gene Bank at New Delhi. • Release of fish breed 'Jayanti rohu'.
1997	• Establishment of Accreditation Board for Higher Agricultural Education.
1998	• National Agricultural Technology Project (NATP) initiated. • Kisan Credit Card (KCC) scheme introduced.
1999	• Agro-Ecological Sub-region map of India prepared.
2000	• Agricultural Technology Information Centre (ATIC) initiated.
2001	• Protection of Plant Variety and Farmers Right Act (PPVFR Act) enacted.
2002	• Bt-cotton approved for commercial cultivation.
2003	• India became free form contagious bovine pleuropneumonia (CBPP).
2004	• First greenhouse gas emission inventory from Indian agriculture prepared.
2005	• Release of export quality basmati variety 'Pusa Basmati 1121'. • Launching of National Agricultural Innovation Project (NAIP). • Laser-guided land leveller developed.
2006	• National Agricultural Innovation Project (NAIP) initiated. • InfoCrop, a crop simulation model for tropical environments, developed. • Developed citrus rejuvenation technology.
2007	• Sea cage farming first started with seabass (*Lates calcarifer*).
2008	• First Bajra Napier Hybrid variety "CO-4" released.
2009	• Developed Jalkund, a low-cost rainwater harvesting structure in hills.
2010	• Induced breeding and seed production of cobia and silver pompano. • Transgenic chicken developed. • Direct-seeded rice drill developed.
2011	• National Innovations on Climate Resilient Agriculture (NICRA) initiated. • Establishment of Agri-innovate India Ltd. (AgIn), "for profit" Company.
2012	• 100 climate resilient villages were established. • Special horticulture train started for fruits and vegetables.
2013	• Buffalo Pox vaccine developed. • First triple disease resistant tomato F1 hybrid Arka Rakshak released.
2014	• Atlas of vulnerability of Indian agriculture to climate change prepared. • Country got freedom from African Horse Sickness.
2015	• Developed Mini Soil Lab- Mridaparikshak. • Indigenous sheep pox vaccine (SRIN-38/00 strain) developed. • Attracting and Retaining Youth in Agriculture (ARYA) programme started. • Mera Gaon Mera Gaurav programme initiated.
2016	• e-NAM (Electronic National Agriculture Market) scheme introduced. • Farmer FIRST (Farm, Innovations, Resources, Science and Technology), programme initiated.

Year	Milestone
2017	• Launched National Agricultural Higher Education Project (NAHEP). • IRRI South Asia Regional Centre established in Varanasi. • Commercial modified happy seeder developed.
2018	• Prepared soil organic carbon map of India. • District agricultural contingency plans prepared for 650 districts. • PM-KISAN Scheme became operational. • ICAR Tableau rolled in Raj Path on 26 January for the first time.
2019	• Ministry of Fisheries, Animal Husbandry and Dairying (MoFAH&D) formed. • Registration of 129 livestock and poultry populations as extant breeds. • Buffalo cloned for the first time in the world by hand-guided cloning. • ICAR Tableau with the theme `Kisan Gandhi' on 26 January won the best tableau prize.
2020	• Developed BHOOMI Geo-portal, a gateway to soil geospatial database. • Quantified erosion induced carbon loss of India. • Developed micro and secondary nutrients deficiency maps of the country. • *Brucella abortus* S19Δ per vaccine developed. • Introduction of pesticide management bill.
2021	• Developed inactivated vaccine for H9N2 virus. • Canine Distemper indigenous vaccine developed. • Captive breeding and seed production of grey mullet and mangrove red snapper developed.

4.5. Natural resources management

Conservation and restoration of natural resources under the realm of ever-intensifying pressures of population and development, and declining in quality, has been the prime priority of agriculture research. The country recognized that the science-led management practices to produce more from less is the only option to ensure sustainable development. ICAR has developed land resources inventories for effective and sustainable utilization of natural resources. The important spatial tools for resource use planning include soil resource maps of the country (1:1 million scale), states (1:250,000 scale) and 55 districts (1:50,000 scale); soil degradation map of the country (1:4.4 million scale) and state soil erosion maps (1:250,000 scale). Geo-referenced soil fertility maps for major, micro and secondary plant nutrients have been developed for a large number of districts of the country to facilitate optimum nutrient use at farm level and prepare fertilizer plans at macro level. Data on wasteland was harmonized for proper implementation of reclamation and conservation measures. To provide a workable solution to land degradation in India, gypsum-based technology has been developed which helped reclamation of more than 1.3 Mha degraded land. Further, for continued monitoring and reclamation - field kit for determining soil sodicity of salt affected soils was developed. Another significant land mark has been the preparation and distribution of soil health cards in which ICAR Institutes and the KVKs played very crucial role. ICAR developed a portable soil test kit/mini laboratory called

Mridaparikshak to supplement soil testing service in the country.

Agriculture consumes over 80% of the fresh water for irrigation. Water resource management, therefore took the central stage immediately after the independence with the initiation of major and medium irrigation projects. Enhancing on-farm water use efficiency and rainwater harvesting are the core activities on which the Council has heavily embarked upon. While several *in-situ* water conservation and management practices have been developed and deployed for the benefit of the farmers in the past, more recent development of regional crop plans for efficient water management has been taken up (ICAR 2021). The drip fertigation for higher water and nutrient use efficiency and integrated farming system (IFS) models for augmenting farm productivity and income of small and marginal farmers have also been developed. More than 65 multi-enterprise IFS models have been demonstrated in various agro-climatic zones of the country. A rubber dam technology for water harvesting in micro watersheds and micro-rain water harvesting structure 'Jalkund' for north-east region with storage capacity of 30,000 litres have been developed.

Global climatic changes are already adversely affecting crops, soils, water, biodiversity, livestock and fisheries. Agriculture contributes to the global warming primarily through the emission of methane and nitrous oxide. Based on very limited measurements done elsewhere, it was reported in 1990 that Indian rice fields emit 37.5 Mt methane per year. With systematic indigenous research the methane emission estimate was rationalized to 3.3 Mt per year and a detailed inventory of greenhouse gas emission from Indian agriculture was prepared (Pathak 2015). The estimate provided strength to the rice-producing, developing countries for global negotiations on climate change. InfoCrop, a crop simulation model for tropical environments, has been developed to assess the impacts of climate change and optimize the input use for higher efficiency and lower emission. Several mitigation and adaptation technologies for climate resilient agriculture has been developed, which will help the country to attain net zero emission and carbon neutrality to fulfils India's commitment to the United Nations. Under NICRA (National Innovation on Climate Resilient Agriculture) project, a Vulnerability Atlas of the country has been prepared and 446 climate-friendly villages in 151 clusters have been developed, which will be upscaled up to 300 climate resilient villages by 2024. Technical backstopping has been provided to the states for implementation of the District Agricultural Contingency Plans, which have been prepared for more than 600 districts of the country. Facilities such as high through-put phenotyping platforms, free air temperature elevation (FATE), carbon dioxide and temperature gradient tunnels (CTGC), rainout shelters, animal calorimeter, shipping vessel, flux towers and satellite data receiving station for climate change research have been established at various ICAR institutes. Detail achievements in natural resource management are presented in Chapter 11.

4.6. Agricultural engineering

Farm implements and machines were developed for improving farm mechanization and save time and labour, reduce drudgery, cut down production cost, reduce post-harvest losses and boost crop output and farm income. Water, energy and fertilizer management and utilization of conventional and non-conventional energy sources in agricultural production and processing activities are some of the areas, which recorded tremendous success in independent India. Water saving devices like sprinkles and drip irrigation were given high importance. ICAR developed 210 technologies/implements/machines and 23197 prototypes of farm machines. One of the success cases has been the development of Happy Seeder, particularly for the north-west India, which has reduced burning of rice straw and increased farmers' income. Similarly, zero tillage machine enabled farmers to practice no-till farming on a commercial scale to save, energy, water and time and also increased yield. Detail achievements in agricultural engineering are presented in Chapter 12.

4.7. Agricultural education

Scientific agri-education system is prerequisite for sustainable agricultural development. The thrust on creating trained quality human resources in the agriculture sector through the countrywide establishment of State Agricultural Universities (SAUs) in the 1960s onwards, along with the deemed universities, had ushered in the Green Revolution, followed by White, Yellow and Blue Revolutions. It started in 1949, when Dr. S. Radhakrishnan, a great educationist and first Vice President of India envisioned the establishment of autonomous holistic rural universities to teach agricultural sciences along with humanities, mathematics and natural sciences. This was followed by the recommendations of the Indo-American teams of 1955 and 1959 for establishing agricultural universities on the line of Land Grant University (LGU) of USA. In 1958, the Indian Agricultural Research Institute (IARI), New Delhi was declared as a Deemed University (DU) by the University Grants Commission. The first State Agricultural University on the LGU pattern was established in 1960 at Pantnagar. Currently, with 113 ICAR Institutes, 74 State Agricultural Universities (SAUs), 4 Deemed to be Universities (DUs), 3 Central Agricultural Universities (CAUs) and 4 Central Universities (CUs) with Agriculture Faculty; the NARES is one of the largest in the world. These Agricultural Universities and DUs are providing advanced degrees in over 30 disciplines of agriculture and allied sectors.

To attract students to higher agricultural education and achieve excellence in teaching, research and capacity building of faculty in the cutting-edge areas of agriculture and allied science subjects, ICAR operates several schemes for faculty such as ICAR Post-doctoral Fellowship, National Professor/National Fellow Scheme, Emeritus Professors and Emeritus Scientists, Summer/Winter Schools (SWS) and Short Courses, and Centre of Advanced Faculty Training (CAFT). The Agricultural Education system has institutionalized and upscaled e-Courses; e-Learning Portal on Agriculture Education or e-Krishi Shiksha; Open and Distance Learning System; AgriLORE platform; Consortium for e-Resources in Agriculture (CeRA) and Digital Library to promote digital learning. With an objective for globalization of higher agricultural education, ICAR has initiated India-Africa and India-Afghanistan Fellowship Programmes and other International Fellowships such as Netaji Subhas-ICAR International Fellowship and BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) Scholarship.

Agri-entrepreneurship has been an integral part of the higher agricultural education. A new programme, Student READY (Rural Entrepreneurship Awareness Development Yojana), has been introduced as integral part of 12 months with the last year of the UG programme. The programme includes Experiential Learning (Business Mode), Experiential Learning - Hands on Training (Skill development), Rural Awareness Work Experience (RAWE), In Plant Training/Industrial attachment/Internship and Student Project. An institutional mechanism of "Dean's Committee' is in place for periodic revision and improvement of course curricula to meet the changing demand of higher agricultural education. A roadmap has been prepared to implement the provisions provided in the New Education Policy (NEP) (2020) for further improving the agricultural education system in India. Detail achievements in agricultural education are presented in Chapter 13.

4.8. Agricultural extension

ICAR has been engaged in development of efficient and effective technology transfer systems for shortening the time lag between technology generation and adoption. The extension system in the country has renewed itself over time from its primordial land grant college pattern of education and top to bottom approach of transfer of technology (ToT). It has shifted its way from input centric production-oriented ToT to income augmenting and market-led diversified technologies and to on-the-job vocational training, complete centralized funding to decentralized bottom to top approach (e.g., ATMA), sustainable agricultural practices and so on. The mass and frontline extension are carried out by 4 major agricultural extension systems: (i) Department of Agriculture and Farmers Welfare (DAFW) and the related ministries of rural development and some voluntary organizations; (ii) frontline extension systems by KVKs, ICAR institutes and SAUs; (iii) business and trade specific commodity extension services by commodity boards and (iv) input specific extension services by agri-business agencies. The KVKs are the only gateway for frontline extension innovation for technology generation and dissemination at district level in the country. Starting with first KVK in 1974 in Puducherry, the network grew to 730 KVKs by 2022 in the country hosted by agricultural universities, State Governments, NGOs, Public Sector Undertakings and other educational institutions.

With over 1.2 billon mobile connectivity, about 3.5 lakh rural common service centres and all the rural districts having frontline technology dissemination centres-KVK, the agricultural scientists and farmers are ready to bring another revolution- Smart Farmers & Farming in India. ICAR has developed over 80 mobiles apps on different aspects of farm and farmer's related services. The KVKs are providing mobile agro-advisories and other services to farmers in mobile handsets in the rural areas. They are now linked with about 3.5 lakh the common service centres to provide demand-driven services to the farmers. The motto of the Council, "*Agri Search with a Human Touch*", speaks volumes of the importance that the Council attaches to transfer of technology to the farming community. The capacity building of community-based organizations and farmers' groups for acquiring knowledge and its transfer is being put in place for a faster dissemination. The research-extension linkages at the national, regional, state and zonal levels have been institutionalized. A number of new concepts and models of participatory research and extension are being evolved now. The innovations include Farmer Producer Organisations, Diploma in Agricultural Extension Services for Input Dealers (DAESI), Climate Smart Extension with technological, institutional and community-led innovations, Farmer FIRST, Attracting and Retaining Youth in Agriculture (ARYA), Mera Gaon Mera Gaurav, Nutri-sensitive Agricultural Research and Innovations (NARI), Knowledge System & Homestead Agriculture Management in Tribal Areas (KSHAMTA), Value Addition and Technology Incubation Centre in Agriculture (VATICA) and ICT-based Extension such as mKisan, DD Kisan, Kisan Sarathi and Mobile Apps. The current robust and efficient extension system is capable of meeting the evolving needs of farmers in the context of changing agricultural scenario and enhance farmers' income and ensure a sustainable growth. The ICT application over time has been scaled up in the ICAR-SAUs-KVK extension system. Detail achievements in agricultural extension are presented in Chapter 14.

4.9. National and international collaborations

Collaborations in research with national and international agencies have major role in shaping the path for agricultural development in India. The collaboration with CIMMYT and IRRI for exchange of dwarf wheat and rice varieties, respectively triggered the efforts for the Green Revolution making India food secure. The ICAR-CGIAR collaborations expanded to various commodities and strategic locations for development of new crop varieties and animal breeds and also managing natural resources. Development of new breeds by harnessing the potentials of the exotic breeds, vaccines and diagnostics, quality standards, health, nutrition and hygiene standards and protocols came out from the international and national collaborations in livestock and fisheries sector. The bilateral cooperation in agricultural R&D extended to all continents touching to 65 nations in 2020-21. India as a founder member of SAARC, BRICS, BIMSTEC shaped the agricultural regional cooperation with member Nations. India made an impressive footprint in its neighbourhood through the establishment of ANASTU in Afghanistan, ACARE in Myanmar, Deemed University for Agricultural Education in Nepal. More information on national and international collaborations are presented in Chapter 15.

4.10. Policy innovations

The agricultural transformation in India from food deficit to food surplus in the past 75 years has seen many bold and dynamic policy interventions. Immediately after the independence, the establishment of SAUs on the land grant pattern of the USA was the policy milestone that resulted into one of the largest agricultural research systems in the world. Imports of seed of dwarf varieties of rice and wheat was another policy decision in 1964 onwards that helped furthering the crop sciences in the country. The policies related to regulations and facilitation of germplasm exchange helped new seeds and planting materials for the research system. Several acts and institutions came into being, modified and remodified with the passage of time to attract scientific research in agriculture, promote public and private investment and facilitate the farmers and others involved 'in' and 'for' agriculture. The Cooperative Societies Act, passed in 1904, and its subsequent reforms for credit support to the farmers was a major milestone. Post-independence, several state-owned commodity institutions were brought under ICAR to reorient and refocus their strength for national and regional aspirations. The input and technology intensive Green Revolution accelerated the need for financial support for agriculture. In the year 1974, the commercial banks were advised to raise the share of the ‘priority sectors’ including agriculture in their aggregate advances to the level of 33.3%. Another landmark policy decision that helped technology reaching directly to farmers by the technology evolver was taken in 1974 for the establishment of KVKs, which were later broadened to at least one in each district of the country. Further efforts were done by attaching each district with a commercial Lead Bank. The Commission for Agricultural Costs & Prices (CACP) and the Food Corporation of India (FCI) were established to assist the farmers with price support operations and ensure the productivity gains reaching the consuming sector through the Public Distribution System (PDS). In the year 1982, the National Bank for Agriculture and Rural Development (NABARD) was established to undertake the agricultural credit-related functions of the Reserve Bank of India. Public institutions both at the centre and states have helped in minimizing risks and costs of inputs used for higher profit realizations. Subsidies and waivers have been the prime instruments for providing such benefits to the farmers. The other institutional intervention to support farmers has been the direct income transfer through the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) scheme. Along with enhancing food production, the export promotion and import substitution are the focus through local to global and one district one product initiatives. The Council has identified processable and high-yielding varieties of various crops and fruits matching with the consumer preference and markets to enhance the export of potential commodities (ICAR 2021). The rise of new generation entrepreneurs or start-ups, since last decade, led by innovative ideas to solve the problems along with ethical business practices are playing in profound ways. Agriculture and allied sector have been witnessing emergence of several start-ups, commonly termed as “Agri-startups”, which help developing products and services to bring efficiency in the value chain. Many of these start-ups are using new generation IT tools like, artificial intelligence (AI), Internet of Things (IoT), imaging & sensors, remote sensing, drone, data analytics, blockchain technology, etc. in agriculture and allied sector for improving yield, efficiency and profitability. ICAR has established 50 agri-business incubators since 2016 and supported 1476 start-ups/entrepreneurs/incubates during 2014-20. The details of investment, policy and entrepreneurial ecosystem for agricultural development have been presented in Chapter 16.

5. Emerging challenges

With the expected population of over 1.6 billion and annual food demand of 400 Mt by 2050, the country requires minimum 4% annual growth in agriculture. The changing macro- and micro-economies will also impact the demand and behavioral changes for food. There would be substantial increase in demand for quality products of fruits/vegetables and livestock. The dietary pattern of eating less with bio-enriched quality food could be another major shift. The challenges of environment protection and globalization shall put tremendous pressure on Indian agriculture. Climate change induced impacts on agricultural productivity is the most imminent of such challenges. The temperature is rising and becoming highly variable. Amount, intensity, variability and extreme events of rainfall are rising, while the duration of rainfall is reducing. Perceptible negative impacts are projected on production of food grains, livestock as well as aquatic systems, both quantitatively and qualitatively.

Sustainable intensification of land resources is inevitable for food security of increasing population. India has 121 Mha i.e., 36% of the geographical area degraded with soil erosion, salinity, alkalinity, acidity, water logging and other edaphic stresses. With 4% of world's renewable water resources, the country has only 43 Mha fully irrigated, 23 Mha partially irrigated and 74 Mha rainfed. In the recent past, both drought and floods have been seen to be stress factors in farming. India's rechargeable annual groundwater potential is around 432 billion cubic metres (BCM), with over 90% utilised in some parts of the country, as can be seen from the depletion of the groundwater table in several states of Punjab, Haryana, parts of Rajasthan, Gujarat, western Uttar Pradesh, as also in the Deccan plateau. With multiple activities on the land resource including farming practices, nutrient deficiencies of different kinds are being increasingly reported. Annually, 8-10 Mt of NPK is mined from soil and 93, 91, 51 and 43% soils are rated low in nitrogen, phosphorus, potassium and zinc, respectively. Fertilizers, therefore have played a crucial role in enhancing crop production and globally, 120 Mt of N fertilizer is used in agriculture, while in India, the consumption is about 17 Mt annually. However, nearly half of the fertiliser N applied is leaked into the environment through volatilization, leaching or emissions resulting in multiple adverse effects on terrestrial and aquatic systems and on human health. These concerns need to be addressed through combinations of crop varieties, reclamation measures and cultivation practices, enabled by emerging technologies and policy interventions.

6. Way forward

India has now several national priorities such as enhancing farmers income (200%), reducing fertilizer use (25%) and water use (20%), increasing renewable energy use (50%), reducing GHG emission intensity (45%) and rehabilitating degraded land (26 Mha) to achieve. At the same time, being a signatory and prominent and responsible member of the United Nations and other global organizations, it has several international commitments to fulfil such as Panchamrit and C neutrality (UNFCCC), land degradation neutrality (UNCCD), biodiversity conservation (UNCBD), regional agricultural development (SAARC) and Sustainable Development Goals (UN). The way forward for Indian agriculture, therefore, should focus on precision agriculture, reducing chemical footprints, nature-friendly farming; use of nano-fertilizers, with more synergy in crop, weather and water cycles and crop planning using ecosystem approaches. Fortunately, along with challenges, the developments in science are creating new avenues for tackling the challenges and fulfilling the priorities and commitments. For timely monitoring of weather, plant and soil indicators and provide artificial intelligence-based advisory to farmers, ICAR initiated a network programme on precision agriculture. Research on agricultural genomics would be one of the core research activities, which has made substantial progress in the past.

The ICAR and the NARES at large, are determined to harness the advances of science for the welfare of society. The Council is committed to transform itself into an organization engaged fully with the farmers, industry, entrepreneurs and consumers. A multi-pronged strategy with integration, diversification, clustering, customised farm mechanisation, value addition and market access is required to realise the full potentials of farming. Developing varieties tolerant to multiple abiotic and biotic stresses using stress-tolerant QTLs, genes and alleles in elite cultivars is an efficient way of achieving higher yields and sustainability. Methods and tools for conserving, storing and enhancing water use efficiency through pressurized, low cost and demand-driven micro-irrigation systems need to be upscaled to horticultural and field crops. Application of neem-coated urea well calibrated according to soil health card and leaf colour charts should become common practices for enhancing fertilizer use efficiency. Microbe-based technologies for nitrogen fixation, nutrient recycling, bio-residue management and alleviation of abiotic and biotic stresses have also been found useful. The conservation agriculture, beyond the irrigated ecosystem, should prolifically be used to reduce the carbon foot-print of production systems. Development and deployment of smart small machines using renewable energy sources and solar-powered water pumps, sprayers and weeders should get more momentum. Greater thrust is needed with regard to agri-infrastructure both during the production and post-harvest phases, the latter in terms of processing and storage facilities. The focus should be on export orientation, ecosystem approach, sustainable food system, smart farming, post-harvest value addition and entrepreneurship engaging youth and women. A two-way digital communication between the farmers and scientists should be the new paradigm of technology delivery system.

7. Conclusion

Ensuring food and nutritional security, improving rural livelihood along with environmental security in a sustainable manner, will remain the major goal of the agricultural development planning. India will strive to help achieve these goals through development of improved agricultural technologies along with their efficient and effective modes of dissemination. It is estimated that the annual growth in the productivity of food grains should be more than 1.5% and that of horticultural crops more than 3% to meet this goal. This will essentially require development of improved varieties of field and horticultural crops with desirable traits under the changing environmental scenario. At the same time, technology will also be needed to increase the input use efficiency to reduce the cost of production and enhanced value addition to make Indian agriculture profitable, competitive and attractive to rural youth. In addition, value addition through processing will help in reducing colossal losses on one hand and increase the income of the farmers on the other. ICAR is ready to take up the challenges with focused research programs keeping in mind the recent developments in science and technology, changed economic environment and opportunities at national and international arenas for higher productivity, profitability, sustainability and climate resilience to meet the aspirations of Indian agriculture.

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Dr. NE Borlaug, Father of Green Revolution and Dr. MS Swaminathan, Father of Green Revolution in India visiting the wheat fields at Indian Agricultural Research Institute, New Delhi

Crop Husbandry in Pre-independent India

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Summary

Agriculture was the mainstay of generating food in ancient India. During the pre-vedic Indus-valley, popularly known as Harappan civilization, cultivation of wheat, barley, mustard, chickpea, cotton, dates, lotus, coconut, pomegranate, lemon and melon was a common practice. In the Vedic era, early Aryans preferred the cultivation of barley as their homeland food. They initially did not know of rice, but later came to know of its existence when they expanded their territory to northern India. Both cultivated and wild rice were cultivated during the Neolithic culture. Diverse cereals, millets, pulses, oilseeds, vegetables, spices and fruits were grown during the rule of different dynasties. The Portuguese introduced new crops like groundnut, potato, chili and tobacco. During the Mughal era, special emphasis was given to grow dry fruits and fragrant flowers. In the British period, improved agronomic practices like crop rotations and inter and mixed cropping were followed. The British also introduced several fruits, vegetables and other commercially important crops. Agricultural research and education institutions and programmes were initiated during the period and contributed to address the agrarian challenges, helped in developing trained human resources and provided a basis for the modern-day agricultural system in India.

1. Introduction

Cultivation of crops through agricultural practices has been the major source of food to the ever-growing population. In the modern era, improved cultivars across crops have been developed through integration of genetics, breeding and biotechnological tools. These cultivars possess resilience to biotic and abiotic stresses and are rich in nutritional qualities. However, in the ancient time, people used the '*hunting and gathering*' method to fulfill the need of energy and nutrition, and had to move through a large area to have the continuous supply of food. Later, families and larger-groups built communities, and had a transition from the nomadic lifestyle to cultivation of crops through agricultural practices. Initial agricultural system started with domestication followed by introduction of crops in the new areas. Agriculture in the Indian sub-continent began way back in 9000 BC. However, more information of crop cultivation could be obtained from the '*Indus Valley*' or '*Harappan*' civilization. Systematic information on crops is available in the *Vedas.* The writings by various famous travelers and writers during the rule of different dynasties also provided information of crops which had been part of the contemporary agricultural system. The

Portuguese travellers introduced many new crops to India. Agriculture became a key interest area during the British rule in India, that followed with the establishment of various institutions that later formed the base for modern agricultural research and education system in India. Development of improved crop cultivars through science-based selection approach was also initiated during the British rule. The present chapter systematically presents the details of cultivation of various crop species, and agricultural practices used during the pre-vedic and vedic era followed by rules of different dynasties and British in pre-independence India.

2. Crop husbandry in the pre-vedic era

Agriculture began as early as 9000 BC in the Indian sub-continent and crops like wheat, barley and jujube were domesticated during that time. However, information on cultivation of crops as part of the agricultural system became more vivid during the 'Indus Valley' civilization popularly known as 'Harappan civilization' which flourished during 2300-1600 BC in western Punjab and Sind province of the Indian subcontinent. The excavation by D.R. Sahni in AD 1921 at 'Harappa' and R.D. Banerjee in AD 1923 at 'Mohenjo-daro', discovered two major cities with rich cultural heritage. The 'Harappan' culture eventually spread to eastern Punjab, western Uttar Pradesh, Rajasthan, western Madhya Pradesh and Gujarat. The excavation revealed wheat and barley cultivation as part of their agricultural system. Among various species of wheat, grains of *Triticum aestivum*, *T. compactum* and *T. spherococcum* were recovered from the Mohenjo-daro site. Barley grains of *Hordeum vulgare* var. *nudum* and *H. vulgare* var. *hexastichum* were also found at Mohenjo-daro and Harappa, respectively. Both the crops being originated in central Asia, it was concluded that 'Indus Valley' civilization had contacts with the 'Mesopotamian' civilization. Among pulses, chickpea grains were recovered from the Harappan site; and sesame, amongst oilseeds, possibly introduced from Africa or Mesopotamia was also cultivated during Harappan civilization. The seeds of mustard, *Brassica juncea* were also recovered from Chanu-daro site indicating its cultivation in Sind. A small fragment of cotton cloth collected from Mohenjo-daro suggested that Indus Valley civilization was the earliest to spin and wove cotton fibres. The fibre quality depicted that those were similar to coarse Indian cotton species like *Gossypium arboreum* and *G. herbaceum*. Cotton cloths produced by the Harappans were used as the main export materials with Mesopotemian civilization in exchange of silver and woollen garments. Among fruits, evidence of availability of seeds and fruits suggested the cultivation of date, lotus, coconut, pomegranate, lemon and melons during Harappan civilization.

Neolithic culture existed as early as 2300 BC. Six geographical places viz., north-western region of Pakistan (Baluchistan, Swat and upper Sind valley), northern regions (Kashmir and Kangra region in Himachal Pradesh), central-eastern (Chota Nagpur plateau and surrounding regions of Uttar Pradesh, Bihar, Orissa and West Bengal), north-eastern (Assam, Chittagong and sub-Himalayan region including Darjeeling), north Bihar (Saran) and southern peninsular region (especially Andhra Pradesh and Karnataka) of India, have the evidence of neolithic cultures. The evidence from excavation of Burzahom site in Kashmir revealed weed seeds and suggested the possibility of wheat and barley crops in the northern neolithic culture. In the southern peninsular region, the evidence at Hallur, Karnataka suggested that ragi (1800 BC) was a crop of choice. Among pulses, grains of horse gram (1780-1500 BC) were collected from Tekkalakota, Karnataka. The grains recovered from Maharashtra also suggested the cultivation of various minor millets. The evidence collected from Navdatoli in Tamil Nadu described that green gram, black gram (1500 BC) and lentil (1500 BC) were cultivated as agricultural crops. Besides, sorghum among millets, linseed and castor among oilseeds, and *ber* and *amla* among fruits were also cultivated. In eastern regions, evidence of cultivation of both cultivated rice (*Oryza sativa*) and wild rice (*O. rufipogon*), wheat, barley, pea and green gram were found at Chirand, Bihar. Evidence from Pandu Rajar Dhibi in West Bengal also confirmed that rice was a popular choice of food. Besides, banana, sugarcane and yam were also cultivated. The evidence of cultivation of rice in India dates back to 2300 BC at Lothal, Gujarat; Rangpur, Gujarat (2000-1800 BC); Chirand, Bihar (2000-1300 BC); Pandu Rajar Dhibi, West Bengal (2000-1001 BC); Navdatoli, Tamil Nadu (1550-1400 BC); Hastinapur (1100-800 BC) and Atranji-khera (1200-600 BC) in Uttar Pradesh. The first evidence of growing of jowar was found in Ahar, Rajasthan during 1725 BC.

3. Crop husbandry in the vedic era

Aryans occupied area of eastern Afghanistan, North-West Frontier province, Kashmir, Punjab, and parts of Sind and Rajasthan. The land was named as '*Saptasindhavah'* after seven rivers viz., Sutlej, Beas, Ravi, Chenab, Jhelum, Indus and Sarasvati flowing through the most fertile land. During the early vedic era (1500-1000 BC), the *Rig-Veda*, the oldest book of the Aryans mentioned barley, white and black coloured sesame, sugarcane, cucumber and bottle gourd. Though Harappans grew wheat and cotton, early Aryans, possibly, did not grow them and stuck to barley as their homeland food. Rice finds no mention in the early vedic literature. They came to know about rice after they expanded their territory to Uttar Pradesh and Bihar. During the later vedic periods (1000-600 BC), vedic literatures like *Sama-Veda*, *Yajur-Veda* and *Atharva-Veda* were composed. *Mahabharata* and *Ramayana* were also written during this period. The cultivated and wild rice, barley, wheat, maize, bajra, foxtail millet, proso millet, barnyard millet, kidney beans, lentils, sesame and *Coix* have found their mention in these literatures. Generally, two crops were grown during the year. The earliest evidence of growing bajra has been found from Rangpur, Gujarat during 1100-800 BC. A clear mention of sowing of barley during winter season and maturity in summer is made, while rice planting in rainy season with harvesting in autumn season. Beans and sesame were grown during the onset of summer rain and harvested during the colder months in winter. Cucumber was also possibly cultivated during the time.

Table 1. Milestones of crop husbandry in pre-independent India

Period	Milestone
9000 BC	Beginning of agriculture by early cultivation of plants and domestication of crops.
2300-1600 BC	Cultivation of wheat, barley, mustard, chickpea, cotton, date, lotus, coconut, pomegranate, lemon and melon was part of *Harappan* civilization.
2300 BC	First report of rice cultivation found in Lothal, Gujarat.
1725 BC	First evidence of growing of jowar was found in Ahar, Rajasthan.
1500 BC	Excavation at Navdatoli, Tamil Nadu revealed the cultivation of green gram, black gram and lentil.
1100-800 BC	The earliest evidence of growing bajra was found from Rangpur, Gujarat.
1510 AD onwards	Portuguese travellers introduced groundnut, tobacco, potato, chilli and *Amaranth* to India.
1555	Grafting technique was introduced by the Portuguese travellers in Goa.
1562	*Babur,* the Mughal emperor is credited to introduce scented Persian rose to India.
1555-1605	Mention of sack-cloth made up of jute from Rangpur, Bengal in *Ain-i-Akbari* written during Akbar's rule.
1605-1627	Production of *'itr'* - the extract of essential oils from the rose petals was mentioned in Jahangir's rule.
1777	Indigo cultivation starts in Bengal.
1788	The Governor General at Calcutta was requested by London to encourage growth to meet the requirements of the Lancashire textile industry
1859-60	Indigo revolt
1868	Agricultural School at Saidapet, Chennai was established.
1871	Department of Agriculture was established.
1884	Experimental farms were established for plantation research.
1890	Botanical Survey of India established.
1892	Agricultural chemist and an assistant chemist looked after research and teaching.
1901	Inspector General of Agriculture was appointed.
1905	Agriculture Research Institute (now Indian Agricultural Research Institute) was established at Pusa, Bihar.
1901-1905	College of Agriculture was established at Coimbatore, Kanpur, Sabour, Nagpur and Lyallpur.
1906	Indian Agriculture Service was constituted.
1907	College of Agriculture was established at Pune.
1921	Indian Central Cotton Committee was constituted.
1926	Royal Commission on Agriculture (Linlithgow Commission) was appointed.

Period	Milestone
1929	Government set up the Imperial Council of Agricultural Research (now Indian Council of Agricultural Research).
1933	Basmati 370 was identified from a large collection of rice cultivars.
1936	IARI (now Indian Agricultural Research Institute) was shifted to Delhi.

4. Crop husbandry during the dynasties

Of the several dynasties, *Magadhan* empire ruled eastern Indian states during 544-492 BC. Pulpy rice being the staple food indicated that rice was their preferred cereal crop. *Mauryan* dynasty ruled during 322-232 BC. The *Arthashastra* mentioned that the crops like rice and sesame were sown early, while green gram and black gram were planted in the middle of the season, with safflower, lentil, barley, linseed and mustard being late crops. It also mentioned that rice was easy to grow, while vegetables had intermediate difficulties with sugarcane being the most exhaustive crop due to the requirement of utmost care and expenditure besides heavy pest incidence. During *Ashoka's* rule (274-237 BC), banana, mango, jack fruit, grape and date were cultivated. During 200 BC to AD 200, various dynasties like *Sungas*, *Satvahanas* and *Kushans* ruled. The coconut cultivation was popular in the coastal states due to its multiple usage as copra, oil, oilcake and fibre. *Pandyas*, *Cheras* and *Cholas* ruled different parts of southern India during first century of the *Christian* era to AD 300. Ragi, sugarcane, pepper, turmeric and cotton were cultivated during this period along with the use of various forest products like bamboo, rice and jack fruit.

The mention of red rice, yellow rice and hog's rice during the rule of *Guptas* (AD 300-550) is found. Growing of *Sali* rice indicated that the technique of transplanting of rice was known to them. A number of other crops in cereals (rice, wheat and barley), pulses (peas and lentil), oilseeds (sesamum, linseed and mustard), spices (pepper, cardamom, cloves, ginger and turmeric), vegetables (cucumber, onion, pumpkin and gourd) and fibre crops (cotton, flax and hemp) were also cultivated. Coconut was extensively cultivated in the coastal areas. Besides, the mention of betel nut, tamarind, indigo and jack fruit. *Hiuen Tsang* visited Kanauj empire of Harshavardhana which existed during AD 606-647. His travelogue, *Si-yu-ki*, had a special mention of a 60-days maturing rice cultivar. He also mentioned the existence of another rice cultivar with extraordinary fragrance. *Shaman Hwui Li*, the disciple of *Hiuen Tsang* mentioned a special rice variety having large seeds as black bean with strong aroma. Various fruits like *Amla*, chestnut, loquat, pear, wild plum, peach, apricot, grape, pomegranate and sweet oranges were grown in plenty. Ginger, mustard, melons and pumpkins were also grown with onion and garlic being cultivated in limited areas.

Chalukyas, *Rashtrakutas*, *Pallavas*, *Pandyas*, *Hoysalas* and *Kakatiyas* ruled southern India during AD 535-1300. During this period, rice cultivation was extended to various areas with irrigation facilities available and millets were restricted to rain-fed areas of Deccan and Mysore plateau. Besides, sugarcane, sesame, ginger, pumpkin, yam, mango, coconut and jackfruit were cultivated throughout the regions. Various *Rajput* rulers ruled north India during AD 650-1155, while *Palas* and *Senas* in Bengal during AD 760-1205. In lexicons written in Sanskrit, eight varieties of rice different in colours, fragrance, size and growing periods have been mentioned. *Magadha* was famous for rice, while rice was part of king's dietary in Kalinga. The seven varieties of beans have also been mentioned in those literature. Coconut, ginger and cinnamon were grown in plenty. Cotton and indigo were also in cultivation in different kingdoms.

The writings of *Medhaitithi*, *Parashara*, *Kashyapa* and early Arabs mentioned in some details the agricultural practices followed during AD 900-1100. Their scripts mentioned that mango, coconut, lemons and rice were grown in large quantities, while sugarcane, pepper and bamboo in specific areas. *Kashyapa* provided the explicit details of transplanting, weeding, irrigation, crop protection measures, harvesting, threshing, selection of seeds and storage of rice cultivation. The unique quality of '*pundra'* sugarcane in producing juice without pressing by any equipment has been specially mentioned. Besides, cultivation of various cereals (barley, wheat and Italian millet), pulses (lentil, green gram, black gram and chickpea), oilseed (sesame), spices (turmeric, ginger and cardamom), vegetables (brinjal, cucurbits and gourd) and fruits (date, coconut, mango and *jamun*) during their time.

The Islamic empire, Delhi *Sultanate* stretched over large parts of the Indian subcontinent during 1206-1526. *Ibn Battuta* had a detailed mention of crops grown during this period. The people grew crops twice a year, one with the arrival of rain during summer, and the other during spring. Rice, millets, green gram and black gram were grown during the summer season and harvested after 60 days during autumn season. Wheat, barley, chickpea and lentils were grown during the spring season. *Ibn Battuta* also mentioned that people in the Indian subcontinent grew rice – the principal cereal crop, three times a year and sugarcane and sesame during the summer season with onset of rain. When he left for southern states, he found abundance of pepper, ginger, sugarcane, coconut and betel vine cultivation in Kerala, and rice in Bengal. *Mahaum*, a Chinese scholar visited Bengal in 1604, also mentioned the abundance of rice, wheat, millets, pulses, mustard, sesame, ginger, onion, squash, brinjal, hemp, jack fruit, mango, pomegranate, sugarcane and betel nut in Bengal. Vijayanagar empire (1336-1646) emerged after the control of *Tughlak* empire receded. During this period, rice, wheat, jowar, barley, beans, green gram, and horse gram amongst field crops and sweet and sour orange, wild brinjal, pomegranate and grapes amongst fruits were cultivated.

Portuguese introduced new American and African crop plants to India through sea routes that moved through Portugal to Brazil to Cape of Good Hope to Goa in India (1510). Many plants of Malay Archipelago and East Indies were also introduced. Groundnut was amongst the many crops introduced by them. Tobacco was also introduced by them during the closing years of reigns of Akbar. Potato was imported to Europe from Chile and Peru during 1580-1585 by the Spaniards and English travelers. The Portugues introduced chilli to India from Brazil or Peru in the 16th century and potato in the 17th century from Chile or Peru. Amaranth was introduced by them into Malabar from Brazil. Besides, chestnut, guava, *sharifa*, *chiku* and pineapple were also introduced by them. They also brought in ornamental plants like *Agave* and *Allamanda*. Another significant contribution by them was the introduction of 'grafting' technique in about 1550. It was restricted to Goa for nearly two centuries, and in about 1790, the grafting technique spread to the rest of India.

5. Crop husbandry during the Mughal era

The rule of Mughals started with the invasion of Babur in 1526. Babur mentioned in his memoirs, the *Babur-nama*, various crops like mango, banana, tamarind, *mahua*, *jamun*, *chironji*, jack fruit, *ber*, *amla*, lime, orange, date palm, coconut and toddy palm. He also mentioned availability of some of the beautiful flowers like oleander, *gurhal*, *keora* and white jasmine. Babur is credited to introduce scented Persian rose to India. Akbar ruled the Mughal empire during 1555-1605. Information on *Ain-i-Akbari* written by Akbar's court historian, *Abu'l Fazl*, and various European travellers gave great details of crops, flowers and fruits grown during Akbar's rule. These literatures mentioned that wheat was predominant in the north west part of India, while barley and chickpea were grown throughout the country. However, cultivation of rice was restricted in Bengal, Orissa, Uttar Pradesh, Lahore, Khandesh, Berar and Kashmir. The book also mentioned that rice in Bengal was cultivated three times a year. Jowar, bajra and other types of millets were grown especially in the north western regions having limited rainfall. Among pulses, chickpea, lentil, pea, green gram, black gram and *arhar* were prominent. Sesame, linseed, *toria*, mustard and safflower were the oilseed crops grown during that time. Besides, sugarcane, cotton, hemp, indigo, poppy, betel nut, melons, gourds, pumpkin and tobacco were also cultivated. Saffron was cultivated in Kashmir. *Abu'l Fazl* mentioned that Bengal recorded the highest sugarcane production. He also stated that three kinds of sugarcane viz., *paunda*, black and ordinary were grown. In the southern part of the country, rice, wheat, jowar, ragi, green gram, horse gram, coconut, ginger, turmeric, cardamom and *Arecanut* were plenty in cultivation. Malabar was famous for growing various spices *viz*., cardamom, ginger, pepper, nutmeg, cloves and cinnamon. *Abu'l Fazl* mentioned that Akbar was interested in garden plants, and he mentioned the name of 21 flowering plants along with their colours and season of flowering in *Ain-i-Akbari*. He further mentioned another list of 29 flowering plants, and some of them were *champa*, *kewra*, *saffron*, *juhi*, *gulal*, *ketki*, *gudhal*, *nag kesar*, *kadam* and *hinna*. Among fruit crops, mulberries, pineapple, *ber*, jack fruit, figs, melon, banana, date palm, pomegranate, guava and water melons are some of the important crops grown during Akbar's rule. Mango was specially grown in Bengal, Gujarat, Malwa, Khandesh and Dekhan. Mention of various dried fruits (dates and walnuts) and water plants (*singhara*) was also found. *Abu'l Fazl* elaborated a list of 18 vegetables of which *palwals*, gourds and carrots are important. In *Ain-i-Akbari*, there is mention of sack-cloth, which later was identified as jute from Rangpur, Bengal. Jahangir ruled the Indian subcontinent during 1605-1627, and during his time, melons, mango, grapes and pineapples were found in abundance. He also mentioned the presence of sweet fragrant flowers like *champa*, *keora*, *ketaki* and *chambeli*. *Nur-Jahan*, mother of Jahangir was credited to develop '*itr'* - the extract of essential oils from the rose petals. During the time of Shah Jahan (1628-1658), improved varieties of cherry, peach, plum, and grapes were introduced from Persia and Afghanistan.

6. Crop husbandry in the British period

East India Company, came to India for trade, established its rule on large areas of India after the battle of Plassey in 1757, which lasted until 1858. In 1858, the British crown assumed direct control of India in the form of the new British Raj which lasted till 1947. Until the middle of the 18th century, only indigenous cotton varieties (*G. arboreum* and *G. herbaceum*) were grown in different regions of the country. Due to the human skills and dexterity of the local artisans, very fine yarns were produced by them from the short staple and coarse cottons grown in India. In 1788, the Governor General at Calcutta was requested by London to encourage the growth and improvement of Indian cotton to meet the requirements of the Lancashire textile industry. Although, the exact area under indigenous cotton and production in India during this period are not available, it is reported that the local production had stabilized by 1900. The jowar, bajra, and other millets; maize- cooked and eaten as a green vegetable; and rice were cultivated during the wet season, and wheat, barley and pulses during the dry season.

Greater proportion of the indigo consumed in Europe was produced in India. It was grown extensively from Dhaka to Delhi. Its culture extended over 10 lakh acres in the Gangetic region. In 1842, the total export from India was valued at £27 lakh. The trade in opium was a government monopoly. Sugarcane was a popular crop among the Indian farmers, and it was also exported to the United Kingdom in large quantities. The wheat yield in India varied with the conditions under which the crop was grown. For example, on unmanured and low rainfed/dry crop it produced 7 bushels per acre, whereas 10 bushels per acre on manured land with better rainfall and 15-25 bushels per acre on manured with irrigated land.

After the construction of the Suez Canal in 1869, the export of oilseeds increased from £2 million to £5 million in a period of 19 years. The principal oil seeds were castor, gingelly, sesame, groundnut, safflower, rape, mustard, niger, linseed and cotton seed. The seeds of the fruits of several trees, such as *Pongamia glabra*, *mahua* and *neem* tree were also used for oil extraction and the trash was used as manure and cattle feed.

The major spices were ginger, saffron, cardamom, pepper, cocoa, areca, and other palm-yielding nuts, which were extensively consumed by the native population. The principal indigenous fruits were mango, the finest of all the Indian fruits; pomegranate, citron, date, almond, grape, pine-apple, and tamarind. In the northern provinces, apple, pear, plum, apricot, and other European fruits were grown. Orange and lemon were also grown by the farmers. Pepper was an important product of the Malabar coast, and the import into the United Kingdom from British India, in 1849, amounted to 3,913,611 pounds. Silk was produced primarily in Bengal and Assam. The mulberry thrived so freely in India that its culture expanded greatly beyond its present amount.

6.1. Crops introduced by the British

Driven by their trade interests the British made efforts to introduce new crops, institutes and systems in Indian agriculture during the 18th and 19th centuries. Setting up of the Royal Botanical Gardens and the Botanical Survey of India to acclimatize exotic crops of commercial importance to Indian conditions were some of them. Pseudo cereals like oat, grain legumes like black bean, fibre crops like cotton, vegetables like beetroot, cauliflower, sweet pepper, squash, carrot, orange, lettuce, tomato, pea, fruits like papaya, strawberry, apple, apricot, cherry, plum, peach and pear; medicinal crops like quinine, and aromatic plants like poppy and vanilla were also introduced.

6.2. Crops rotation and mixed cropping

Indian farmers used to practice crop rotation, and also followed mixed cropping. Often millets like jowar were sown mixed with leguminous crops like arhar. Rice was cultivated as a sole crop on silt-renewed lands that needed little or no manure, and which were plentifully supplied with water. Differences in the mode of cultivating rice was followed in some parts of Bengal, where it was the rule to sow rice broadcasted one year and transplanted in the next. In the Bombay Presidency, crops were systematically rotated in the irrigated garden. Less attention was paid to the rotation of purely dry crops. The reason was that everywhere on dry crop land, the practice of mixed cropping prevailed and the practice avoided to some extent the necessity of other rotation.

6.3. Trading and export of agri-commodities

The British Indian agricultural products cotton, indigo, opium, and rice emerged as major commodities of global trade. The production of the more commercialized crops like indigo and opium, tended to be restricted. The second half of the nineteenth century, however, saw significant expansion of land under cultivation. In new crops that emerged as major exportable, such as cotton and wheat, a steady rise in yield per acre was seen. National income estimates confirmed that agricultural production expanded in the late nineteenth century at the average rate of about 1% per year, due to increasing area under cultivation and the wasteland made cultivable by canal irrigation. Large scale expansion in cropped area usually involved the relocation of capital and labour on a large scale as well. Important regions of agrarian expansion were the Punjab, the Narmada valley, western part of the United Provinces, and coastal Andhra. From 1891-1946, the annual growth rate of all crop output was 0.4% and food-grain output was practically stagnant. There were significant regional and inter crop differences, however, non-food crops did better than food crops. Bengal had below-average growth rates in both food and non-food crop output, whereas Punjab and Madras were the least stagnant regions. Agricultural prices experienced pronounced cycles in the first half of the nineteenth century, but from the third quarter began to rise steadily and significantly until around 1920. For example, the price of wheat in 1920 was roughly increased three times to its 1870 level. The expansion of the global economy and greater overseas demand for primary commodities accounted for the relatively greater rise in prices of exportable food grains as compared to other commodities. In the inter war period, population growth accelerated while food output decelerated, leading to declining availability of food per head. The crisis was the most acute in Bengal, where food output declined at an annual rate of about 0.7% from 1921-1946, when population grew at an annual rate of about 1%.

6.4. Institutionalization of agricultural research and education

In the second half of the 19th century, started the talk of effecting 'large scale' improvements in Indian agriculture. All this talk merely led to the establishment of a few experimental farms and some agricultural schools. A fundamental department of agriculture in India was started in 1871. Although the chief function of the department named 'Department of Revenue, Agriculture and Commerce' remained revenue and there was no work on agricultural development. Plantation research in colonial India, though the experimental farms were established in 1884, the provincial agricultural departments could seldom go beyond the collection of revenue data and famine relief operations. Primarily, the department was established by the government with a view to supply cotton to the textile industries of Manchester, and not to feed the famine-ravished India. Based on the reports of the Famine Commissions of 1880, 1898 and 1900, the government was determined to set up a central 'Department of Agriculture' controlled by the Imperial Secretariat and agriculture departments were to be set up in the provinces to primarily look after agricultural enquiry, agricultural development and famine relief in the country.

Indian Agricultural Research Institute at Pusa, Bihar

However, the key duty of the agriculture departments both in the center and the provinces lingered on famine relief. In 1892, an agricultural chemist and an assistant chemist were allotted to look after research and teaching in India, which manifested the first scientific staff in the Department of Revenue and Agriculture. Eventually, in 1901, an Inspector General of Agriculture was appointed to advise the imperial and the provincial governments on agricultural matters. An imperial mycologist was appointed in the same year, and an entomologist was appointed in 1903.

During the severe famines of 1899-1900, Lord Curzon, the then Viceroy of India, was convinced that the government must urgently concentrate on the agricultural sector to overcome the damages caused by frequent famines. As a consequence, the Agriculture Research Institute together with a college for advanced agriculture training, was established at Pusa (Bihar) in 1905; and its director was the agriculture adviser to the government till 1929. The Agricultural School at Saidapet, Chennai, which was established as early as 1868, was later relocated to Coimbatore during 1906. Likewise, a branch for teaching agriculture in the College of Science at Pune (established in 1879) was subsequently developed into a separate College of Agriculture in 1907. Similarly, agricultural colleges were established at Kanpur, Sabour, Nagpur and Lyallpur, now in Pakistan, between 1901 and 1905.

Systematic research was initiated at the Agriculture Research Institute, Pusa (Bihar) for developing improved cultivars of major crops. The importance of strength of straw in wheat cultivation was mentioned in the reports. Another limiting factor in the growth of wheat in India was temperature. It used to be too hot during the sowing of wheat, and also advent of the hot weather in spring checked ripening and the crop withered. Research was undertaken to overcome these limitations and breeding programmes successfully brought out wheat varieties like Pusa-4, which had a good plant stand in spite of rain and wind. It was of shorter duration, and used to be sown in first week of November and harvested in early March. Pusa-12 was the first wheat variety released through hybridization breeding in 1910, while Pusa-4 was adjudged as the 'best quality wheat' in 1911. Dr. Benjamin Peary Pal commenced the rust resistance breeding programme in wheat at Tutikandi, Shimla and Pusa Bihar. The Pusa wheat varieties varied considerably in their degree of resistance to rust diseases. The most resistant wheat varieties were Pusa-52 and Pusa-4, while the most susceptible cultivars were Pusa-12 and Pusa 80-5. Pusa-111 was fixed from a natural cross in Pusa-4, but was more resistant to rust than Pusa-4.

Breeding programmes of oat and barley were also undertaken for developing high yielding and early maturing varieties. Selections in oats *viz*., 12-1 and 19-1 were found very promising and termed as BS Type 1 and BS Type 2, respectively. Barley constituted one of the main cereal crops of Northern India and a number of pure line strains were isolated. B-4 became the highest yielding cultivar during the time. Tobacco research was also undertaken during colonial period. Tobacco variety Type 28 (Pusa-28) became very popular among Indian states during 1916-1920 with about 12,000 acres of cultivation each year. The area under tobacco was suddenly increased by manifold with about 50,000 acres under cultivation in 1921. Successful trials of Type 28 variety of tobacco were also made by Indian Leaf Tobacco Development Company in Bihar. The company also undertook trials of Pusa-28 in British East Africa, Kenya and Zanzibar. Considerable progress was made in the isolation and study of linseed crop as well. The study of inheritance of various characters in linseed was undertaken. Type 124 of linseed gave higher yield compared to Type 12 and Type 121. Commercial possibilities of safflower oil were also explored. Gram was another important crop in which breeding programmes successfully brought out promising genotypes named Pusa-17 and Pusa-18, which gave higher yields compared to the local genotypes. IARI (now Indian Agricultural Research Institute) at Pusa, Bihar was later shifted to New Delhi in 1936.

Sugarcane breeding in colonial India continued to give promising varieties. A new sugarcane variety, Co 290 released from Coimbatore in 1924, superior to Co 213, had proved suitable for all sugarcane growing areas. It was reported that in 1926-27, the area under Coimbatore canes in North India was estimated at 23,600 acres and the increased profit to cane growers placed at Rs. 14,50,000. In 1927-28, the area increased to one lakh acres with more than proportional increase in profits. In case of rice, GEB 24 was the first rice variety released through an official breeding programme in 1921. In 1933, Basmati 370 was identified from a large collection of Basmati rice cultivars grown all over the North Western India.

An All-India Board of Agriculture was established in 1905 with a view to bring the Provincial governments more in touch with one another and make suitable recommendations to the government. The Indian Agriculture Service was constituted in 1906. The Royal Commission on Agriculture (Linlithgow Commission), which was appointed in 1926, authoritatively reviewed the position of agriculture in India and reported the same in 1928. According to the proposal of the Royal Commission on Agriculture, the Department of Education, Health and Lands of the government set up the Imperial Council of Agricultural Research (now ICAR) on 16 July 1929. Several semi-autonomous Central Commodity Committees were set up by the Ministry of Food and Agriculture. The Indian Central Cotton Committee was the first one to be established in 1921 on the recommendation of the Indian Cotton Committee (1917-18). The chief function of the Central Cotton Committee was cotton improvement with special focus on the development of improved methods of growing and marketing cotton. The Committee's support led to the development of 70 improved varieties and considerably improved fibre quality. IARI became the premier national institute for agricultural research, education and extension in India.

After independence in 1947, Indian Council of Agricultural Research (ICAR) steered agricultural research, education and extension in post-independent India. Intensive efforts of the scientists through innovative breeding programmes and suitable crop husbandry (agronomic) practices, coupled with the conducive policies of the Government, active involvement of extension professionals and farmers resulted in the 'Green Revolution' in 1960s thereby ensuring food security to the country. Subsequent achievements in crop improvement and its management are discussed in the subsequent chapters.

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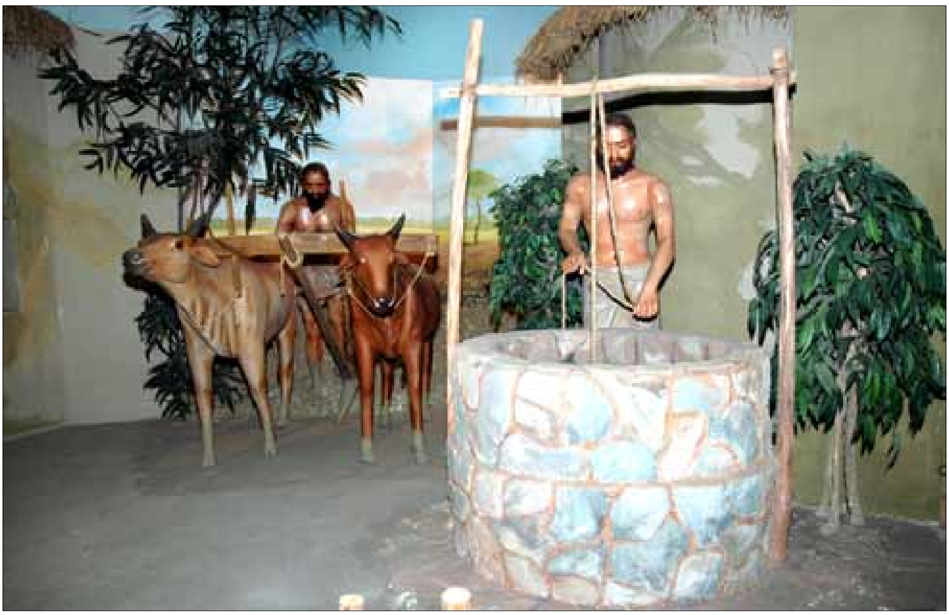

3
Chapter

Animal Husbandry in Pre-Independent India

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Summary

Human-animal relationship dates back to the Harappan Civilization as evident by the cave arts. Since then, animals have been used as a source of food, draft-power, skin, games and recreation. Sheep and goat were the first domesticated animals in the Indian sub-continent. Cattle gained more importance during the Vedic period leading to initiation of professional cattle breeding. The science of animal Ayurveda was also documented in this era while the use of cow dung manure in the agricultural fields was first observed in the Iron Age. Later on, buffalo was recognized for dairying in the Mauryan period. Horses and elephants received special attention during this period as they were required in battle and transportation. Their importance can be observed from the fact that specific feeding schedule was followed for horses and there was a ban on killing the elephants for their tusks. Use of animals for food, religious purposes and transport continued in the pre-Mughal era dynasties. Literature of Mughal era shows that people by then were aware about the best animal breeds and feed management practices. They used oxen for traction and milk as an important ingredient of various cuisines. This period is also known for the science related to horse rearing and breeding. Horse breed improvement followed by scientific developments in the field of cattle rearing and management continued with the advent of colonial rule. Formal veterinary education, establishment of agricultural research institutes, setting up of processing plants and development of vaccines/treatments for various animal diseases can be counted as important achievements of the British era.

1. Introduction

Animal rearing in India is centuries-old and there are sufficient evidences that suggest domestication of farm animals happened even before the beginning of the written history. "All these stages of man-animal relationship from the pre-historic time to early historic time are depicted in the art of the cave dwellers" (Mathpal 1984). Ancient Indian literature Vedas, Puranas, Brahmanas, epics, do mention about animal care and disease management. It is believed that man-animal relationship or domestication was initiated during Mohenjo-daro and Harappa period of Indus Valley Civilization. Domestication of animals started simultaneously at around 2500 BC in certain places of northern India. Excavations from the Bronze Age Civilization revealed animal husbandry practices including care and management of various types of livestock species including bovines, small ruminants, elephants, poultry etc. Early Historic man confined animals particularly to use/misuse them during battles. Humped Cattle breeding was more depicted during the Rig Vedic period (1500–1000 BC). The cow was then called *Kamdhenu*, the one who fulfils all daily needs, deriving its meaning from- '*Kamna'* meaning desire and '*dhenu'* meaning fulfilment. It was during Vedic period that the love for cow started (Somvanshi, https://www.vethelplineindia.co.in/veterinary-medicine-and-animal-keeping-in-ancient-india/). When the Aryans came, they advocated the protection of cows. Animal diseases and their cure using herbal medicines were well described in the ancient text 'Atharvaveda'. The text of '*Haya Ayurveda*' and '*Gaja Ayurveda*' written by Shalihotra and Palakapya, respectively describes the equine and elephant husbandry including care and treatment of some ailments. According to the ancient history, Shalihotra is considered as the first known Veterinarian of the world. Thereafter, animal husbandry in the country has passed a long way achieving various milestones and making the country one of the global leaders in this sector (Table 1). This chapter describes the major milestones in animal husbandry in the pre-Independent India.

Table 1. Milestones of animal husbandry in the pre-Independent India

Year	Milestone
9000 BC	Domestication of sheep and goat.
8000 BC	Domestication of cattle.
6000-4500 BC	Domestication of dog and fowl.
4000 BC	Domestication of water buffalo.
2000 BC	Domestication of Asian elephant.
1500–1000 BC	Humped Cattle breeding started.
1000-900 BC	Atharvaveda was composed. It provides interesting information about ailments of animals, herbal medicines, and cure of diseases.
300 BC	King Ashoka erected the first known veterinary hospitals of the world.
1794	Establishment of first Horse Stud at Pusa, Bihar.
1809	Establishment of Camel Breeding Farm in Hisar, Haryana.
1815	Cattle and Horse breeding started in the Government Cattle Farm, Hisar, Haryana.
1868	Cattle Plague Commission was formed.
1882	First veterinary college was established at Lahore (now in Pakistan).
1889	First military dairy farm was established at Prayagraj, Uttar Pradesh.
1889	Creation of Civil Veterinary Departments in the provinces.
1889	Establishment of Imperial Bacteriological Laboratory in Pune. It was later shifted to Mukteswar, Uttarakhand in 1893.

Year	Milestone
1889	Development of anti-Rinderpest serum at IVRI, Mukteswar, Uttarakhand.
1902	Anti-Anthrax Serum was developed.
1902	Indian Civil Veterinary Department was established.
1908	Black Quarter Vaccine and Polyvalent HS Vaccine were developed at IVRI, Mukteswar, Uttarakhand.
1913	Another branch of Imperial Bacteriological Laboratory was opened in Izatnagar, Bareilly which was later renamed as Indian Veterinary Research Institute (IVRI) in 1947.
1915	Polson dairy-the first large scale milk processing plant in India was established at Bombay.
1923	Imperial Institute of Animal Husbandry & Dairying was started in Bangalore. In 1955, its headquarters were shifted to Karnal, Haryana and it was renamed as National Dairy Research Institute.
1925	Use of Artificial Insemination (AI) for the cattle started in Military Dairy Farms.
1927	Goat Tissue Virus (GTV) Rinderpest Vaccine was developed at IVRI, Mukteswar, Uttarakhand.
1939	Poultry Research Section was established at IVRI, Izatnagar, Uttar Pradesh.
1940	Development of Ranikhet Disease Vaccine at IVRI, Mukteswar, Uttarakhand.
1940	Collection centres and distribution network were set up for linking the rural milk producers in Bombay with the urban consumers.
1946	Cooperative movement started in dairying with the establishment of the Kaira District Cooperative Milk Producers Union (AMUL) in Gujarat.

2. Animal husbandry in ancient India

2.1. Pre-vedic era and the Harappan ethos

Valuable information pertaining to ancient animal keeping were revealed from the archaeological evidences dating back to Harappa (Montgomeri) and Mohenjo-daro (Larkana) districts, from Punjab and Sindh province, respectively. People from these periods raised and used animals for games and recreation. Numerous livestock products were consumed namely, milk, curd, ghee, etc. The animal skin and hides were also documented for having important uses. Importance of cattle, pig, fish and other animals including tortoise as food is vastly mentioned during Harappan period although fish was the main animal food for people during this period. Excavations of various paintings, seals and stamps and scripts recovered from the Indus valley civilization provided tremendous knowledge about their culture and animal husbandry ethos but many of the scripts on the seals have not been decrypted fully.

Bull seal of Harappa

2.2. Vedic and post-vedic era

In the Vedic period, animals gained more importance. It was during Vedic period in India, cows were cherished as religious entity and were referred as '*Aghanya'* i.e., not to be killed. "Vedic people regarded cow as the source of their good fortune, happiness, and good health" - Rigveda (6.28.1, 6). We have plentiful information on the status of animal keeping, care and management in the Rigveda. According to it, people used to feed their cows on nearby pastures to their homes. If sufficient pastures were not available, there was a practice to generate pastures for cows by clearing the forest lands. It is written that the cows were milked thrice a day, indicating their utility for milk and availability of quality germplasm, pastures/grazing lands.

Cattle were considered as symbol of wealth. Aryans fought wars with local tribes for acquiring their cows, a valuable asset, and named these wars as "Gavishti". Evidence exists that Aryans also kept dogs for guarding houses and for hunting of boars and preferred cow over buffalo for giving milk. A 'Nandi' or the breeding bull was selected based on several characters of body and the mother's history of milking. Management practices like castration of male animals were also practiced during the Vedic era and oxen were used for farm transport, ploughing and irrigation of agricultural fields. Small ruminants and their importance had been clearly documented during this period, where goat was mostly kept for milk and sheep for wool. In the sacred text of Rigveda, material used to feed domestic animals are mentioned which includes barley, sugarcane, and deoiled sesame cake. The science of animal Ayurveda was also documented during the Vedic period. The information about curing the cow through medicinal herbs and dietary supplements is believed to be written in some of the Vedic hymns. Atharvaveda mentions the treatment of various cow ailments through the use of animal Ayurveda. Vedic people also used surgical methods such as grafting, removal of foreign bodies, treatment of dislocations, fractures and fistula for managing the animal diseases (NAVS 2015).

The Aryan people in later period of Vedic age, also known as Iron Age witnessed the composition of two great epics of Hindus - Ramayana and Mahabharata which also mention the management of animal diseases using medicine, oils, herbs, and also cure through surgical corrections performed by trained Vaidhyas. It was during this period, the use of cow dung as manure in the agricultural fields was noticed.

It's the Gopala or Krishna (900–1000 BC) era where we found the information about '*Gau-palan*' and '*Gau Sanrakshan'*. Govinda was another name given to Krishna (meaning the protector of cows). It was during this period when milk and its products especially milk-butter assumed importance and tax was paid to the king in terms of butter. *Gopashtami* was started by Krishna where worship of cows was done on a specific day after Deepawali. Panchagavya which includes five things, namely cow milk, curd and ghee prepared from cow milk, cow dung and cow urine, gained importance during this period and was practiced in religious rituals. The religious texts, namely, 'Shrimad Bhagwat', poetry and paintings of the era depicted the role and importance of cow husbandry in the society.

2.3. Mauryan era

Care and management of domestic animals is documented for the Mauryan period (322-232 BC). An important text written by Kautilya during the Mauryan period was *Arthashastra*, which discuss in detail the role and duties of a king in providing care and protection to cows. *Arthashastra* also recognizes the role of various domestic livestock, and it was during this period that buffalo was also recognized for dairying and difference in milk-fat with cow was documented, indicating that buffalo milk has a higher fat content. Texts of '*Arthashastra*' suggested the creation of separate department in the state for accounting the livestock and land maintained for pastures, by village-based accountants called 'Gopas'. Mauryan period is also known for the introduction of state funded veterinary services (NAVS 2015). The text describes optimum herd size, male to female ratio of cattle, feeds and fodder. It also mentioned the earnings and trade through different livestock products, skin and hide, fur and wool. The text mentioned the law (Veterinary Jurisprudence), and provision of punishments and penalties imposed on committing crime (robbery or on ill treatment to cows) and non-compliance to pay taxes related to animal husbandry. During the Mauryan period, the horses received special attention, as grading of horses based on their utility in battle or transportation has been documented. Thoroughbred horses were widely kept during this period. Besides feeding grasses, a good detail of their feeding schedules has been described which included the parched rice, drippings, minced meat, and red rice-powder. Elephants were the prized possession of the kings and were used in warfare, to storm the forts of enemy kings and smash open the massive doors of the forts. Kings and army used elephants to move even in dense forests and marshy lands. Provision for capital punishment was kept on killing the elephants for their tusks during this period. The great king Ashoka (300 BC) gave veterinary science a major thrust in India. It is described that "the first known veterinary hospital of the world existed in Ashoka's regime - Schwabe (1978). During the Gupta period, the knowledge documented in '*Arthashastra*' prospered until Islamic rulers invaded India in 800 AD.

3. Animal husbandry during the medieval era

3.1. Medieval Indian dynasties

The medieval India is the period between the end of the Gupta Empire in the 6th Century and the start of the Mughal Empire in 1526. During this period, Indian subcontinent was majorly ruled by 32 dynasties at different periods in different geographical regions. Many dynasties were contemporary with each other. Among 32 dynasties, the documentary evidence on animal husbandry is possibly available for 18 dynasties. In these dynasties, animals were majorly used for the purpose of military, transport, draft, food, ceremonial activities, maintenance of temples, and recreational fighting. As the elephants and horses were used in military and for the transport of royal class, veterinary science was well developed especially in Reddy dynasty (Reddy 1991). Cow ghee was used for perpetual lamps in temples. Specifically, during the Eastern Chalukya period, cows, sheep and goats were donated to temples for performing daily sacred activities. The numbers of animals were donated according to the number of perpetual lamps in a temple and they were maintained by a community called "Golla or Boya". Apart from the milk and ghee, people used to consume meat. The meat of goats, sheep, pigs, poultry, hare and boar was commonly sold in Chalukya dynasty (Sastri 1955). Use of goats, sheep, pigs and fowl continued for meat purpose in Western Chalukya dynasty (Sastri 1955). Similarly, hides were the part of exports during Rashtrakuta dynasty, in which bullocks and horses were used for business travels (https://en.wikipedia.org/wiki/ Economy_of_Rashtrakuta_empire_of_Manyakheta). Although, people used to eat meat, cows and horses were worshiped. For example, the cows were given almost equal rights as of humans in Chola Empire. In the same empire, the provision of feed to the cows was similar to the provision of food to humans during famines (https://en.wikipedia.org/wiki/Ellalan).

Similar to the cow, horse was also considered as a sacred animal during Vijayanagara Empire. In Harsha Empire, animal slaughter was banned (https://en.wikipedia.org/wiki/Harsha). To meet feeding needs of cattle, pasture lands and grazing fields were maintained in villages in Pala Empire. Particularly, Viasya community used to take care of cattle along with other trade articles (Targa 1999). Interestingly, cattle breeding was a separate profession and cattle breeders used to pay separate tax during Pallava dynasty (https://factsberry.com/all-about-the-pallava-dynasty). Overall, animals played a major role in the economy of medieval dynasties, which was evident especially in Kakatiya dynasty, in which the economy was a mix of animal keeping (sheep, goat), crop husbandry (jowar and paddy) and trade including the export of 'wool' and cotton textiles. However, in Delhi Sultanate, not much development was seen in the farm animal sector but still taxes were imposed on the basis of number of cattle.

3.2. Mughal era

The Mughal reigned India from 1526 to 1857 during which the country was home to large cattle population. Historian Irfan Habib in his book *The Agrarian System of Mughal India* pointed out that there were more cattle in India than in Europe but with lower milk yields. Productivity of the cattle and buffalo varied from 1-5 seers and 2-30 seers, respectively (1 seer ~1 kg). Cattle of Gujarat and buffalo of Punjab were considered to be the best. Feeding management of the dairy animals was solely dependent on the milk productivity. Cattle with good milk production was considered as "*Khas*" class/breed and fed with near about 6 kg of grain and 15 kg of green grasses per day, whereas, remaining classes were fed with the half of this ration. But, peasants of the Mughal era used to take extra care of their buffaloes as they were the main milch breed. Around 8 kg of wheat flour, 500 grams of molasses, 1.50 kg of grain and 20 kg of green grasses were fed to the buffalo. Small ruminants like sheep and goat were the integral part of the animal husbandry out of which goat breed of Bengal and Coach Bihar are specifically mentioned in the literature. The Mughal emperor Akbar improved the irrigation facility throughout his dynasty and cattle/ox was used for powering the *Sakia* or Persian Wheel to bring irrigation water. Beside traction, livestock were used for improving the soil fertility. Peasants of the southern India used to keep goat and sheep flocks for few nights in the crop field for droppings which was considered to be a good source of quality manure. It was assumed that a flock of 1000 sheep / goats with five-to-six-night stay on a piece of land of 1.32 acres may maintain the fertility of the field for 6 to 7 years.

Milk was one of the important food items in the diet during the Mughal period. Narayanan (2015) argued that milk and various milk products including yoghurt, ghee and butter were also a fairly conspicuous part of the diet in many parts of the northern India. Therefore, many indigenous milk products like *rabri, phirni, khir,* etc. were very popular during Mughal period. *Kulfi*, a delicious frozen dairy dessert, often described as "traditional Indian ice cream" originated in the Mughal Empire in the 16th century. Krondl (2011) quoted from *Ain-i-Akbari* where Abu'l Fazl mentioned use of saltpeter for refrigeration as well as transportation of Himalayan ice to warmer areas to prepare delicious *Kulfi*.

The horses were regarded as a status symbol in the Mughal society (Chowdhury 2017). The Mughal paid great attention to the horses due to its military, economic and political importance. Throughout the dominant Mughal period, 1526-1707, the Mughals maintained a larger cavalry force and it was their main military strength (Irvine 1903). Therefore, the science of horse achieved ultimate heights during the Mughal period. Chowdhury (2017) argued that though the Indian climate was not suitable for the horse-breeding, then, also, numerous personal or institutional breeding centers and studs were established all over the Mughal dynasty with state patronage. State even promoted cross breeding of indigenous horse with the imported horse like *Arabian, Persian, and Turki* horses. *Baytars* (veterinarian) was considered as one of the gentleman professions. The state also provided protection and patronage to the writers of the equine veterinary literature i.e., *faras-namas* which tells about the skills of animal-medical-wisdom for caring, healing and managing horses in the stable during Mughal era.

4. Animal husbandry during the British era

The Company rule in India effectually started from 1757 and ended with the 1857 rebellion after which the British government directly ruled the country until the independence in 1947. Development of animal husbandry in India during the colonial era was as per the military and economic needs of the British Empire. They were initially interested in breeding and health care of only horses which were important for maintaining the cavalry. Later on, cattle rearing gained attention due to increase in demand of military establishments for animal food (milk and beef) leading to the establishment of Military dairy farms. Much of the scientific developments in the field of dairying in India started from these farms. The Britishers were least concerned about the requirements of common Indian people; however, they had to take steps for overall development whenever their interest was connected with the common people. One such example is setting up of research institutions for controlling the spread of animal epidemics in the country so that it does not affect the herds of Military Dairy Farms. These institutions developed a number of vaccines and treatments for various animal diseases. Formal veterinary education in India also started during the colonial period which helped in developing skilled man power. Another important development during the colonial era was commercialization of milk. New dairy processing plants, marketing organizations and dairy cooperatives were established for linking the rural producers with urban consumers. Besides horses and cattle, the Britishers were also interested in camels, mules, zebra and poultry for fulfilling their various requirements.

4.1. Horse breeding

The preliminary work related to the improvement of horses in India started as early as 1793. William Frazer, an army officer presented a plan for improving the horse breeds of the Ganges valley by setting up a stud and assembling the best mares from different parts of the country. In his view, the horses from Cutch in Gujarat were at par with the Arabic horses and he offered to breed them with best Arab stallions (Randhawa 1983). His proposal was approved and a board was formed in late 1794 for supervising operations related to horse breeding in India. The first stud was established in Pusa (1794) and subsequently different forage crops like Alfalfa, Bermuda grass, Clover and Guinea grass were introduced in the region. Thereafter, more studs were established in Ganjam, Hisar and Hapur. The work of Frazer was carried forward by Moorcroft who introduced better feeding and health management practices in the studs. In 1815, horse breeding started in a farm in Hisar, Haryana which was established in 1809 for breeding of camels. The responsibility of imperial horse breeding was entrusted to the Army Remount Department in 1904 while the local bodies were in charge for provincial horse breeding.

4.2. Establishment of military dairy farms

The Britishers established military dairy farms in order to ensure sufficient availability of quality milk and milk products for military and British families in India. The first military dairy farm was established at Allahabad in 1889. Later, more farms were established across the country and there were around hundred such farms at the time of independence in 1947. Improved milch animals with higher productivity were reared and proper records were maintained in these farms (Wieser 2000). The use of artificial insemination for the cattle in these farms started in 1925 which assisted in herd improvement to some extent. Besides milk production, some of these farms helped in preservation of local breeds. Military Dairy Farms can be considered as the first step towards organized dairy farming in India.

4.3. Cattle improvement and management

The common people in India during the colonial period used to prefer buffalo over cow for dairying due to their higher milk yield as well as more fat content in the milk. The yield of buffaloes was somewhere around 2.27 litre per day. Cows were specifically preferred in those areas where pastures were present. The average milk yield of cow in the country ranged from 0.4 to 1.8 litre per day depending on the breed, place of rearing and management practices. Moreover, the length of their lactation period was only six months (Randhawa 1983). Some cattle breeds like Gujarat, Sind, Ongole and Nellore were considered better than others while there was a vast scope for improvement of other local cattle. Good dairy animals were fed with oilcake and cotton seed for maintaining their productivity.

During late eighteenth century, William Frazer suggested breeding of indigenous cattle with the bulls of Nagore breed. Afterwards, cattle breeding started in the Government Cattle Farm of Hisar in 1815. The major focus of the farm was on Hariana, a dual-purpose cattle breed. In order to improve the milk yield, Mysore cattle was also crossed with Sind, Gujarat, Ongole and Nagore breeds in the Hisar farm. Moreover, the Gujarat cows were studied in detail in Pune. The Royal Commission on Agriculture (1928) reported poor health and low milk yield of Indian cattle as a major constraint in dairy development following which exotic breeds were introduced in the country for breed improvement. For increasing the milk yield, Ayrshire and Friesian bulls were recommended for crossing with the native cows. Gradually, provincial agricultural departments took the responsibility of cattle breeding and some of the provincial governments further encouraged the projects related to livestock improvement.

There was a huge outbreak of Cattle Plague (Rinderpest) in 1865-67 and millions of bovines died in different parts of the country leading to a series of famines (Mishra 2011). In order to avoid spread of disease to the military farms, the government was forced to take concrete steps for its control. As a result, Cattle Plague Commission was formed in the year 1868 for proper disease management. Unfortunately, government was interested in disease management only when their own herd was under threat. However, between 1901 and 1904, lots of work was carried out for the treatment of anthrax and hemorrhagic septicemia and a vaccine was developed each against black-quarter and rinderpest.

4.4. Effect on pastoralism

Animal husbandry was an important source of livelihood not only for the farmers practicing settled agriculture but also for the pastoral communities. The colonial rule affected the lives of pastoralists to a great extent. Most of the grazing lands were diverted for cultivation which led to the decline of pastures. Stringent forest rules further restricted the access of livestock to the grasses available in the forest. Grazing tax was introduced in the mid-nineteenth century and pastoralists had to pay tax on every animal they grazed on the pastures (NCERT 2006).

4.5. Commercialization of milk and market linkage

Commercialization of milk started in the early twentieth century. British troops and growing cities like Bombay were the main demand centres of milk. In the absence of fast transportation and chilling facilities, majority of the milk (68.8%) was converted into less perishable milk products like ghee, butter, khoa and curd. Liquid milk which used to fetch higher prices accounted only for 31.2% of the total sales while the share of ghee (52.7%) was highest. The collection centres and distribution network for linking the rural producers in Bombay with the urban consumers were set up in 1940. The well-organized milk marketing organizations took the responsibility of milk distribution in other metropolitan cities like Delhi, Madras, Calcutta, Karachi, Kanpur and Nagpur. Polson dairy which was established in 1915 in Bombay was one of the first large scale milk processing plant in India. Keventers and Express Dairy were the other two popular dairy processors. Profit was the main motive of these plants and they were not concerned with the development of rural producers. Farmers were exploited due to dominance of middlemen and contractors in this system (Banerjee 1994) which led to larger discontentment among the milk producers. As a result, the cooperative movement started in dairying with the establishment of the Kaira District Cooperative Milk Producers Union in Gujarat in 1946, which was quite successful and encouraged formation of dairy cooperatives across the country after independence.

Kaira District Cooperative Milk Producers Union in Gujarat

4.6. Development of other livestock

Horses and cattle received the major attention of the British government but some advancement also took place in the case of other animals like camel, mules, donkey, sheep, zebra and poultry birds. Camels were used by the Britishers for transportation and a government farm was established in Hisar for camel breeding in 1809. Later on, this farm was also used for breeding of bullocks, mules, zebra and sheep. Local ewes were crossed with Merino rams in the farm and an improved breed of sheep namely, Hissardale was developed which yielded superior quality of fleece. Status and scope of poultry was discussed in the report of the Royal Commission on Agriculture (1928) and subsequently, the Institute of Poultry Research was established at Izatnagar in 1938 (Sinha 2010).

4.7. Slaughter houses and the gaushalas

The Britishers started killing cows for beef soon after settling down in India. They established slaughter houses on the western pattern in different parts of the country. The cow slaughter and consumption of beef increased manifold in northern India during the colonial period. But soon after the first war of independence in 1857, many native people were mobilized and they collectively started a movement for protection of cows. After rescuing the cows from the butchers, they were reared in Gaushalas. Large numbers of Gaushalas were established in the country for this purpose between 1880 and 1893. This movement also received the support of Mahatma Gandhi in the year 1891. Prohibition of cow slaughter was one of the many objectives of Swaraj movement. The British Government imposed some restrictions on slaughter of cattle in 1944 and the army was not allowed to slaughter working cattle, pregnant and milking animals and the cattle fit for bearing offspring.

4.8. Establishment of veterinary colleges and research institutions

The first veterinary college was established at Lahore in 1882. Two years later, approval was granted for starting a three-year veterinary course in Parel, Mumbai. Afterwards, three more veterinary colleges were started in Madras, Calcutta and Bihar. Cattle Plague Commission which was appointed in 1868 after the severe outbreak of cattle plague epidemic led to the creation of Civil Veterinary Departments in the provinces in 1889. The Indian Civil Veterinary Department was established in 1902 and the responsibility of animal husbandry and dairying was entrusted to the provinces in 1919.

Mother campus of ICAR-Indian Veterinary Research Institute at Mukteswar, Uttarakhand

The Cattle Plague Commission submitted its report in 1871 (Hallen et al. 1871). Scientific work on animal diseases in India started in 1889 when an Imperial Bacteriological Laboratory was established in Pune where Dr. Alfred Lingard worked on diseases of camel and horses (Sinha 2010). This laboratory was later shifted to Mukteswar, Uttarakhand in 1893 as its cool climate was favorable for bacteriological research and vaccine preservation. In 1913, another branch of the laboratory was opened in Izatnagar, Bareilly for mass production of vaccines and serum. It was renamed as Imperial Institute of Veterinary Research in 1925 and later on as Imperial Veterinary Serum Institute, Imperial Veterinary Research Institute and Indian Veterinary Research Institute respectively in 1930, 1936 and 1947. Meanwhile, an institute for dairy specific research was started in Bangalore in 1923 by the name Imperial Institute of Animal Husbandry & Dairying. It was renamed as Imperial Dairy Research Institute in 1936. Its headquarters was shifted to Karnal, Haryana after the independence in 1955 and again renamed as National Dairy Research Institute.

5. Conclusion

In the pre-independent India, animal husbandry was largely a subsistence activity. There was some knowledge about good animal breeds, feeding schedule and disease management. During colonial era, scientific developments like breeding, artificial insemination, food processing, record-keeping etc. started but these were mostly restricted to the Government farms and institutes. The common people were able to gain direct benefits from these advancements to a limited extent. Wide-spread poverty and low productivity of animals were the immediate challenges at the time of independence. India which is now the top milk producing country was suffering due to milk shortage in 1947; presents the complete picture of that period. Despite all this, developments like beginning of formal veterinary education, establishment of research institutes and initiation of dairy cooperative movement laid the foundation for the progress achieved in the post-independence era.

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4
Chapter

Natural Resource Management in Pre-independent India

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Summary

Climate, water and soil have been the major determinants of agricultural productivity. These three vital natural resources are eternally related with one another and also with crop, animal and human health. Climate determines the availability of water and formation as well as health of soil. Climatic processes, on the other side, are also influenced by water bodies and soil. Since the beginning of the civilization, when the hunting and food gathering humans started to settle down initiating domestication of animals and growing crops, these natural resources shaped the human activities and dictated the path of the progress of the civilization. The importance of these resources was well known to the Indians since the Vedic and Epic ages. Kautilya's *Arthasastra* discussed meteorological aspects of agriculture, different rain-bearing clouds and measurement of rainfall using a fixed dimension vessel as a rain gauge. Poet Kalidasa mentioned the dates of onset of monsoon and its path over central India in his famous epic *Meghdoot.* Manu, of the fame of "*Manusmriti*", recognized the Sun as the source of energy for all weather systems. Varāhamihira's *Brihat Samhita* discussed planetary movements, eclipses, rainfall and clouds. Scientific study of climate, however, started in the 17th century after the inventions of instruments for accurate measurements of climatic controls. In 1793, first meteorological unit, one of the oldest stations of the world, started in Madras by J. Goldingham. With several other developments in climatology, the climatological charts of India and neighbourhood was published by India Meteorology Department (IMD) for meteorologists and Airmen in 1946. As agriculture grew, the use of water available in rivers, lakes and underground reservoirs through the water withdrawal structures were developed. The Kings, Emperors and Rulers constructed withdrawal and conveyance structures to carry water to the fields and domestic use. Construction of Lake Sudarsana in 300 BC followed by Grand Anicut, Bahur Tank, Gangaikonda Cholapuram Tank, Bhojpur Lake, Anantaraja Sagara Tank, Early Western Yamuna Canal, Early Bari Doab or Hasli Canal and Early Eastern Yamuna Canal are some of the prominent examples of irrigation systems in the county before independence. Modern irrigation systems are backed by the strong ancient knowledge of water resource management. The *Vedas* and *Upanishads* mentioned soil as synonymous with '*the Mother*'. Farmers of the Indus Valley Civilization used to plough the soil, apply cow dung as manure, broadcast seeds and use a certain sequence of cropping and fallowing. The Mauryan Empire categorized the soils.

Understanding the nature, properties and classification of soil improved considerably in late 1800s with initiative of J.W. Leather, commonly acknowledged as the father of Soil Science and Agricultural Chemistry in India. Indian scientists assessed the contributions of biological nitrogen fixation and methods of ameliorating the problem soils. In a land mark development, first soil map of India based on soil characteristics was prepared in 1943. Researchers of pre-independent India did many significant works for improving the scientific understanding of climate, water and soil; which still stand as classical foundation of modern science for natural resources management. The concepts such as one health, circular economy, organic farming, integrated farming system, crop planning and several others, which emerged in the ancient period are now being refined and reemphasized for climate-resilient, sustainable agriculture.

1. Introduction

The biotic process of agriculture is majorly controlled by abiotic factors of climate, water and soil. Most often, agricultural productivity is seriously limited by various abiotic stresses such as salinity, drought, flooding, heat, cold and freezing. The reduction in performance of crops, livestock, poultry and fishes have been found to be due to the negative impacts of these stresses on growth and development. Industrialization, urbanization and climate change further exacerbate the detrimental effects of these stresses on agriculture. Management of natural resources is thus, crucial for the progress of Indian agriculture. Efficient utilization of water and soil has been practiced from the ancient times in one or other forms. Ancient literature (Vedas, Upanishadas, Ramayana, Mahabharata) have descriptions of climate, water soil and their inter-relationships. The scriptures described the five elements of the universe (*Pancha Mahabhutas, Pancha Tatwas*) as the keys to crop, animal and human welfare. The concepts of one health, circular economy, organic farming, integrated farming system, crop planning and several others emerged in the ancient period for improving the productivity and sustainability of crop and animal husbandry. Starting from the Indus Valley Civilization, the rulers of all the subsequent periods gave importance to the development of irrigation infrastructure and soil management systems. As the science progressed, so did the management of natural resources. Efficient management of these resources played a major role in enhancing agricultural production and achieving food security in India, particularly during the period of the Green Revolution. Several natural resource management technologies have been developed for enhancing and stabilizing agricultural productivity. This chapter discusses the major developments in climatology, water and soil in pre-independent India, on which the foundation of modern research and development of natural resources management has been built.

2. Climatology in pre-independence era

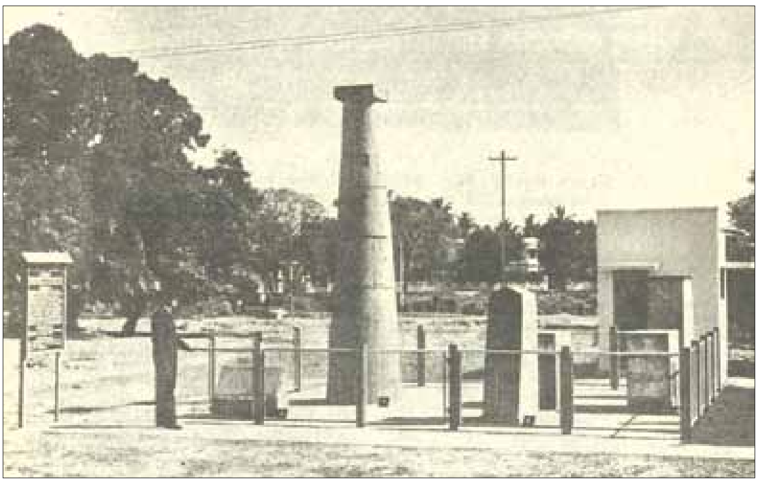
Climate has been the major determinant of agricultural production in India. A favourable southwest monsoon is critical in securing good yields of rainfed crops as well as water for irrigating crops. Failure of monsoon causing drought has led to major famines in the past in several parts of India. Accordingly, Indian scientists tried to analyse and understand the climate processes and predict their behaviour so that the crop calendar can be set and risk management strategies developed. The trace of meteorology and climate science in India can be found since the ancient times (Table 1). The earliest reference is in the Rig Veda (5000-2000 BC), which mentions the classification of seasons, bursts of monsoon, rain-producing weather systems, cloud formation and their classification. It also linked the Hindu deities with weather events such as Indra to rain and Marut to wind (Ghosh 1983). The occurrence and intensity of weather events were also linked to the deities' pleasure or displeasure. The *Upanishadas* (3000 BC) mentions about the processes of cloud and rain formation (Booth 2015) and describes the seasonal cycles as an effect due to earth's movement around the Sun. Kautilya's *Arthasastra* (321-296 BC) discussed meteorological aspects of agriculture, different forms of rain-bearing clouds and measurement of rainfall using rain gauge, which was a circular vessel (20 fingers width, 8 fingers depth) and the unit to measure rain was *adhaka*, which is equal to 12 mm (IMD 1976; James and James 2013). It also mentions forecasting of weather using the planetary motions of Jupiter and Venus (Iyenger 2009). Kalidasa, the poet and dramatist, in the 1st century AD mentioned the dates of onset of monsoon and its path over central India in his famous epic *Meghdoot* (Datta 1983). Around 200 AD, Manu, also known as Svayambhuva, in his famous compilation "*Manusmriti*," recognized the Sun as the energy source for all weather systems. The motto of the India Meteorological Department (IMD) '*Adittyat Jayate Vrishthi*' meaning 'From the Sun, rain is born', has been taken from this publication. Panini in the 5th century described the rainy season and process of rainfall measurement. Varāhamihira (505-587 AD) wrote *Brihat Samhita* and discussed about planetary movements, eclipses, pregnancy of clouds, pregnancy of air, quantity of rainfall, and signs of immediate rain. The *Brihat Samhita* also mentions of rain measuring vessels of fixed diameter and depth. Yuan Chwang, a traveller from China to India during the 7th century AD mentioned the climate of different parts of India such as Mathura (hot) and Andhra (moist and hot) (IMD 1976). In his treatise, there are many citations of flood and drought events in different parts of India. Halley (1636), a British astronomer, in his treatise on Indian summer monsoon, described it as a seasonal reversal of wind due to differential heating of landmasses. This treatise is considered to be one of the landmarks in the field of climatology (Rajeevan et al. 2021).

Table 1. Chronology of some important meteorological events in pre-independent India

Period	Milestone
5000-2000 BC	*Rig Veda* presented the classification of seasons, bursts of monsoon, rain producing weather systems, cloud formation and different types of clouds. Upanishadas discussed cloud, rain and seasonal cycles due to earth's movement around the Sun.
321-296 BC	Kautilya's *Arthasastra* discussed meteorological aspects of agriculture, different rain-bearing clouds and measurement of rainfall using a fixed dimension vessel as a rain gauge.
1st century AD	Kalidasa mentioned the dates of onset of monsoon and its path over central India in his famous epic *Meghdoot*.

Period	Milestone
200 AD	Manu in his compilation of "*Manusmriti*" recognised the Sun as the source of energy for all weather systems.
505-587 AD	Varāhamihira's *Brihat Samhita* discussed planetary movements, eclipses, rainfall and clouds.
1636	Halley published a treatise on Indian summer monsoon and attributed it to seasonal reversal of wind due to differential heating of land masses.
1793	First meteorological unit, one of the oldest stations of the world, started in Madras by J. Goldingham.
1835	Henry Piddington in Calcutta coined the term 'cyclone'.
1842	Henry Piddington in Calcutta published "Law of storms".
1843	Earliest upper air observation by Dr. Buist in Byculla using a balloon.
1852	Radhanath Sikdar, first Indian superintendent of Government observatory, recorded systemic weather observation for the first time.
1874	H.F. Blanford was appointed as first Imperial Meteorological Reporter to the Government of India. He initiated the systems of long-range forecast in India.
1875	First headquarters of IMD started at Alipore, Calcutta.
1878	First solar observation in India was recorded at Dehradun.
1878	Publication of the Indian Daily Weather Report (IDWR) and first weather charts from Shimla.
1886	First operational long-range forecast for south-west monsoon rain was issued by IMD. India became the first country to start systematic development in long-range forecast.
1905	Upper air measurement of winds started by tracking balloons with theodolites.
1909	Sir Gilbert walker developed multiple regression model for forecasting monsoon rainfall over India.
1924	Sir Gilbert Walker discovered "walker circulation" and "southern Oscillation". Linked the monsoon with global meteorological phenomenon.
1928	Establishment of Pune Headquarters of IMD and first all India weather summary and forecast was issued from Pune.
1932	LA Ramdas, Indian Meteorologist, studied the horizontal and vertical climatic variations near the ground surface. The agricultural meteorology branch of IMD also started functioning under him in 1931.
1933	Manufacture of Symon's rain gauge, cup anemometer and windvane was started in India by IMD.
1943	Radiosonde observations commenced.
1944	S.K. Banerjee became first Indian Director General of IMD.
1944	Based on data up to 1940 (a) 5-day normal pressure, humidity and temperature and (b) aviation climatological tables were published by IMD.
1946	Climatological charts of India and neighbourhood was published by IMD for meteorologists and Airmen.

The beginning of modern meteorology in the world is marked with the invention of the barometer and thermometer in the 17th century. These inventions started the scientific measurements of the atmospheric variables on scientific principles. The earliest meteorological observation in India was taken at Madras in September 1793 by J. Goldingham, who was the second astronomer appointed at Madras observatory by the British East India Company. The Madras Observatory was established in 1792 and is considered as one of the oldest observatories of the world. The second observatory in India was established at Colaba, Bombay in 1823. Henry Piddington, an English sea captain, settled in Bengal, significantly encouraged the growth of meteorology and climatology in India by publishing around 40 papers related to tropical storms during 1835 in the journal of Asiatic Society. He coined the term "cyclone" meaning "coil of snake" and in 1842, his monumental work "Laws of storms" was published (Piddington 1842). In 1843, in-charge of Colaba observatory, Dr. Buist started the earliest attempts of recording upper air observations using a balloon at Byculla station in India. In October 1852, Radhanath Sikdar added another milestone in the Indian climatological history by becoming the first Indian Superintendent of the Government Observatory at Calcutta. He introduced systematic and accurate observation recording systems at the Calcutta Observatory in December 1852, which were published regularly in the Journal of Asiatic Society of Bengal during 1853-76. The publication consisted of hourly, daily and monthly means ranges and extremes of principal and derived weather parameters. This was one of the landmark events in data recording for long-term studies. In 1874, H.F. Blanford was appointed as first imperial Meteorological Reporter to the Government of India (Raj 2013). In 1875, Government of India set up the Meteorological Department at Calcutta under H.F. Blanford to bring all the meteorological work in the country under one organization. This was initially known as The Alipore Office (the first headquarter of IMD. Blanford (1886) published a book "Rainfall of India," a remarkable contribution on India's weather and climate. He also initiated the systems of long-range forecasting of rainfall in India. Though the first solar observation was made at Dehradun in 1878, the systematic recording of solar radiation started in 1893, when the Government of India sanctioned the first solar physics observatory at Kodaikanal in Palani hills in Tamil Nadu. India became the full member of the International Meteorological Organisation in 1878 and in the same year, India Daily Weather Report (IDWR) started publishing from Shimla (IMD 1976).



Madras Observatory *(Source: IMD)*

The country realized the need for seasonal forecast of rainfall, which was issued first by IMD on 4th June 1886. This made India the first country to start systematic development in long range forecasting (LRF). In 1889, John Eliot, was appointed as first Director General of Observatories of IMD at Calcutta. He was well known for improving the LRF of monsoon rains along with Gilbert Walker (IMD 1976). Upper air measurements started in India in 1905 using tracking balloons with theodolite, followed by routine observations from pilot balloon in 1913 (Katz 2002). In 1909, Walker developed multiple regression models for forecasting monsoon rainfall over India. In 1924, he discovered the 'Walker Circulation' and 'Southern Oscillation' and established the link between the Indian monsoon with global meteorological phenomenon (Adamson 2020). In 1928, with an objective to undertake monsoon research with improved facilities, IMD headquarters was established in Pune and in the same year the sounding balloon ascents commenced in India from Pune, which is considered as start of an important research area to study the vertical profile of the atmosphere. K.R. Ramanathan published the diagram of the distribution of upper atmospheric distribution over the globe in 1928, and in 1930 he published "discussion of results of sounding balloon ascents". In 1931, P.R. Krishna Rao published "distribution of temperature in lower stratosphere". In 1932, L.A. Ramdas studied the horizontal and vertical climatic variations near the ground surface (Ramdas and Malurkar 1932). The agricultural meteorology branch of IMD also started functioning under his leadership in 1932, which was one of the earliest of its kind in the world. By 1933, India made significant improvements in manufacturing measurement devices for weather parameters and started the manufacture of Symon's rain gauge, cup anemometer and wind vanes. In 1936, IMD published "*Meteorology for airmen in India*" for aviation sector. The advancements of upper air measurements continued to grow and in 1943, L.S. Mathur developed clock type (C-type) radiosonde and in the same year S.P. Venkateshwaran developed Fan type (F-type) radiosonde in India. This was followed by the historic event of the first radiosonde observations in India in 1943 and radio wind in 1949. In 1944, S.K. Banerjee became first Indian Director General of IMD. In 1946, "*Climatological charts of India and neighbourhood for meteorologists and Airmen*" was published by IMD (IMD 1978). All these developments formed a sound basis for subsequent progress in climate research of the country after independence.

3. Water resource management in pre-independent India

Since ancient times, agriculture evolved, and the civilizations prospered along the rivers, which were water sources for domestic use and irrigation. Water from the rivers used to be diverted to the fields through inundation channels. Shallow open wells were also used in some areas. The region where sub-strata consisted of rocks, and it was not easy to dig well; rainwater used to be collected in tanks, reservoirs and upstream of embankment constructed across the drainage lines. Water from these reservoirs was released to the field in regulated quantities. Systematic irrigation became a necessity when civilizations started to flourish. Earliest available records indicate that Indians practiced irrigation for raising crops as early as the fourth millennium BC. References on sources of water, evaporation, condensation, cloud formation and the hydrological cycle, construction of anicuts across perennial rivers, excavation of canals from such rivers, tanks and wells are available in the Vedas. Mention of *pranali*, *kuly*, *sarase*, *nika* and *nalika* in Sanskrit literature suggests that the canals were used for irrigation in ancient time. The Vedic texts suggest that Eastern Afghanistan, North West Frontier Province, Kashmir and parts of Sindh and Rajasthan were the regions covered by the seven rivers - the Saptasindhu and the channels from these rivers were used for irrigation. According to ancient lore, Rishi Narda once enquired king Yudhishtra, "Are the farmers sturdy and prosperous? Are their dams full of water and big enough and distributed in different parts of the kingdom and that agriculture does not depend on rains only?" There is also mention of irrigation from river and *Kheya* (dyke) and *Bendhya* (Bund constructed to prevent water from flowing out of field) in *Narada Smruti* (Rangachari et al. 2012).

3.1. Ancient Irrigation System

History of irrigation goes back to the time of Indus Valley Civilization around 4500 BC. Well-designed irrigation and drainage systems led to the prosperity during Indus Valley Civilization and planned settlements with drainage and sewers. In ancient times, flood or *sailab* irrigation was the common practice in the flood plains of rivers in northern India and the deltaic region of central and south India. Tanks were used for rainwater harvesting and irrigation in Southern Peninsula. Well irrigation was common in the alluvial plains of northern India and in other parts of the country. Artificial reservoirs at Girnar dated to 3000 BC and an early canal irrigation system around 2600 BC (Rodda and Ubertini 2004). In the Indus Valley Civilization water-lifting devices were used to lift water from wells. Archaeological evidences suggest that irrigation and drinking water supply system from large lined-well existed during that period. Reservoirs to collect rainwater were found in Dholavira, which is an important Indus Valley site. Sir Robert Eric Mortimer Wheeler, a British archaeologist and officer in the British Army, in his book '*Early India and Pakistan*' wrote that food crops and cotton were grown with irrigation during the Indus Valley Civilization. Mohenjo-daro had protective banks and bunds to save the land from disastrous inundation. Mention of dams and barrages are found in *Manusmriti* and *Arthasastra*. Mention of the words such as *Varsha Pramana* (rain measurement), *Jalasutrada* (water engineers or hydraulic engineers) in ancient literature indicate that water management and irrigation were practiced in ancient India (Rangachari et al. 2012).

In situ rainwater harvesting in different types of structures and utilization or rainwater harvesting in large reservoir and transporting it to water scarce areas had been practiced in India since ancient time. As the rainfall varies in time and space, different regions in India had different types of rainwater harvesting structures depending on the rainfall, soil type, slope and climate. Rainwater harvesting and storage structures such as khadin, baoli, gul, Kund, alabs, johad, ahar-pynes, bamboo pipes, kul, katta, zabo, eri, virdas and surangam, which were evolved in ancient time are used even now. City of Delhi when founded in early eleventh century, was getting water from Suraj Kund, which was constructed to harvest the rain over the Aravalli hills. The Pynes and Ahars systems used in south Bihar and Jharkhand were evolved during the Mauryan rule. Ahars are water storage areas having embankment on three sides with fourth side left open for surface runoff to fill the area naturally. Pynes are diversion channels that transport the flood water to fields and Ahars. Contouring, bunding, bench terracing and Gabarbands used in Harappa are used for *in situ* moisture conservation in several parts of India.

With the increase in population, the traditional rainwater harvesting structures were not able to supply the water needed for domestic and agriculture sector. The shortage of water during the drought years affected agriculture production and water availability for domestic use severely. Severity of drought during 1769-70, 1783-84, 1791-92, 1837-38, 1860-61, 1865-67, 1868-70, 1873-74, 1876-78, 1896- 97 and 1899-1900 was so much that it resulted in worst famines the country faced. Several million people died during these famines. British Government set up Famine Commissions to find out the reasons and suggest measures. Along with several measures to prevent the famine, Lyall Commission set up in 1897, recommended the development of irrigation facilities. After the famine of 1899-1900, Lord Curzon set up Mac Donnell Commission in 1900 to re-evaluate the report of the previous commissions. It recommended several measures including improvement of irrigation facilities. Again in 1901, Lord Curzon formed a special commission to report on the irrigation as a protection against famine. This was the first Indian Irrigation Commission, which recommended for increasing irrigated area initiating a very extensive programme of protective irrigation works in the tract that were likely to suffer from famine.

Designing of irrigation and drainage structures was known to Indians from the time of Harappan civilization. They knew how to plan, design and construct water reservoirs, drinking water supply system, irrigation channels, well-graded drains, water distribution systems and sewerage system. Well-developed irrigation infrastructure and water distribution rules during the Mauryan era (321 to 185 BC) are good examples of public irrigation works. Taxes were collected from cultivators availing irrigation facility from the state. There is mention of the construction of dam across the river and provision of sluice gates for withdrawals of water in *Arthasastra*. Megasthenes, the famous Greek Ambassador to the Court of Emperor Chandragupta (Around 300 BC), recorded in his book that the district officers used to measure the land and inspected the sluices so that everyone could get a fair share of the benefit. King Avantivarman carried out extensive engineering work in the Vitasta (Jhelum) valley in Kashmir for its drainage and irrigation system. Efficient regulation of the river course by engineer Suyya of Kashmir is an example of reducing flood damage and creating land for cultivation and irrigation (9th century AD). Kallanai, the dam on river Kaveri constructed during the 1st-2nd century AD, is one of the oldest dams in the world still in use (Singh and Yadava 2003). During the Chola Empire (875-1279), land was transferred and collective holding of land gave way to individuals, each with their own irrigation system. The Cholas also had bureaucrats to oversee the distribution of water by tank and channel (Palat 1995). The diffusion of Indian and Persian irrigation technologies brought about economic growth (Siddiqui 1986). Engineer Suyya during the rule of King Avantivarman in Kashmir had developed water regulation system which controlled flood and created additional land for irrigation in the 9th century. Tank irrigation was very common in west, central and southern part of India which depended on rainfall for agricultural activities. Every ruler in southern part of the country had a separate department for construction and promotion of tank. A summary of the irrigation works carried out during different periods is given in Table 2.

Table 2. Major irrigation works carried out till eighteenth century

Period	Irrigation works	Builder and features
1. 300 BC	Lake Sudarsana	Chandragupta Maurya, renovated by Emperor Ashoka at Kathiawar, Gujarat
2. 100 BC-100 AD	Taming Cauvery River	Chola King Karikala to control flood in the Cauvery Delta.
3. 2nd century	Grand Anicut	River Cauvery in southern India.
4. 10th century	Bahur Tank	Bahur, Pondicherry, maintained by villagers from the penalty to defaulters.
5. 11th century	Gangaikonda Chola-puram Tank	King Rajendra Chola, embankment of 25.8 km with sluices and channels for irrigation.
6. 11th century	Bhojpur Lake	King Bhoj of Dhara in Central India, covered an area of 647.5 km^2.
7. 14th century	Anantaraja Sagara	Prince Bhaskara, 1st Vijayanagara Dynasty in Andhra Pradesh.
8. 14th century	Early Western Yamuna Canal	Ferozshah Tughlak, Munak branch of canal was constructed to carry water to Delhi.
9. 17th century	Early Bari Doab or Hasli Canal	Shahjehan to carry water from river Ravi to Shalimar Gardens at Lahore. A branch was constructed to carry water to the Golden Temple.
10. 18th century	Early Eastern Yamuna Canal	Mohammed Shah to carry water from river Yamuna. Canal was remodelled during the British rule.

3.2. Irrigation development during the British rule

During the British rule, the existing irrigation infrastructures were renovated and improved besides the construction of new irrigation systems. Large irrigation projects such as Cauvery, Godavari, and Krishna Delta systems were constructed during the early and middle of the 19th century. The Western and Eastern Yamuna canals, the Ganga and Bari Doab canals were also constructed. That was the time when private companies were encouraged by the Government for construction of irrigation systems. The East India Irrigation and Canal Company were established in 1858, originally for the coastal plains of Odisha and adjoining areas. The irrigation projects such as Mahanadi, Brahmani, Baitarani, Subarnarekha and Kosi derived their names from the rivers from which they originated. The Madras Irrigation Company was formed in 1863. Tungabhadra project in south India was completed, partly by the company and partly by the Government. The Sone Canal in Bihar was constructed during this period. Government of India initiated some large irrigation projects during the period 1836-1866, which are referred as 'Classical Works'. These were the Upper Ganga Canal in Uttar Pradesh, the Upper Bari Doab Canal in the Punjab and Godavari and Krishna Delta Projects in Andhra Pradesh. The Upper Ganga Canal, known as Ganga Canal at that time, was the classical project completed during 1836-1854. It was the largest irrigation canal in the world during the time. The other important projects completed during the British rule were Sirhind Canal, Lower Sohag and Para Canals, Lower Chenab Canal and the Sidhnai Canal in Punjab; Lower Ganga Canal, Agra Canal and the Betwa Canal in Uttar Pradesh; the Periyar System of Canals in Madras; the Mutha Canals in Maharashtra, Jamrao and Western Nara Canals in Sind (now in Pakistan), the Periyar Dam in Tamil Nadu (1887) and the Nira Canals (1877-1894) (Rangachari et al. 2012). The important irrigation projects completed before independence are given in Table 3. It is well-accepted that the country needs to go with ancient as well as modern systems of rainwater harvesting and irrigation system for meeting the need of agriculture and other sectors in the emerging era of water shortage and changing climate.

Upper Ganga Canal

Source: https://www.atlasobscura.com

Table 3. Important irrigation projects completed in 20th century

Project	Year
1. Pravara River Canals, Maharashtra	1899-1902
2. Godavari Canal Project, Andhra Pradesh	1907-1916
3. Sarda Canal Project, Uttar Pradesh	1915-1926
4. Gang or Bikaner Canal, Rajasthan	1922-1927
5. Krishnarajasagar Project in Mysore	1911-1931
6. Nizamsagar Project in Andhra Pradesh	1924-1931
7. Cauvery Mettur Project in Madras	1921-1935
8. Sutlej Valley Canals Project	1921-1935
9. Haveli Trimmu River Project	1937 and 1939

Mettur Dam, Tamil Nadu

Source: http://www.walkthroughindia.com

4. Soil management in pre-Independent India

4.1. Ancient and Middle Ages

There are repeated references of soil and its management practices in the Vedic texts (Table 4). The 'Hymns to Goddess Earth' in the Atharva Veda provide excellent reference to earth and soil and their connects to the individual and society. It highlights that soil is not a commodity but a part of our living community: '*The earth that supports all, furnishes wealth, the foundation, the golden-breasted resting-place of all living creatures ....*". In the Vedic period farmers used to plough the soil, broadcast the seeds and used a certain sequence of cropping and fallowing. Cow dung was used for fertilizer (Anonymous 2012). The Indus Valley Civilization provides evidence of an animal-drawn plough dating back to 2500 BCE (Lal 2001). The Mauryan Empire (322-185 BCE) categorized soils and made meteorological observations for agricultural use. They also constructed dams and had horse-drawn chariots, which are quicker than common bullock carts (Anonymous 2008). Megasthenes, the Greek diplomat (c. 300 BC), in his book Indika, observed, "*India has many huge mountains which abound in fruit-trees of every kind and many vast plains of great fertility. The greater part of the soil, moreover, is under irrigation, and consequently bears two crops in the course of the year. Since there are two monsoons in each year, the inhabitants of India almost always gather in two harvests annually*".

Importance of organic manure has been mentioned in the Rig and Atharva Vedas. The Holy Quran also implies recycling of post-harvest residues mentioning that at least one-third of what is taken out from soil should be returned to it. The Deccan plateau region developed the ash mound tradition dating back 2800 BC. This is characterized by large mounds of burned cattle dung and other materials for growing millets and pulses. They also herded cattle, sheep and goat and were largely engaged in pastoralism (Fuller 2006). In the east of India, Neolithic people grew rice and pulses as well as kept cattle, sheep and goat. During the early common era systematic ploughing, manuring, weeding, irrigation and crop protection were practiced in south India for sustained agriculture (Pillay 1972). Agricultural 'zones' were broadly divided into those producing rice, wheat or millets (Anonymous 2008). During this era, sugar mills were developed and use of a draw bar for sugar-milling appeared at Delhi in 1540. Geared sugar rolling mills later appeared in Mughal India, using the principle of rollers as well as worm gearing by the 17th century (Habib 2011).

4.2. Mughal Era (1526-1757 CE)

Agricultural production increased during the period and India's population growth accelerated. A variety of crops including wheat, rice, barley, cotton, indigo and opium was grown. By the mid-17th century, India started growing maize and tobacco, the new crops from the Americas (Karl 2015). Land management was strong during the regime of Akbar the Great (1556-1605). Scholar-bureaucrat Todarmal implemented elaborated methods for management of agriculture on a rational basis (Kumar 2005). The Mughal administration emphasized agrarian reforms, which began under Sher Shah Suri. Akbar also adopted and furthered with more reforms. The civil administration was organized in a hierarchical manner on the basis of merit, with promotions based on performance. They built irrigation systems across the empire to produce more crop yields and increase the net revenue base, leading to increased agricultural production (Karl 2015). A major reform introduced by Akbar was a new land revenue system called 'zabt', which was a monetary tax system based on a uniform currency. With this system, extensive cadastral surveying was conducted to assess the area of land under plough cultivation. The Mughal state encouraged greater land cultivation by offering tax-free periods to those who brought new land under cultivation (Richards 2003). Indian agriculture was more advanced compared to many other parts of the world, such as the common use of the seed drill, which were adopted by the peasants of other countries much later (Habib et al. 1987). When the farmers of the other parts of the world used to grow very few crops, Indian farmers were skilled in growing a wide variety of food and non-food crops. The increased agricultural productivity led to lower food prices; which was about one-half in South India and one-third in Bengal, in terms of silver, in the 18th century (Parthasarathi 2011). Farmers of Bengal learned techniques of mulberry cultivation and sericulture, establishing Bengal Subah as a major silk-producing region of the world (Richards 1995). During the second half of the 19th century, land under cultivation expanded at an average rate of about 1% per year. Due to extensive irrigation networks Punjab, Narmada valley and Andhra Pradesh became the centers of agrarian reforms.

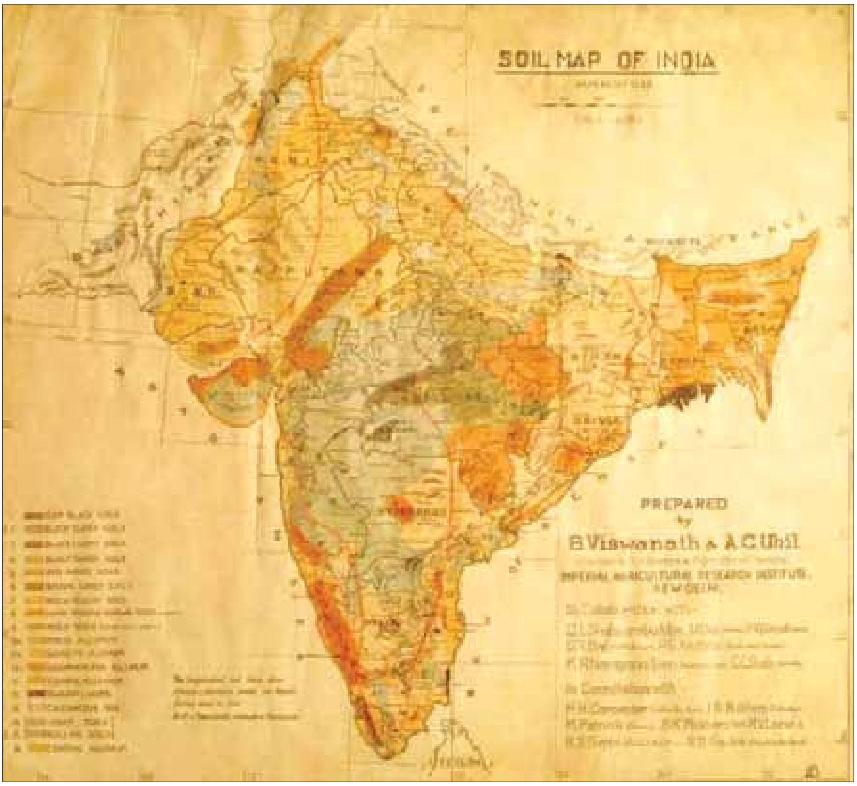
Table 4. Milestones of soil science in pre-independent India

Period	Milestone
5000-2000 BC	*Vedas* and *Upanishads* mentioned soil as synonymous with 'the Mother'. *Rig Veda* has the earliest discussion on the importance of organic manure.
322-185 BC	Mauryan Empire categorized soils.
1883	J.W. Leather started permanent manurial experiments at Kanpur and Coimbatore.
1906	J.W. Leather devised an indigenous method of characterizing Indian soils.
1920	N.V. Joshi started the first systematic research on the isolation and identification of *Rhizobium* in India.
1922	J.N. Mukherjee gave the concept of diffused double layer, neutralization of the charge of colloids and nature of soil acidity.
1930	S.L. Das developed the potassium carbonate extraction procedure for plant-available P in calcareous soils.
1932	Madam Scholasky prepared the first Soil Map of India.
1933	Vaidyanathan summarized more than 5000 permanent manurial experiments.
1935	Indore composting for organic farming initiated by Albert Howard.
1935	A.N. Puri developed methods for measurement of exchangeable bases, lime and gypsum requirement.
1936	P.K. De first time discussed the role of *cyanobacteria* in soil fertility.
1940	C.N. Acharya developed biogas plant and methods of composting.
1942	R.N. Singh showed the role of blue green algae for supplying N in rice soils.
1943	Viswanath and Ukil at IARI prepared a Soil Map of India based on soil characteristics.

4.3. British era (1757-1947)

4.3.1. Soil resources and fertility

In view of recurring famines and no breakthrough happening on application of the recommendations made by various Famine Commissions, the Imperial Establishment observed the need for seeking the help of one first class expert to make a general enquiry into the character of soils and agricultural conditions of the country. Accordingly, in 1889, J.A. Voelcker was appointed to advise upon the best course to be adopted to apply the principles of agricultural chemistry to induct improvements in Indian agriculture. This is regarded as the first serious endeavour to frame a policy of agricultural research having orientation to soils suiting Indian conditions. Appointment of J.W. Leather was an outcome of his recommendation to infuse a sound system of scientific investigation with agricultural chemistry as the central approach. Visit of the Royal Commission on Agriculture in 1926 and its report in 1929 are the events that drew attention to the condition of Indian soils, which have been depleted to the extent that no further depletion is possible. J.W. Leather, commonly acknowledged as the father of Soil Science and Agricultural Chemistry in India, devised an indigenous method of characterizing Indian soils based on geological formations and soil colour. He classified soils as alluvial, black, red and lateritic, which still stand as a classical work. On the basis of information emanating from different surveys, Madam Scholasky prepared the first Soil Map of India, which she displayed in 1932 in England. A map depicting the physiographical and geological foundations of the country's soils was published subsequently in 1935 by D.N. Wadia, J.N. Mukherjee and M.S. Krishnan under the aegis of the Geological Survey of India. The first ever Soil Map of India depicting soil properties, however was prepared in 1943 by B. Viswanath and A.C. Ukil at Indian Agricultural Research Institute (IARI), New Delhi. The All-India Soil Survey Scheme, initiated in 1943, examined and collated the available soil survey information and the related analytical data, which could be suitably projected on the Soil Map of India. Its final report prepared by S.P. Raychaudhury in 1953, embodied the first comprehensive work on soil survey in the country.



Soil map of India prepared by Viswanath and Ukil (1943)

Pioneering work of J.W. Leather set the cornerstone of soil fertility research in India. He compiled soil fertility research work for the first time in India in 1907, describing recommended methods for soil analysis. He also established permanent manurial experiments at Cawnpore (now Kanpur) and Coimbatore in the year 1883 on the lines of

Lawes' Rothamsted Experiment in United Kingdom for evaluating soil productivity on a long-term basis. Stewart (1947) recommended large-scale manurial trials to allow interplay of soil, climate and management factors to generate reliable data for practical use.

Role of organic sources for supplying plant nutrients was realized long back. Organic matter status, C/N ratio and fluctuations in the amount of soil humus were investigated at several locations i.e., Coimbatore by W.H. Harrison, P.V. Ramiah and B. Viswanath (1922-1935); Nagpur by D.V. Bal and J.G. Shrikhande (1936-1939); and Allahabad by N.R. Dhar and associates (1932-1939). D.V. Bal, A. Srinivasan and J.K. Basu (1927-1939) significantly contributed for accurate estimation of nitrogen in the soil. This was followed by the determination of various forms of soil nitrogen and estimation of leaching and volatilization losses during the next few years (1932-1939) by V. Subramanyan and J.G. Shrikhande. At Lahore, A.N. Puri with his co-workers worked on extraction of humus and determination of its physico-chemical properties (1936-41) and R.C. Hoon on organic matter of hill and mountain soils. From 1937 to 1940 G.C. Esh and S.S. Guha carried out detailed studies on humic acids as well as characteristics of peat and organic soils. Vaidyanathan (1933) summarized more than 5000 permanent manurial experiments and suggested manure application during fallow periods to restore soil fertility.

During 1925-45, J.N. Mukherjee, a Physical Chemist at the University of Calcutta made sterling contributions on electro-chemicals and rheological properties of soil clays and clay minerals, cation exchange in soil, X-ray and dehydration studies of clays, and exchange of aluminum and hydrogen ions in clays with other. Mukherjee's contributions on the concept of diffused double layer, neutralization of the charge of colloids and nature of soil acidity (Mukherjee 1922a, b) have great significance and present-day relevance (Nature 1972). The significance of base-exchange and buffering properties of soils of South India had also been brought out by B. Viswanath during 1929-33. The other major centre of activity in soil chemistry functioned under the guidance of A.N. Puri who was first to work on soil physical chemistry in India as a Physical Chemist at IARI, Pusa Bihar (1924-30) and then moved to Lahore as Director of the University Institute of Chemistry. He did pioneering work on ion exchange characteristics, particularly, in salt-affected soils and practical applications of ion exchange properties in soil management. S.L. Das at IARI, Pusa (Bihar) developed potassium carbonate extraction procedure for plant available P in calcareous soils (Das 1930). This proved to be the fore-runner of the today's most widely used Olsen's procedure (sodium bicarbonate extraction) for soil P determination.

Systematic research on problem soils was initiated in the late 19th century (1894-96) by J.W. Leather with constitution of the *Reh* Commission to examine various aspects of *usar* soils. The Departments of Agriculture in Uttar Pradesh, Bengal, Bombay, Bihar, Punjab and Travancore came out with a score of status reports on the distribution, characteristics and reclamation of sodic soils (1910-27). A publication entitled "Alkali soils of Deccan" was brought out by D.L. Sahasrabuddhe in 1937. At Allahabad, in addition to survey work, emphasis was laid on the reclamation of these soils by using materials other than gypsum during the period 1934 to 1942 by N.R. Dhar, S.K. Mukherjee, B.K. Mukherji and R.R. Agarwal. Molasses and press-mud wastes from the sugar industry supplemented with organic wastes showed excellent positive results on reclamation. Attention towards saline soils was drawn years afterward when W.H. Harrison and G.S. Henderson followed by P.V. Ramiah, V.A. Tamhane and B. Viswanath carried out useful studies on salinity problems in soils during 1910s and 1920s. At Lahore, A.N. Puri and R.C. Hoon conducted pioneering studies on soil salinity, especially, measuring the effect of electrical conductivity (EC) and its impact on soil fertility. Coastal saline soils of Bengal were featured in the investigations by J.N. Mukherjee in first half of 1940s. Soils of Assam and North-east India were investigated during first half of 1920s by P.H. Carpenter and C.J. Harrison, who showed that soils in the region were acidic, and required lime for amelioration.

4.3.2. Use of organic manure and fertilizer

Rao Bahadur B. Vishwanath in 1937 emphasized that organic manure is the life of soil. Sir Albert Howard at the Institute of Plant Industry, Indore believed that a shift from nature's methods of crop production to the adoption of newer methods leads to loss of soil fertility (Howard 1940). Acharya Vinoba Bhave experimented with "*Rishi Krishi*" at his Paunar Ashram near Wardha, Maharashtra. These retrogressive thinking sowed the seeds of the organic movement in India today placing great emphasis on the use of composts and other sources of organic nutrients to the total exclusion of chemical fertilisers and plant protection chemicals. The root of organic farming, thus initiated in India with the work of Albert Howard, an agricultural scientist and Robert McCarrison, a doctor. Composting in India was initiated by Howard (1935) also called the *Indore* Method of composting. Howard published details of the Indore method in 1931 in a book called "*The Waste Products of Agriculture: Their Utilization as Humus"* (Howard 1931). Howard concluded that humus-rich soils are the key for successful organic farming. In his famous book '*An Agricultural Testament*', he emphasized that the whole farm is the starting point and basic unit of agricultural research and that much of the disease is due to inadmissible farming methods without proper care of soil (Howard 1947). Robert McCarrison, worked at the Nutrition Research Laboratories in Coonoor, studied the relationships among soil fertility, food quality and human nutrition. He examined that food quality decreases with increased use of mineral nitrogen fertilizer (McCarrison and Viswanath 1926). He defined 'wheel of health' consisting of soil, plant, animal and humans i.e., properly composted organic residues create a fertile soil, on which healthy plant grow to offer healthy diet for animals and humans. During 1934 to 1939, scientists at Bangalore (Subramanyan 1929; Acharya 1935) worked on the determination of organic matter in soil and its various components like cellulose, hemicelluloses and furfural (Ghosh 1984). Acharya (1949) quantified the cattle manure and town waste produced in India and estimated its composition. Shrikhande (1943, 1945) showed that 60% N becomes available from green manures, composts and oilcakes in 60 to 70 days, beyond which there is insignificant mineralization. Chemical fertilizers were introduced in the country in 1940s. Their large-scale use, however, started with the advent of Green Revolution in the 1960s with the introduction of high-yielding dwarf varieties that were resistant to lodging on the application of high doses of fertilizers and development of irrigation facilities.

4.3.3. Soil biology and biochemistry

The pioneering work of C.M. Hutchinson laid the foundation of soil microbiology in India bringing out the importance of bacteria in soil fertility. The earliest landmark was C. Barghtheil's work during 1903 to 1908 on soil inoculation of indigo (*Indigofera tinctoria*) in North Bihar. Subsequently, soil inoculation was introduced to nodulate Egyptian clover (*Trifolium alexandrinum*). N.V. Joshi was the first to work on nitrogen fixation in groundnut, and nitrification from 1911 to 1919, and then on biological decomposition of organic matter and prevention of nitrogen losses from soil during 1919 to 1921 (Joshi 1932). Nitrogen fixation was also investigated by P.E. Lander in Punjab from 1925 to 1927 and B. Viswanath at Coimbatore during 1925. Studies on actinomycetes were undertaken by R.V. Norris and V. Subramanyan from 1929 to 1930. B.N. Singh developed a methodology for the study of soil protozoa and other soil flagellates (1941, 1946) highlighting their role in biological equilibrium in soil.

For the first time in India, systematic research on isolation and identification of *Rhizobium* from different cultivated legumes started with a study by N.V. Joshi in 1920. Non-symbiotic nitrogen fixation and the mechanism involved were investigated at Bangalore and Coimbatore by T.R. Bhaskaran and V. Subramanyan during 1935-38, and in Punjab by N.V. Joshi, S.V. Desai and M.R. Madhok during 1933 to 1939 (Ghosh 1984). C.N. Acharya in 1940 recognized the importance of organic manures in enriching soil fertility and better utilization of agricultural wastes for production of biogas and compost. P.K. De (1936) reported that the fertility of Indian rice fields is maintained due to the proliferation of *Cynobacteria* in the soil. Later, R.N. Singh (1942) at Banaras Hindu University established agricultural significance of blue green algae (BGA) in the nitrogen economy of soils growing rice. Establishing the role of biological nitrogen fixation by V. Subramanyan, loss of nitrogen during decomposition by T.R. Bhaskaran and relationship of soil fertility with total microbiological activity by S.V. Desai and W.V.B. Sundara Rao are regarded as other significant developments in the field of soil microbiology during 1936 to 1941 (Ghosh 1984).

5. Conclusion

Under the ever-intensifying pressures of population and unscientific development, the natural resources have been shrinking and declining fast, reaching a critical level. Global climate change is adversely affecting crops, soils, water and biodiversity aggravating the deterioration of the resources. There may be considerable effects on land use due to snow melt, availability of irrigation, frequency and intensity of inter-and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands and availability of energy, and on trade and overall economy. In order to meet the expanding needs of food, agricultural products and clean drinking water, these resources should be conserved and further enhanced. Science-led management practices should be developed to produce more and more from less and less to ensure sustainable development. The ancient and eternal philosophy of 'Living in harmony with nature' and 'Simple living and high thinking' should be the central concepts of agricultural development. Indian scientists since ancient, medieval and British periods have made formidable contributions towards this cause, which formed the backbone of modern research and development in climate, water and soil research in the country and elsewhere.

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Chapter

Achievements in Field Crops in Independent India

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Summary

India has witnessed phenomenal transformation from a food importing to a food surplus nation during seven and half decades of its independence. The journey of this transition is delineated by ushering 'Green Revolution' in mid-1960s, the 'Yellow Revolution' in the early 1990s, the 'Gene Revolution' in early 2000s, and the 'Pulse Revolution' in the 2010s. India has emerged as world's largest producer of pulses, pearl millet and cotton, and second best in wheat, rice, groundnut, rapeseed & mustard and sugarcane. In the recent past, it emerged as the largest exporter of rice. In this long journey, several milestones through the organized research have been achieved. The consistent efforts in varietal improvement since 1951 resulted over 5,508 high yielding varieties of all major crops such as rice, wheat, cotton, oilseeds crops, pulses, and sugarcane. These varieties and their matching production and protection technologies have been the hallmarks of the organized research programme in the country. Apart from the miracle variety IR 8 of rice and Sonalika and Kalyansona of wheat during green revolution period, several varieties in different crops like Jaya, Samba Mashuri and Swarna of rice, Lok 1, PBW 343, HD 2329 and HD 2967 of wheat, CSH 9 of Sorghum, JAKI 9218 of Chickpea, ICPL 87119 (Asha) of pigeonpea, IPM 02-3, SML 668 and Virat of mungbean, JS 335 of soybean, LRA 5166 of cotton, JRO 524 of Jute and Co 0238 and Co 86032 of sugarcane emerged as mega varieties in respective crops which revolutionized the Indian Agriculture. The disruption in the form of Bt cotton proved game-changer in 2002. The area of cotton recorded sharp rise after 2002 and Bt cotton occupying more than 94% of the cotton area in 2020-21. India became the first country to develop composite maize and successfully developed pearl millet, pigeonpea, castor and cotton hybrids. After attaining food security, India's next major initiative was

to breed food crops with better nutritional value. The intensified efforts helped to develop about 85 biofortified varieties of different crops by 2021. DRR Dhan 45 of rice, HPBW 01 of wheat, Shakti - the QPM composite of maize, NRC 147 with the high oleic acid and NRC 127 free from Kunitz trypsin inhibitor of Soybean, Girnar 3 with high oleic acid of groundnut and Pusa Vaibhav with high iron of lentil were the first biofortified varieties in respective crops paved the way for developing a greater number of such varieties in different crops. To develop crop adaptation to climate change, 1300 climate-resilient varieties of different crops were developed for cultivation by farmers during 2010-2021. Flood tolerant Swarna sub1 of rice, salt tolerant Kharachia 65 and heat tolerant JG14 of chickpea found prominence in cultivation. Varietal development programmes were successful in insulating crops against key diseases. Rusts in wheat, blast and blights in rice, wilt in chickpea and lentils, powdery mildew in field pea and urdbean, downy mildew in sorghum, and white rust in rapeseed and mustard were successfully contained through resistance breeding. India became the first country to overcome Ug99 attack of stem rust and now almost all releases are resistant to Ug99. Crop improvement programmes in the recent decades have been reoriented with greater emphasis on genomic resource development for targeted traits and crops. India has contributed significantly to the publication of genome sequences of seven crops including rice, wheat, pigeonpea, chickpea and jute. The molecular marker-assisted technologies so far led to the development of 48 varieties in cereals, oilseeds, and pulses for different traits. Future efforts are endeavoured to accelerate the breeding process through speed breeding protocols and genomic selections, adaptation to climate change, value addition and diversification. Genome editing and transgenic development protocols are providing hope for developing and cultivating new varieties of agricultural crops. The technological developments and policies will help not only in increasing the productivity of crops but also reaching the crops in non-traditional niches for area expansion.

1. Introduction

India marched from food-aid dependency to self-sufficiency in food production, which has been the most remarkable achievement of post-independent India. About six-fold increase in food grain production, more than five-fold increase in rice production, over sixteen-fold increase in wheat and maize productions, eleven-fold increase in cotton and jute, six-fold increase in oilseed and sugarcane and more than three-fold increase in pulses production have been achieved over the last seven and half decades. India ranks number one globally, in the production of pulses, pearl millet and cotton, and second in wheat, rice, groundnut, rapeseed & mustard and sugarcane. The country has emerged as the largest exporter of rice in the recent past. Such achievements became possible with the innovations in technologies including high-yielding varieties, irrigation, fertilizer, and farm policies.

The agricultural sector is the primary source of livelihood for about 58% of the population in the country. The share of agriculture in the gross domestic product (GDP) is about 17% about half of which is contributed by the agricultural crops (MoF 2020-21). The food grain production in India has reached an all-time high to 314.51 million tons (Mt) in 2021-22. In the pre-Green Revolution period (1951-52 to 1966-67), India was heavily dependent on food imports. The Post-Green Revolution (1967-68 to 1985-86) period, however, experienced a visible acceleration and food grain production doubled from 74.2 Mt to 150 Mt. The production has again doubled from 150 Mt in 1985-86 to 314.51 Mt in 2021-22 but it took longer time of about 35 years due to deceleration in agricultural productivity 1997-98 onwards. Nevertheless, continuous supply of agricultural commodities, especially staples like rice, wheat and pulses enabled to achieve the food security in the country.

While Green Revolution revolutionised the food production, it also strengthened and expanded the National Agricultural Research System (NARS). Many research institutes, All India Coordinated Research Projects (AICRPs) and State Agricultural Universities were initiated and made operation under the ambit of the Indian Council of Agricultural Research (ICAR). The research institutes on rice, jute and sugarcane, established in the pre-independent India, were brought under the purview of ICAR in 1966. The organized research on other crops was carried out by the establishment of AICRPs in 1967. For achieving sustained agricultural growth of 4%, India further expanded NARS in 1977-93 and Directorate and National Research Centres on some selected crops were established to give research impetus. Subsequently, directorates on different crop groups such as pulses and oilseeds, were upgraded to the Institute level to foster multidisciplinary research. Currently, the crop-based research is being carried out by 28 national institutes including one deemed-to-be-university, 3 bureaus, 2 project directorates, 1 national research centre, 22 AICRPs and 10 All India Network Projects (AINP).

The technological developments and policies helped in increasing the productivity and simultaneously pushed the crops in non-traditional niches for area expansion. The area expansion of rice and sugarcane in north, groundnut in Gujarat, chickpea in the southern peninsula, mungbean in Rajasthan, soybean adoption in Madhya Pradesh and Maharashtra are few examples to cite. In addition, significant contribution has been made by public and private sector in hybrid technology for cotton, pearl millet, castor and pigeonpea in public as well as private sectors.

Crop improvement programmes in the recent decades have been reoriented with greater emphasis on genomic resource development for targeted traits and crops. Pre-breeding efforts have been intensified for identification of desirable genes in related and wild species. Such efforts helped to broaden the genetic base by transferring desirable alleles from wild sources. Significant progress has been made in biotechnological tools such as marker-assisted breeding and transgenic development for efficient crop improvement. Decoding of genomes of rice, wheat, flax and chickpea was done through international collaboration. India has contributed significantly to the publication of genome sequences of seven crops. Sequence information provided the protein-coding genes for disease resistance and tolerance to drought, heat and salinity, which will be a useful resource for pigeonpea improvement (Singh et al. 2012, Varshney et al. 2012). The draft genome sequence information was also generated in chickpea (Varshney et al. 2013) and Jute (Sarkar et al. 2017). Marker-assisted backcrossing was successfully employed in the development of more than 48 cultivars. Pusa Jai Kisan variety of mustard was the first product of biotechnology and Pusa Basmati

1 was the first product of marker-assisted breeding in rice. Improved Pusa Basmati 1 of rice and chickpea varieties developed for drought tolerance (BGM 10216) and fusarium wilt resistance (MABC WR SA 1) are other such examples of varietal development using marker-assisted backcrossing. Efforts are also being made to harness cutting-edge technologies like genome editing.

2. Milestones in field crops research

Between 1951 and 2021, food grain production increased six-fold. The initial phase started with adaptive research for selecting crop varieties that were suited for various agro-ecologies. The innovations in population selection in field crops paved the way for the development of improved crop varieties. Many premier institutes such as Central Rice Research Institute (established in 1946), Jute Agricultural Research Laboratory, later called Central Research Institute for Jute and Allied Fibres became very active in contributing to the development of improved crop varieties. The institutional development for organized research continued and crop-based institutes were established during different plan periods. Further, for accelerating the coordinated research on different crop commodities, the All India Coordinated Research Projects (AICRP) for multi-location evaluation of varieties and technologies was started in 1957 with AICRP on the Maize. During the same period, the Project on Intensification of Regional Research in Cotton, Oilseeds, and Maize (PIRRCOM) was established under the Indian Agricultural Research Institute (IARI), New Delhi and various crop centres were established. Subsequently, during 1960-70, AICRPs on several other crop commodities such as rice, cotton, pearl millet, small millets, etc. were commenced to generate breeding materials, crop production, and protection technologies and their testing in multi-location trials. The concept of the AICRPs, which are 60 at present (22 in crop science division), has been one of structural contributions in the field of organization and management of multi-location agricultural research in India.

The first cereal crop hybridization in maize resulted in the development of Ganga series, Ranjit, and Deccan hybrids. The first sorghum hybrid, CSH-1 was released in 1964. India became the first country to develop composite maize in 1967 and successfully developed pearl millet and cotton hybrids first time in the 1970s. Subsequently, hybrids have been developed in other crops including castor, safflower, rice, pigeonpea, sunflower, and rapeseed-mustard. A turning point in the Indian cotton breeding program was the release of the World's first hybrid (H4) in 1970, which has long-staples with good uniformity. During the 1970–1990s, national agriculture research priorities shifted towards conservation and improvement of genetic resources of other crops like oilseeds and pulses to raise productivity. The research efforts were supported by the Government's ambitious programme on Technology Mission on Oilseeds (TMO) launched in 1986 and later in 1991, pulses were included under the Mission to make it Technology Mission on Oilseeds & Pulses (TMOP). This resulted in the country's oilseed production surpassing the target of 18 Mt by 1989-90 and quantum jump in oilseed production from 10.83 Mt (1985-86) to 24.75 Mt (1998-99). This golden era witnessed the release of 200 HYVs and hybrids of oilseed crops. During past six decades, the consistent efforts in varietal improvement led to the development of more than 5,508 HYVs of all major crops such as rice, wheat, cotton, oilseeds crops, pulses, and sugarcane. The HYV and their matching production and protection technologies have been the hallmarks of the organized research programme in the country.

In the past two decades (2001-2021), efforts were intensified to explore new technologies in the field of biotechnology and genetic engineering. Transgenic technology for cotton has proved to be a game-changer leading to sharp rise in its area after 2002 which increased to 11 million ha in the last 19 years. Consequently, cotton production almost doubled due to significant increase in its productivity. This is an excellent example of the faster adoption of technology. For the first time, molecular marker-assisted selection/pyramiding and backcross were successfully employed. A bacterial blight-resistant rice variety, Improved Pusa Basmati 1 in aromatic rice was developed by introgression of '*xa13*', and '*Xa21*', genes from IRBB 55. The improved Pusa Basmati 1 has earned Rs. 32,806 crores in 2018-19. Chickpea varieties for drought tolerance (BGM 10216) and Fusarium wilt resistance (MABC WR SA 1) also developed using Marker-Assisted Backcrossing. The molecular marker-assisted technologies so far led to the development of 48 varieties in cereals, oilseeds, and pulses mostly for incorporating race-specific resistance against key diseases, tolerance against abiotic stresses and quality traits. After attaining food security, India's next major initiative was the adoption of 'biofortification' - a process of breeding food crops with better nutritional value. Intensified efforts in this direction helped to develop about 85 biofortified varieties of different crops by 2021. The programmes were also oriented towards making crops adapted to global climate change. Development and release of flash flood-tolerant rice variety (Swarna Sub 1) and heat tolerant chickpea variety 'JG 14' have been the remarkable achievements in making progress towards climate-resilient agriculture. During the present decade 1300 climate-resilient varieties of different crops were developed for cultivation by farmers. Many of these significant outputs could be achieved during different plan periods and ushered 'Green Revolution' in mid-1960s followed by the 'Yellow Revolution' in the early 1990s, the 'Gene Revolution' in early 2000s, and the 'Pulse Revolution' in the 2010s. These revolutions in agriculture transformed India from a net importer of food to a self-sufficient agricultural economy (Pingali et al. 2019).

2.1. Green Revolution

The Green Revolution, one of the greatest achievements of the 20th century helped India triple food-grain production in about three decades (from 1968 to 2000). Such miraculous achievement helped to combat food insecurity and poverty despite the population had almost doubled during the same period (Singh 2014). Before the Green Revolution, India was importing 10 Mt of food grains under the PL-480 scheme. During 1966, India launched a mega-project aiming to import large quantities of seeds of semi-dwarf varieties of wheat from Mexico. Through this project, India brought Sonara 64 and Lerma Rojo 64, semi-dwarf high-yielding Mexican wheat varieties. The seeds of large segregating populations from Norman E. Borlaug were also imported. Subsequently, Indian breeders developed semi-dwarf wheat varieties using the genetic background of Indian wheat germplasm.

Within a short period of time, Indian breeders released high-yielding varieties of wheat with superior yield, quality, and resistance to major diseases. Landmark wheat varieties such as SD 227, C 306, and Sonalika changed the prospects for higher harvest in the country. Wheat varieties such as Kalyan Sona, WL 711, WH 147, UP 262, and HD 2189, and HD 2009 were significant contributions along with their production technologies to achieve the green revolution in the country. During 80's wheat varieties HUW 234, Lok-1, HD 2285, HD 2329 and UP 2338 proved landmarks which with their production technologies had changed the course of the country's food production.

Similar to wheat, Green Revolution brought exponential growth in rice production. In 1966, a new HYV, IR 8 was developed at IRRI Philippines by introgression of a dwarfing gene from the Taiwanese variety Dee -Geo-Woo-Gen. The IR 8 commonly described as the 'miracle rice', reached India from the Philippines. The variety had characteristic plant architecture comprised of traits like semi-dwarf stature, photoperiod insensitivity, high fertilizer responsiveness-linked high yield potential, and medium maturity duration. Such unique trait combinations in IR 8 offered an unprecedented opportunity for a rice revolution in the country. Subsequently, breeders developed several rice HYVs, which were better performing than the IR 8. Interestingly, rice cultivation from the unconventional area, the irrigated Indo-Gangetic wheat belt during the late 1960s, helped India to fulfil food-grain requirements. Especially the medium maturing, Basmati-derived, high-yielding fine rice varieties bred at the Indian Agricultural Research Institute (IARI) (Swaminathan 1993, ICAR 2015) found suitable in an unconventional area such as Punjab, Haryana and Uttar Pradesh.

2.2. Yellow Revolution

After the Green Revolution in food grain crops, Yellow Revolution in oilseed crops helped India to achieve near self-sufficiency in edible oils during the early 1990s. The intensified efforts in oilseed crops research resulted in a quantum jump in edible oil production from 10.8 Mt (1985-86) to 24.7 Mt (1998-99). Just in a decade period from 1985 to 1996, area under oilseed cultivation increased from 19.0 to 26.0 Mha. Such an increase of 36% in the area resulted in an increase of 125% in production. Similarly, the overall productivity of oilseed crops increased from 570 to 926 kg ha^{-1}. During the Yellow Revolution over 200 varieties were released. The development of HYVs and improved crop technologies helped to achieve significant improvements both in yield and profits to the farmers. As a result of the Yellow Revolution, the edible oil imports declined from Rs. 700 crores in 1985-86 to Rs. 300 crore in 1995-96. The lead in oilseed production during the yellow revolution remained ephemeral as import of edible oil increased considerably from 0.35 Mt (1994-95) to 14.46 Mt (2019-2020) mainly due to increase in per capita consumption, growing demand of increasing population and greater freedom of import to the open market through open general licensing (OGL). The demand for edible oil was 25.63 Mt in 2019-20 against domestic production of 10.53 Mt (7.03 Mt from primary sources and 3.50 Mt from secondary sources) necessitating the import of 15.10 Mt to fill the demand and supply gap.

2.3. Sugar Revolution

India has witnessed Sugar Revolution during the past 70 years. Sugarcane production increased from 57.05 Mt (1950-51) to 405.42 Mt (2019-20). The country has the best infrastructure for R&D in sugar crops. Integrative R&D efforts enabled the release of short duration, drought- and disease-tolerant sugarcane varieties and helped to its spread to central, northern, and western India. In independent India, 115 improved varieties have been developed which helped in the steady increase of sugarcane production with improved sugar recovery. The 'wonder' sugarcane variety Co 0238, which was notified in 2009 with a rare combination of high cane yield and sugar recovery, as these are negatively correlated has been benefiting both farmers and the sugar industry. The Co 0238 showed consistent performance across India. In a short period, it occupied >80% area during 2012-13 in Uttar Pradesh, the largest sugarcane growing State. From 2016 to 2021, the average cane productivity increased from 69.0 to 82.9 t ha^{-1}.

2.4. Gene Revolution

India has been the key player in reaping the harvest of the 'Gene Revolution' in the early 2000s. The partnership of Indian private company Mahyco with the multi-national private company Monsanto, formulized with the efforts from ICAR and the Department of Biotechnology (DBT), led to the release of the first three genetically modified Bt cotton based on transgenic technology in India in 2002. Later, RCH-2 hybrid of Rasi Seeds was approved in 2004. The cotton area got a boost from 7.7 Mha area in 2002-03 to 13.4 Mha area by 2020-21 with >94% share of Bt cotton hybrids. The Bt cotton proved a game-changer for exports from India. India emerged as second major exporter of cotton. In 2019, increased cotton production enabled India starting cotton export which earned over three billion US dollars.

2.5. Pulse Revolution

India has witnessed the 'Pulse Revolution' assuring near self-sufficiency in pulses in the late 2010s. The indigenous production of total pulses registered impressive growth during the last five years with the evidence that production jumped from 16.26 Mt (2015-16) to 25.72 Mt (2020-21) registering impressive growth in productivity from 786 kg ha^{-1} (2016-17) to 892 kg ha^{-1} (2020-21). At the time of independence, India was producing the pulses to the tune of 8 Mt only. The ever-highest production of pulses could be recorded during 2020-21 (25.72 Mt) which was almost twice the production of 13.30 Mt realized during 1993-94. The dependency on imports has considerably reduced from 6.61 Mt in 2016 to 2.46 Mt in 2020. Several factors contributed to pulse revolution including R&D efforts for developing HYV and technologies, quality seed, extension and policy support. Amongst these, the most tangible effort is in developing/promoting a total of 716 HYVs (including 211 in chickpea, 145 in pigeonpea, 133 in mungbean, 67 in urdbean, and 46 in lentil) released so far with unique attributes and yield potentials to fit into various cropping systems/agro-ecosystem in the country.

3. Major achievements in various crops

3.1. Rice

India is the second-largest rice-producing country with a share of 22% in the world after China. India has a production of official figures for 2020-21 is 124 Mt with average productivity of 2.7 t ha^{-1} of rice i.e., 4.1 t ha^{-1} paddy. While the rice area in the country remained almost the same (43-44 Mha) in the last seven and half decades, a steep increase in rice production has driven the country to a state of exportable surplus (Fig. 1). India has also become a major global exporter both for premium i.e., Basmati and general quality grades of rice while ensuring a steady supply of rice for more than 1.35 billion of people in the country. In the pre-independence era, rice cultivation was restricted to a single crop per year with low yield, and the cultivation was mostly done with photo-sensitive, lodging, disease, and pest susceptible traditional verities of very long duration (>180 days). During the Green Revolution era, with the discovery of the semi-dwarfing gene source *sd1*, there was a phenomenal hike in the genetic gain of rice. This semi-dwarf gene supported the green revolution ensuring the food security of the country. The first semi-dwarf high yielding variety developed was TN1 in Taiwan, which was followed by miracle variety 'IR8' developed by IRRI that transformed the fortunes of rice growers across the globe including India. During 1966 to 2021, a total of 1199 varieties including 127 hybrids of rice have been released and notified by Central Sub-Committee on Crop Standards, Notification, and Release of varieties. The 90s witnessed the development of rice hybrids using parental lines received from IRRI, Philippines and improved by several committed research groups in India and multi- location testing to validate their superiority over varietal checks in AICRIP. The hybrids showed superiority over inbred varieties by 10-15%. In the same decade, under AICRIP, non-basmati quality trials were also initiated with aromatic short grain rice varieties, targeting the export markets. Decoding of complete rice genome by International and Indian efforts in 2005 helped greatly in mapping and MAS for important traits (IRGSP 2005). A classical work was done on molecular mapping, map-based cloning, and characterization of a dominant rice blast resistance gene *Pi54* (*Pi-k*^{h}) at ICAR-National Research Centre on Plant Biotechnology, New Delhi (Sharma et al. 2005). It has started a major program on molecular breeding of rice in the country which resulted in the release of many blast-resistant rice varieties (Khanna et al.2015). Single-copy gene-based SNP chip has been developed which has been extensively utilized for genetic studies and molecular breeding in rice (Singh et al. 2015). Intensive research in the last two decades through marker-assisted breeding resulted in the development of landmark varieties such as Improved Samba Mahsuri and Improved Pusa Basmati 1 with bacterial leaf blight resistance. Efforts were made to introgress the major QTL for submergence tolerance, '*Sub1*', into popular varieties such as Swarna, Ranjit, Bahadur, CR 1009, Samba, IR64, etc., which were tested in the target environment and released in different states. Similarly, emphasis was made on improving the nutritional quality of rice varieties during the last one decade which resulted in the development and release of high protein varieties, CR Dhan 310 and CR Dhan 311; high zinc varieties, DRR Dhan 45, DRR Dhan 48, DRR Dhan 49, Chhattisgarh Zinc Rice 1; Low Glycemic Index varieties, Improved Samba Mahsuri and Telangana Sona.

With the increase in the demand for export quality rice, special attention was given towards enhancement of grain quality of rice, which lead to the release of about 30 export quality basmati and aromatic short grain rice varieties. These include Pusa Basmati 1, Yamini, Pusa Basmati 1121, Pusa Basmati 1509 and Pusa Basmati 1718. Among them, few varieties were developed using extensive use of molecular marker technology (Singh et al. 2011) Identification of herbicide-tolerant gene through chemically induced mutation and its introgression in two popular basmati rice varieties viz., Pusa Basmati 1121 and Pusa basmati 1509 is a landmark scientific discovery that will help in the expansion of area under direct-seeded rice cultivation.

Significant progress in hybrid rice research and development during the last three decades resulted in development of 133 hybrids. The private sector played a dominant role in hybrid rice development. During the year 2021, hybrid rice was planted in an area of 3.5 Mha and more than 80% of the total hybrid rice area is in the states of Uttar Pradesh, Jharkhand, Chhattisgarh, Madhya Pradesh, Odisha and Haryana. With the development of new hybrids in MS grain category with superior grain quality like head rice recovery (>60-65%), alkali spreading value of 4-5 and intermediate amylose content (22-25%), the area under hybrid rice in South India is likely to increase upto 8-10 Mha in the next 5-6 years.

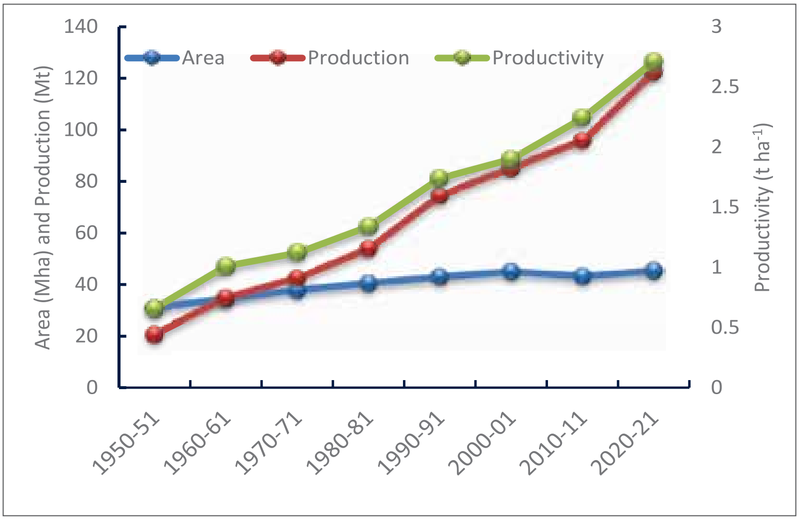

Fig. 1. Area, production and productivity of rice in India

Table 1. Milestones in rice improvement

Year	Milestone
1946	Establishment of Central Rice Research Institute (Presently National Rice Research Institute), Cuttack, Odisha.
1951	Indica - Japonica hybridization programme initiated.
1965	Establishment of All India Coordinated Rice Improvement Project (AICRIP) at Hyderabad.

Year	Milestone
1966	Introduction of miracle variety IR-8.
1968	Release of first indigenously developed semi-dwarf high yielding variety Jaya.
1980	Release of two Mega varieties 'Samba Mahsuri (BPT 5204)' and 'Swarna'.
1981	Release of another miracle rice variety 'IR 36' developed by Dr Gurdev Singh Khush at IRRI was resistant to several biotic stresses.
1983	Establishment of Directorate of Rice Research, Hyderabad which was upgraded to Indian Institute of Rice Research in 2014.
1989	A widely cultivated rice variety IR 64 introduced by IRRI having multiple resistance to biotic stresses.
1989	Development of first semi-dwarf Basmati variety 'Pusa Basmati 1'.
1994	Release of first hybrid rice (APHR 1) in India.
2001	Release of popular and most widely grown hybrid 'PA 6444' from private sector.
2004	The whole genome of rice sequenced (India as part of IRGSP consortium).
2005	Cloning and characterization of a major blast resistance gene '*Pi54*(*Pi-k*^{h})'.
2005	Release of export quality basmati variety 'Pusa Basmati 1121'.
2007	Release of varieties developed through Marker Assisted Selection (Improved Samba Mahsuri and Improved Pusa Basmati 1).
2015	Release of flash flood-tolerant rice variety (Swarna Sub 1).
2016	Release of first rice biofortified varieties (high zinc rice variety DRR Dhan 45 and high protein rice variety CR Dhan 310).
2018	Release of first flash flood and drought-tolerant rice variety developed through Marker Assisted Selection (DRR Dhan 50).
2021	Release of first low soil P tolerant and bacterial blight resistant variety developed through Marker Assisted Selection (DRR Dhan 60).
2021	Release of first superfine multiple biotic stress resistant variety (Bacterial blight and Blast resistance) developed through Marker Assisted Selection (DRR Dhan 62).
2021	Release of first herbicide-tolerant (Imazethapyr) basmati variety developed through Marker Assisted Selection (Pusa Basmati 1979 and Pusa Basmati 1985).

Box 1: Jaya-The Pride of India

'Jaya' the miracle rice variety was developed by Padma Shri SVS Shastry, released in 1968 ushered the green revolution. It is a semi-dwarf rice variety with 130 days duration with a yield potential of up to 5 t ha^{-1}. It has strong seedling vigour, resistance to lodging, early maturing, photo-insensitive, with desirable cooking and eating quality. By breaking the yield barrier, brought self-sufficiency by late sixties to early seventies. Even after glorious 55 years of its release, it is still grown widely across India.

Box 2: Pusa Basmati 1121- making the country a rice exporter

Pusa Basmati 1121 (PB 1121) is a milestone in Basmati rice improvement. The milled rice of PB 1121 is extra-long slender, appealing taste, pleasant aroma, good mouth feel and easy digestibility. During 2006-2020 contributed to ~35% of the breeder seed indented for Basmati rice in India. In terms of total economic surplus, PB 1121 has generated ₹ 52334 crores (at 2020-21 prices), and ₹ 66007 crores at constant prices (base year: 2011-12). The approximate cumulative earning due to export of PB 1121 since 2008 has been estimated to be ₹ 2,00,000 crores.

3.2. Wheat

Wheat is an important staple food, next to rice, serving as an integral part of food and nutritional security. The total wheat produced in the country accounts for nearly 37% of the food grains production. Since 2014-15, the country has witnessed a consecutive record output of wheat surpassing the 100 Mt mark in 2018-19. The production has witnessed a massive increase of over 16 times from 6.46 Mt (1950-51) to 109.52 Mt (2020-21) (Fig. 2). The change in production, since the independence, is attributed to several factors, especially the high-yielding varieties, fertilizer & irrigation intensification and synergy between technology, extension, policy, and institutions (Singh et al. 2019). Efforts are being made to attain the target of 140 Mt by 2050 amidst several production constraints and challenges.

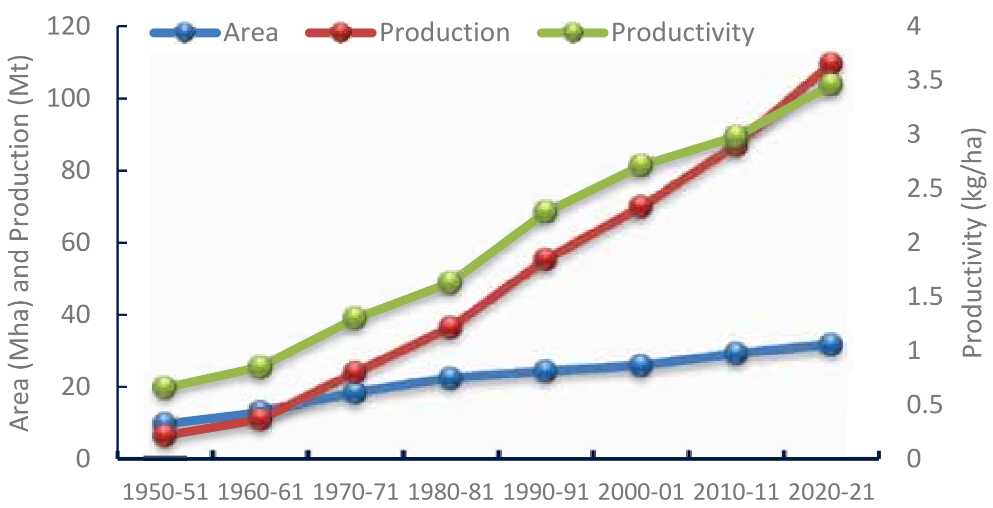

Fig. 2. Area, production and productivity of wheat in India

The quantum jump in wheat production is largely attributed to several interventions in the form of wide adoption of high yielding semi-dwarf varieties like Sonara 64, Lerma Rojo, and Sonalika during 1970s; increased use of mechanization in the progressive states like Punjab and Haryana during 1980s; intensive promotion of the newly released improved wheat varieties and management technologies during 1990s; introduction of 1B/1R translocation leading to the release of a mega variety PBW 343 in 1995; popularization of resource conservation technologies in the early 2000s; release and wide spread of promising varieties like HD 2967, HD 3086 and DBW 187 in the recent decade (2010s) (Singh et al. 2019). More than 448 cultivars were released since 1964-65 including several landmark varieties like C 306, HD 2329, WL 711, HD 2009, UP 262, HD 2189, HUW 234, WH 147, HI 617 (Sujata), Lok 1, HD 2285, Raj 3765, PBW 343, PBW 502, HD 2967, HD 2733, HD 3086, DBW 17, GW 496, GW 273, PBW 550, GW 322, DBW 187, DBW 222 in bread wheat; and Raj 1555, PBW 34, HI 8498 and PDW 233 in durum wheat that led to over 16 fold increase in wheat production since 1950-51.

Wheat rust epidemics had been very frequent worldwide and latest were caused by *Yr*9 virulence world over and Ug99 pathotype has spread to twelve wheat-growing countries. India has been successful to contain wheat rusts during the past five decades even when all the adjoining countries had epidemics (Bhardwaj et al. 2019). Anticipatory breeding for rust-resistant wheat is in place and molecular markers are assisted to deploy more than one resistance gene as a gene deployment strategy (Tomar et al. 2014). The success in containing rusts has now become a model system for the management of plant diseases.

HD 2967, HD 3086, and DBW 187 are considered the mega varieties for their wider adaptability and pest & disease resistance especially yellow and brown rust. HD 2967 occupied around 10 Mha, followed by HD 3086 with 4.7 Mha and DBW 187 with 1.89 Mha. Similar to DBW 187, DBW 222 and HD 3226 are now emerging as a preferred and promising variety among farmers. The progress of research in terms of wheat quality has been remarkable and gained an impetus with a special focus on bio-fortification. India's first biofortified variety in wheat, WB 02 (42 ppm Zn and 40 ppm Fe) along with HPBW 1 was released in 2017. Twenty-six other biofortified wheat varieties were also released for defeating malnutrition in the country. In addition, promising wheat genotypes were identified for value addition and nutritional quality. For instance, the average sedimentation value, which is an indicator for flour recovery and palatable for bread making has witnessed a significant improvement in the recent decade.

Box 3: HD 2967-Securing nation on food front

HD 2967 is a double dwarf wheat variety, has contributed significantly to the national food security. It is resistant to rust disease has replaced the susceptible variety PBW343. It is the most preferred wheat cultivar and covering 11 million ha presently.

Table 2. Milestones in wheat improvement

Year	Milestone
1949	Indian Council of Agricultural Research sponsored the Coordinated Wheat Rust Control Scheme for further augmenting the wheat rust programme.
1954	Release of World's first all rust resistant cultivar of wheat NP 809.
1965	Release of C306 wheat variety with high chapatti making quality.
1965	Establishment of the All India Coordinated Wheat Improvement Project (AICWIP) in 1965 by the ICAR.
1966-69	Release of semi dwarf wheat varieties – Lerma Rojo, Sonora 64, Kalyan Sona, Sonalika, Chotti Lerma, Safed Lerma led to green revolution in the subsequent years.
1975	Release of HD 2009, high yielding dwarf wheat variety.
1977	Release of WL711, high yielding wheat variety.
1978	Establishment of Directorate of Wheat Research (DWR) at New Delhi, which later was shifted to Karnal in 1990.
1981	Release of Lok 1, wheat variety with superior grain quality.
1982	Release of HD 2329, high yielding wheat variety, first Indian variety that covered more than 4 Mha, replaced Kalyansona.
1985	Release of HD 2285 replaced late sown wheat variety Sonalika.
1994	Release of UP 2338, high yielding wheat variety.
1995	Release of PBW 343, high yielding wheat variety that replaced HD 2329 and occupied 7 Mha in 2004.
2005	India became the first country to overcome Ug99 attack of stem rust and now all HD and HI releases are resistant to Ug99.
2011	Release of HD 2967, high yielding wheat variety. In its third year of release, it covered > 8 million ha in 2014-15.
2013	Release of HD 3086, high yielding wheat variety.
2015	Improved HD 2932 and Improved HD 2733 are the first varieties develop through MAS against leaf, stem and stripe rusts.
2017	WB2 & HPBW01, first biofortified wheat varieties released.

3.3. Maize

The maize production in the country has increased over 15 times from 2.00 Mt in 1950-51 to 30.24 Mt in 2020-21 with an average annual growth rate of 3.90%. The productivity increased by 5.6 times and area by 2.93 times during the same period. The major area expansion happened in the States of Uttar Pradesh, Bihar, Rajasthan, West Bengal, and Madhya Pradesh. The peninsular region represents about 40% of area and 52% of production. The demand for maize will continue to increase in India due to its continued requirement in poultry and livestock feed. The growth trend of demand indicated likely requirement of 45 Mt by 2030. This requirement may be possible to achieve through scientific interventions like the development and expansion of single-cross hybrid technology, development of climate-resilient maize genotypes, and application of novel breeding techniques in maize and mechanization of maize cultivation and popularization of conservation agriculture.

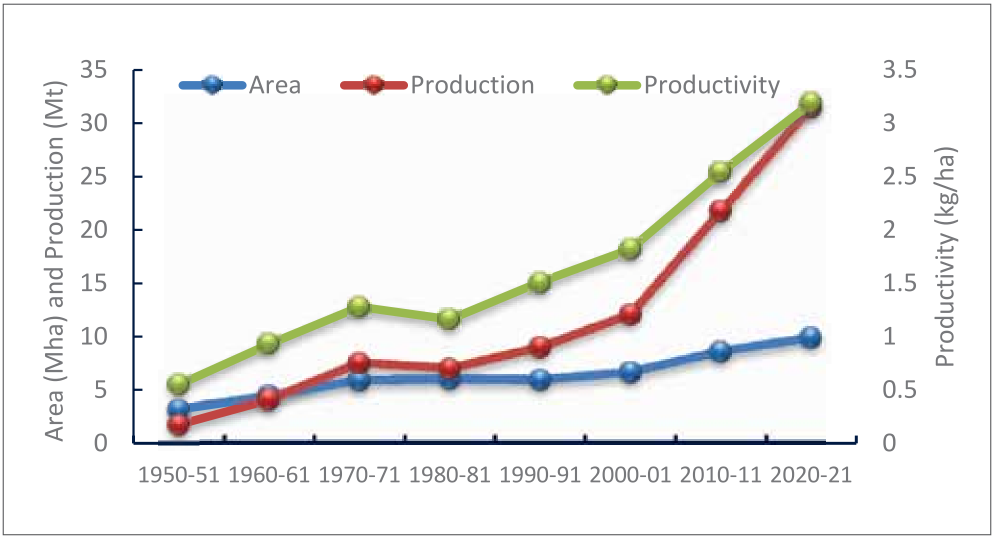

Fig. 3. Area, production and productivity of maize in India

The first AICRP for organized multilocation research started on maize in 1957. Prior to 1957, the maize productivity was very low at 0.55 t ha^{-1}. The Government of India introduced several maize hybrids from the USA, and promising ones were recommended for cultivation after their evaluation. However, there was no significant impact on productivity due to the temperate nature of these hybrids, dent type, late maturity, and tropical conditions of India. The organized research on maize brought about several breakthroughs, such as the first set of double-cross hybrids, Ganga 1, Ganga 101, Ranjit and Deccan in 1961; the first OPV Jawahar in 1967; the of double cross hybrid (Hi-starch, Ganga 5, Ganga Safed 2) in 1969; high protein varieties, *viz*., Shakti, Rattan, and Protina with *opaque 2* in 1971; first single cross hybrid Paras in 1995 and first marker-assisted derived hybrid Vivek QPM 9 with high lysine and tryptophan in 2008. The composite breeding started in 1967 and continued till 1988 (Rakshit and Chikkapa 2018). Six composite cultivars *viz.*, Vijay, Kisan, Amber, Vikram, Sona, and Jawahar were released for cultivation in 1967 using the exotic and native germplasm populations through the systematic crossing. These became very popular at farmer's fields. During 1988 to 1996 the mix of composites, double, double top, top, and three-way cross hybrids were followed to maximize the maize productivity. Till 1988 in India almost 100% maize area was covered by the public bred cultivars or local landraces. In the 1990s, the single cross hybrid (SCH) program was started with the adoption of a new seed policy and the first single cross hybrid 'Paras' was released by the Punjab Agricultural University, Ludhiana. After 1996, the maize research was shifted to single-cross hybrid development only. The maize productivity increased from 1.8 t ha^{-1} in 1997-2006 to 3.19 t ha^{-1} primarily due adoption of single-cross hybrid technology (Fig. 3).

The discovery of two mutants namely, *Opaque-2* (O_2) containing high lysine and tryptophan and *flory-2* (fl_2) having relatively more methionine in the 1960s, diverted the maize research towards quality protein maize (QPM). The QPM has 2-3 folds more lysine and tryptophan compared to normal maize. In 1971, three composites, *viz.,* Shakti, Rattan, and Protina were released containing *Opaque-2* mutant. However, these composites did not become popular due to their chalky look and soft endosperm, which made it more susceptible to storage insect pests. To address this issue first hard endosperm composite Shakti1 was released with *opaque-2* and desired modifier in 1997.The first three-way cross QPM hybrid, Shaktiman 1 was released in 2001 and single-cross hybrid, Shaktiman 2 in 2004. These hybrids were white seeded with little acceptance. Subsequently, the first yellow colour hybrid QPM namely Shaktiman 3 and Shaktiman 4 were released in 2006. The first MAS-derived QPM hybrid, QPM Vivek 9 was released in 2008. Subsequently, a series of MAS-derived QPM hybrids *viz.,* Pusa HM8 Improved (AQH8), Pusa HM 9 Improved (AQH9), and Pusa HM4 Improved (AQH4) in 2017 and Pusa VH 27 Improved, Pusa HQPM 5 Improved, Pusa HQPM 7 Improved in 2020 were released. The development of vitamins and micronutrient enriched hybrids in maize is the recent focus to improve the nutritional quality of maize. The first provitamin-A rich hybrid 'Pusa Vivek QPM 9 Improved' was released in 2017. Speciality corn includes sweet corn, baby corn, and popcorn, which became more popular in recent years due to its diverse applications. The VL 54 was the first popcorn composite released in 1982. The first sweet corn variety, Madhuri was released in 1990 and baby corn variety, VL 78 was released in 2004. A normal corn hybrid, HM 4 was released in 2005 which gained much popularity among farmers for baby corn purposes. Later on, number of hybrids were released which are specifically bred for baby corn, sweet corn, and popcorn. In the case of baby corn, IMHB 1532, IMHB 1539, LBCH 3, VL 78, VL Baby corn 1, VL Baby corn 2. Similarly, for sweet corn, Pusa super sweet corn 1 & 2, VL sweet corn hybrid 1 & 2 were released. In the same way, popcorn hybrids viz., DMRHP 1402, LPCH 2, and LPCH 3 were also released. The recent focus is on cytoplasmic male sterile (CMS) based hybrid to reduce the labour requirement on detasseling. Recently in 2021, the first male-sterile baby corn hybrid of the public sector viz., Pusa HM4 male-sterile baby corn (Shishu) has been released for cultivation. Similarly, sweet corn breeding focuses on overall green cob yield along with the introduction of coloured pericarp and development of high yielding mushroom type hybrids in case of popcorn have been initiated.

Table 3. Milestones in maize improvement

Year	Milestone
1957	ICAR established its first All India Coordinated Research Project (AICRP), namely 'All-India Coordinated Maize Improvement Project'- a unique system worldwide.
1961	Four double cross maize hybrids, namely Ganga 1, Ganga 101, Ranjit and Deccan were released for commercial cultivation.
1962	Winter Nursery Centre for maize was established in Hyderabad.
1965	Maize productivity of India first time surpasses 1 t ha^{-1}.

Year	Milestone
1967	A set of six composite maize cultivars, namely Amber, Jawahar, Kisan, Vijay, Vikram, and Sona were released.
1973	Quality Protein Maize composite variety, Shakti was released.
1982	First popcorn composite, VL Amber Popcorn was released.
1990	The first sweet corn composite named ‘Madhuri’ was released.
1991	The first three-way maize hybrid of India, Trishulata was released.
1994	Establishment of Directorate of Maize Research.
1995	The first single cross maize hybrid of India, Paras was released.
2001	The first Quality Protein Maize hybrid in India, ‘Shaktiman-1’ was released.
2004	First Quality Protein Maize Single Cross Hybrid, Shaktiman 2 was released.
2004	Maize productivity of India surpasses 2 t ha^{-1}.
2008	First Marker Assisted Selection derived hybrid, Vivek QPM 9 was released.
2010	First sweet corn Single Cross Hybrid, SCH 1 was released.
2015	Directorate of Maize Research upgraded into Indian Institute of Maize Research.
2015	India’s first medium duration popcorn hybrid BPCH 6 was released from PJTSAU, Hyderabad.
2017	First pro-vitamin A rich maize hybrid in India and pro A+ QPM in world viz., Pusa Vivek QPM 9 improved released.
2018	India’s first early maturing popcorn hybrid DMRHP1402 released for cultivation from ICAR-IIMR.
2019	Maize productivity of India surpasses 3 t ha^{-1}.
2021	Inia’s first public sector’ Pusa HM4 male sterile baby corn hybrid (Shishu) released from IARI, New Delhi.

3.4. Millets

In India, millets are grown over 13.8 Mha area with production of 17.3 Mt. The millets production contributes about 10% to the country’s food grain requirement. Millets were traditionally consumed as food but due to the push given to food security through the green revolution in the 1960s, millets were rendered as ‘orphan crops’ and thus are less consumed and almost forgotten. Before the Green revolution, millets made up around 40% of all cultivated grains, which has dropped to around 20% over the years. Despite the many benefits of growing millets, there has been a downward trend in the cultivation of millets in the country. In the past six decades, the area under millets has gone down by 62.57%, dropping from 36.34 Mha (1955-56) to around 13.83 Mha (2019-20). Yet, the production target of all millet crops is maintained with an increase in productivity per hectare over 4 times in pearl millet and more than 2 times in sorghum, finger millet, and small millet crops over the decades.

After independence, enormous progress has been made to improve the productivity of sorghum, pearl millet, and small millets by developing high-yielding cultivars and hybrids. In fact, sorghum and pearl millet hybrids established the seed industry in the country. Hybrids were successfully developed in sorghum (often cross-pollinated crop) and pearl millet (cross-pollinated crop) due to the availability of the male sterility system for hybrid seed production. Private entrepreneurs and companies have also contributed significantly to the development of superior hybrids and their commercialization in pearl millet, forage sorghum, and grain sorghum. Through ICAR- AICRP on pearl millet, a total of 206 varieties and hybrids were released for cultivation in different agro-ecological zones of the country. It is the first crop where MAS strategies and tools were applied to develop Improved HHB 67, and to develop biofortified variety "Dhanashakti" in collaboration with ICRISAT and Harvest Plus programs. Some biofortified hybrids, AHB 1200, AHB1269, HHB 299, HHB 311, RHB 233 and RHB 234, GHB 1129 with high iron & zinc were released. Development of CMS lines for hybrid development remarkably contributed in yield improvement during the second phase (1967–1983) of crop improvement in which an annual increase of 6.6 kg ha^{-1} in productivity was achieved. Similarly, during phase III (1984–2000), many genetically diverse CMS lines were developed and utilized in hybrid breeding. In phase III, 19.0 kg ha^{-1} yr^{-1} productivity was achieved. During phase IV (2001–2018), greater emphasis was on genetic diversification and adaptation to niche areas of cultivation. The grain productivity further increased to 31.1 kg ha^{-1} yr^{-1} during this phase. The overall productivity gain was about 470% of the productivity gain achieved during the first phase (Yadav et al. 2021).

Recent advancements in next-generation sequencing technology helped to formulate 1,000 genomes sequencing projects, which is a major milestone in pearl millet improvement (Varshney et al. 2017). This project will help in better exploration of available genetic resources, QTL/gene mapping, marker development, and most importantly for genomic selection. Substantial improvement has been made in sorghum with the development and release of 223 varieties and hybrids released by different states. The feat of improved productivity could be achieved by exploitation of heterosis through hybrid breeding particularly in Kharif season. The hybrids, CSH 9, CSH 14, CSH 16, and CSH 30 are widely cultivated in Kharif season. Further, CSH 35 and CSH 41 are also getting popular in recent times. Among Kharif varieties, CSV 15, CSV 27, and CSV 31 along with many state releases are promising with higher net incomes realization from sorghum cultivation. Potential rabi varieties available to farmers are CSV 216R, CSV 18, CSV 22R, CSV 26R and CSV 29R among others. In sorghum, there has been an increase in productivity from 458 kg ha^{-1} in 1965 to 989 kg ha^{-1} in 2019.

Small millets improvement efforts during the late 1950s and 60s have contributed significantly by releasing several HYVs and developing crop protection and agronomical techniques. However, real growth in finger millet productivity was achieved during 1950-60 when the hybridization technique was successfully established. The finger millet varieties, CFMV 1 and 2 are rich in calcium, iron, and zinc, and the little millet variety, CCLMV1 is rich in iron and zinc. In the other five small millets, genetic improvement has been limited due to lack of genetic diversity, difficulty in recombination breeding, and lack of serious crop improvement programmes with requisite funding support. A total of 211 small millets varieties have been released in the country with 136 varieties in finger millet.

Box 4: CSH 16 - A landmark sorghum hybrid

CSH 16 is a medium duration kharif sorghum hybrid released in 1997 had high acceptability amongst the sorghum farmers because of its grain quality. The hybrid yields, on average, 4.1 t ha^{-1} of grain and very popular in the states of Karnataka, Maharashtra, Madhya Pradesh and Andhra Pradesh. It also performed well in the rice fallows in the coastal belt of Andhra Pradesh where the yields of sorghum obtained ranged from 5 to 8 t ha^{-1}. CSH 16 in rice fallows is a success story. The last ten years results revealed CSH 16 yielding 7.73 t ha^{-1}, significantly better than the locally popular private hybrids.

Table 4. Milestones in millet improvement

Year	Milestone
1962	Introduction of male sterile source of pearl millet Tift 23A from Tifton, Georgia.
1964	CSH 1- First sorghum hybrid developed based on ms CK 60A.
1965	All India Co-ordinated Millets Improvement program (AICMIP) established in Delhi.
1965	First pearl millet hybrid HB 1 released.
1968	CSV 1 (Swarna)- First sorghum variety developed, Bajra hybrid HB 3 released that increased production from 3.5 to 8.0 Mt.
1969	M 35-1- A widely cultivated and popular rabi sorghum variety released.
1970s	Popular male sterile lines of pearl millet 5141A and 5054A derived from mutation of Tift 23A.
1974	CSH 5- High yielding medium maturing kharif sorghum hybrid released.
1976	Two high yielding finger millet varieties Indaf 1 and Indaf 3 containing stress resistance genes from exotic African germplasm.
1977	SSG 59-3, a mega multi-cut forage sorghum variety developed.
1982	WC-C75 variety of pearl millet which occupied 2 Mha and maintained pearl millet production when hybrids became susceptible to downy mildew.
1983	CSH 9- High yielding mega hybrid, covered > 50% of kharif area.

Year	Milestone
1992	CSH 14- first early maturing sorghum variety released; most popular in Maharashtra and Karnataka; highly suitable for inter-cropping.
1995	Hybrid Mahyco 204 of pearl millet was released which covered 22% area in Maharashtra.
1995	CSH 15R- First rabi sorghum hybrid with good rabi adaptability traits.
1996	CSV 15- Popular dual purpose kharif sorghum variety developed.
1997	CSH 16- Medium maturing kharif sorghum hybrid with grain mold tolerance which has become very popular in farmer fields.
1998	GPU 28- A finger millet variety with broad based resistance for blast and high yield.
2002	Pearl millet Hybrid GHB 558 released that covers 95% area in Gujarat.
2004	Proagro-9444 released and it occupies around 40% of area in Haryana and 5% of area in Rajasthan.
2005	Development and release of CSH 22SS, the first sweet sorghum hybrid which was exploited by many sugar industries for pilot scale ethanol production.
2005	Pearl millet hybrid HHB 67 improved was released. It is a downy mildew resistant version of HHB 67, created through MAS and covers 2% area in Rajasthan and 30% area in Haryana.
2009	CSH24MF- most popular multi-cut forage variety; occupies 40% of forage area in the country.
2012	Earliest maturing Foxtail millet variety SiA 3088 (Surya Nandi) (70-75 days) variety was notified.
2014	QTL for stay-green, a component of terminal drought identified involving M35-1 x B35. Stg2, Stg3 and StgB were prominent in their expression.
2015	PS 1, a partial genetic male sterile line of finger millet was developed from mutagenesis of GPU 28 to facilitate recombination breeding in difficult-to-cross finger millet to evolve heterotic crosses.
2017	CSV33MF-mutant multi-cut forage high yielding variety released.

3.5. Pulses

In post-independent India, pulses registered significant progress in production from 8.41 Mt in 1950 to 25.72 Mt in 2021. The more conspicuous growth in the pulse production has been witnessed in recent years marching towards self-sufficiency which could be regarded as protein revolution. The development of nearly 570 high yielding and short-duration varieties insulated against major biotic and abiotic stresses, and increased infusion of quality seeds of such new releases, in spite of area shift from northern to central and southern India, ensured increased production and productivity of protein-rich crops spread over traditional and non-traditional pulse growing areas.

The systematic work on pulses improvement started in 1966 with the establishment of the All India Coordinated Pulse Improvement Project (AICPIP) headquartered at IARI, Delhi. The first widely adaptable variety of chickpea C 235 for north India was released in 1972. In 1984, Pusa 256 with improved plant type was developed through Desi x Kabuli introgression. In 1980s, major emphasis was made on the development of short-duration genotypes with disease resistance, particularly fusarium wilt and root rots. Consequently, wilt-resistant chickpea cultivars like Radhey, Avarodi, and KWR 108 were developed. In the late nineties, programmes on drought and heat tolerance and grain quality in chickpea were initiated resulting in the development of a heat-tolerant most popular variety of chickpea JG 14 in 2011 which occupied a sizeable area in Central India (Ali and Gupta, 2012). Recently in 2019, marker-assisted breeding resulted in the development of race-specific wilt-resistant chickpea varieties like Pusa Chickpea 20211, Super Annigeri 1, and IPCMB 19-3 and drought-tolerant chickpea varieties Pusa 10216, IPCL 4-14, and BG 4005. The first extra-large seeded Kabuli Chickpea variety 'KAK 2' was released in 1999 which opened the scope for the export of Kabuli chickpea. Subsequently, JGK 6, MNK 1, RLBGK 1, Kota Kabuli chana 2, Shubhra and Ujjawal were released. In recent years, chickpea varieties suitable for mechanical harvesting such as Phule Vikram, Pusa 3062, JG 2016-24, NBeG 47, RVG 204, Shubhra, IPC 2010-134, GBM 2 were also developed. Systematic breeding efforts in pigeonpea started in the seventies resulted in the development of the most popular varieties of early duration UPAS 120 and late duration Bahar, which ruled the pigeonpea cultivation for four decades. Asha was another multiple disease-resistant variety developed in 1993 and covered a large area under pigeonpea. Emphasis on the development of hybrid technology in pigeonpea involving genetic male sterility system was the main focus during the late eighties. Resultantly, ICPH 8, the first GMS-based hybrid in pigeonpea was released in 1991. Later on in 1999, the focus of the hybrid programme has been directed to the cytoplasmic male sterility system, and consequently first GMS-based hybrid in pigeonpea GTH 1 was released in 2006 for Gujarat state. Mungbean improvement programme started back in 1949 with the development of T 44 as the first product of hybridization which was subsequently used as a parent in most of the mungbean varieties released in India. Pusa Baisakhi released in 1971 has been a landmark variety that paved the way for mungbean cultivation possible in summer/spring. Subsequently, several releases like IPM 02-3, Samrat, SML 668 and Virat with a shorter duration and photo-thermo insensitivity increased the area under mungbean cultivation in non-traditional niches from 6 lakh ha to 12 lakh ha in the last 6-7 years. Virat, an extra early variety of mungbean developed in 2016 which matured in 55 days brought the additional area under mungbean in several non-traditional niches. Efforts were made to incorporate resistance to MYMV, pod shattering, and early synchronous maturity in high yielding background. Interspecific hybridization of mungbean x urdbean has resorted for the development of mungbean varieties which brought synchronous in maturity and durable resistance against MYMV. The first product of interspecific hybridization, HUM 1 was released in 1999. Subsequently, several other products of interspecific hybridization were brought to commercial cultivation. The release of a photo-insensitive variety of mungbean IPM 02-3 in 2009 along with MH 421 and GM 4 helped three-fold increase in the area in Rajasthan in a short period of 6 years making the state as leading mungbean producing state in the country. Breeding efforts in urd bean started with the selections from land races for high yield and plant types. T 27 was the first release of urd bean in 1949. A landmark variety of urd bean T9 was developed in 1975 and ruled for more than three decades. Since then, breeding programmes aimed at developing suitable varieties for different growing situations having resistance to major diseases (MYMV and powdery mildew). In 1983, the first powdery mildew resistant variety LBG 17 was released which brought urd bean revolution in coastal Andhra Pradesh. LBG 787, the first photo-thermo insensitive variety of urd bean was released in 2016. This variety could be grown successfully in all seasons and helped in spreading urd bean cultivation in non-traditional niches. Significant progress has been made in lentil breeding during the last seven and half decade. Pant Masoor 639 has been the first product of hybridization released in 1977. The K 75 was the first large-seeded lentil variety released in 1986. Even today, developments of extra-large seeded varieties for export purposes are the breeder's priority. Similarly, efforts have been made for the development of suitable varieties for utera cultivation. The large-seeded were mostly susceptible to wilt, therefore, efforts were made to insulate against wilt. DPL 62 was the first wilt-resistant bold seeded variety which brought stability in production in Bundelkhand region of UP, the lentil bowl of India.

Box 5. Virat: expanding area under mungbean

Virat (IPM 205-7), the world's first extra early synchronous variety of mungbean matures in 52-55 days, is amenable to a single harvest. It is resistant to the devastating yellow mosaic disease. Within five years of its release in 2016, this variety has become number one indented mungbean variety with wider acceptability in Punjab, Haryana, Uttar Pradesh, Karnataka, Tamil Nadu, Madhya Pradesh, Maharashtra and Gujarat. During 2020-21, Virat had a share of >25% in the national breeder seed indent with an expected cultivated area of >3 lakh ha. The variety is being grown in the Indo-Gangetic plains, canal command areas of Central India and new delta area of southern peninsula.

Pusa Vaibhav was the first biofortified variety of lentil released in 1996. IPL 220 is another biofortified variety with high iron and Zinc which was released in 2017. The program on Lathyrus started in the eighties with an aim of reducing ODAP content. Bio L 212 was the first low ODAP variety of Lathyrus is somaclone of P 24 released in 1997. Low neurotoxin Lathyrus varieties Mahateora, Prateek, etc. have been developed and seeds of such varieties are being made available for large-scale cultivation. Efforts are being made for the development of varieties that can be accelerated through marker-assisted breeding and the defects of mega varieties may also be corrected through marker-assisted backcrossing

Box 6: JAKI 9218 led expansion of Chickpea in Central and South India

JAKI 9218 is a landmark chickpea variety which has significantly contributed towards increased chickpea area in the country in central & south India. It was released in 2007 for cultivation under rainfed condition of Central India. The variety has a yield potential of 20 qha^{-1} with moderately resistance to Fusarium wilt. It became very popular in Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh and Karnataka. In 2016-17, 18.5% of total breeder seed indent accounted for by JAKI 9218.

Table 5. Milestones in pulses improvement

Year	Milestone
1960	Release of first pigeonpea variety Khargone 2 for cultivation in Central Zone, first chickpea variety 'Annegeri 1' released for peninsular India, first chickpea wilt resistant variety C 104 released for cultivation.
1966	Establishment of All India Coordinated Pulse Improvement Project at IARI, New Delhi.
1970	First early maturing pigeonpea variety, CO-1 released for cultivation in South zone.
1971	First mid-late maturing variety pigeonpea 'Sharda' was developed, the first variety of mungbean 'Pusa Baisakhi' released for summer cultivation.
1972	Pusa Ageti, first medium maturing variety of pigeonpea, Shweta, first late maturing variety of pigeonpea and first widely adaptable variety of chickpea C 235 for north India developed.
1973	The most popular late duration and sterility mosaic resistant pigeonpea variety 'Bahar' was released from Dholi, Bihar.
1976	Landmark variety of early pigeonpea 'UPAS 120' released; first Kabuli variety of chickpea 'L 144" was released.
1978	Establishment of Project Directorate on Pulses at Kanpur which was upgraded to Institute in 1993.
1980	The first landmark variety of field pea 'Rachna' resistant to powdery mildew was released which became the cornerstone in developing resistant varieties of field pea against powdery mildew.
1983	First variety of urdbean resistant to powdery mildew 'LBG 17' suitable for rabi rice fallow cultivation brought blackgram revolution in coastal Andhra Pradesh.

Year	Milestone
1984	First chickpea variety developed through desi x kabuli introgression- Pusa 256.
1988	First dwarf variety 'Aparna' and first leafless variety 'HFP 4' of field pea were released.
1990	Development of GMS based hybrid research in pigeonpea, ICPH 8, first GMS based hybrid released for cultivation in central zone in pigeonpea.
1993	Landmark variety of pigeonpea 'Asha (ICPL 87119)' developed which is widely adopted in central and south zone and multiple diseases resistant.
1996	Release of first biofortified variety of lentil 'Pusa Vaibhav'.
1997	Landmark variety of lentil 'DPL 62' released which was wilt resistant and bold seeded.
1999	First chickpea variety 'JG 11" developed through polygon breeding, first large seeded Kabuli chickpea variety 'KAK 2' released, field pea variety HUDP 15' developed with combined resistance for rust & powdery mildew diseases.
2006	Identification of CMS source for hybrid pigeonpea and development of first CMS based hybrid of pigeonpea 'GTH1' released for cultivation in central zone.
2008	Development of popular variety of pigeonpea'TJT 501' tolerant to pod borer and pod fly.
2008	First product of interspecific hybridization in urdbean 'Mash 114 'developed.
2011	Most popular and heat tolerant chickpea variety 'JG 14' released which brought cultivation of chickpea in southern peninsula.
2016	First extra early variety of mungbean 'Virat' maturing in 55 days; first photo-thermo-insensitive variety of urdbean 'LBG 787' developed for cultivation in all seasons, development of chickpea varieties amenable to machine harvesting developed for Andhra Pradesh (NBeG 47), Karnataka (GBM 2) and Maharashtra (Phule Vikram).
2019	Chickpea varieties through Marker Assisted Selection Backcrossing developed for drought tolerance (BGM 10216) and Fusarium wilt resistance (MABC WR SA 1).

3.6. Oilseeds

Oilseeds account for 17.9% of arable land and 14.3% of the gross cropped area in India. India is the 4th largest vegetable oil economy in the world. India stands first in the production of castor, sesame, safflower, and niger, whereas second in groundnut, third in rapeseed-mustard, fourth in linseed and fifth in soybean. About 14 million farmers are engaged in oilseeds production and another million in their processing. Among the edible oilseed crops, soybean (36%), groundnut (32%), rapeseed-mustard (29%) contributed 97% of the total edible oilseeds production. Sesame, sunflower, safflower and niger contributed about 3%. Contrary to the production, the major contribution to domestic edible oil kitty comes from rapeseed-mustard (3.2 Mt, 45%), Groundnut (1.8 Mt: 25%), and Soybean (1.8 Mt, 25%) amounting to 95%. The minor edible oilseeds (Sesame, Sunflower, Safflower and Niger) contribute about 5% of the total domestic production of 7.03 Mt. Around 3.50 Mt of edible oils come from secondary sources (cotton seed oil, palm oil, corn oil, rice bran oil, coconut oil, and other TBOs).

During the 70 years from 1950-51 to 2020-21, oilseeds production increased by seven folds from 5.16 to 36.10 Mt. The average national productivity of nine annual oilseeds has increased from 0.43 t ha^{-1} in 1967 to 1.25 t ha^{-1} in 2020, mainly due to development and deployment of high-yielding varieties/hybrids and crop management technologies. Presently, India produces nearly 40% domestically and imports 60% of its total demand for edible oils. The *per capita* consumption of edible oils has grown from 15.8 kg yr^{-1} in 2012-13 to 18.8 kg yr^{-1} in 2019-20 with a CAGR of 2.17%. The demand and supply gap has widened over the years. The demand for edible oil was 25.63 Mt in 2019-20 against the total domestic production of 10.53 million tons which necessitated an import of around 15.1 Mt (palm oil about 60%; soybean oil 25%; sunflower 12% and others 3%) costing around Rs. 69000 crores to the national exchequer.

The establishment of the All India Coordinated Research Project on Oilseeds (AICRPO) during 1967 helped accelerating research on oil seed crops. The project initially confined only to groundnut, rapeseed-mustard, linseed, sesame, and castor. In 1972, sunflower, safflower, and niger were added to the AICRP-Oilseeds. Research on soybean was initiated separately during 1967. AICRP-Oilseeds was stationed at IARI, New Delhi initially. With the establishment of the Directorate of Oilseeds Research (DOR) at Hyderabad in 1977, the responsibility to coordinate and monitor these programmes shifted to directorate and respective Project Coordinators. The AICRP on groundnut and AICRP on rapeseed-mustard were shifted to NRCG, Junagadh and NRCRM, Bharatpur during 1979 and 1993, respectively. The AICRP on soybean continued under NRCS, Indore established in 1987. The Project Coordinating Units of sunflower, safflower, sesame & niger, and linseed were located at UAS, Bangalore; MPAU, Sholapur; JNKVV, Jabalpur, and CSAUA&T, Kanpur respectively. Following the recommendations of the Jain Committee constituted by ICAR, the positions of Project Coordinator for groundnut, rapeseed-mustard, soybean, sunflower, castor, and safflower were withdrawn during IX Plan and the responsibility of coordination was entrusted to the concerned Project Director and Directors of NRCs, concerned.

Presently, ICAR is implementing five AICRPs on nine annual oilseeds. Besides, basic and strategic research on annual oilseeds are ongoing in commodity-specific institutes namely ICAR-Directorate of Groundnut Research, ICAR-Indian |Institute of Soybean Research, ICAR-Directorate of Rapeseed-Mustard Research and the ICAR-Indian Institute of Oilseeds Research, and some other ICAR institutes like ICAR-Indian Agricultural Research Institute, ICAR-National Bureau of Plant Genetic Resources, ICAR-National Institute of Plant Biotechnology, and ICAR-Vivekanand Parvatiya Krishi Anusandhan Shala. Concerted research in these institutes and AICRPs led to development of improved varieties/hybrids with a higher yield, earliness in maturity, photo-thermo-insensitivity, amenability to mechanization; superior quality, tolerance/resistance to major abiotic and biotic stresses, etc. This resulted in notification of 930 high-yielding climate-resilient varieties/hybrids of nine annual oilseeds for cultivation during 1969-2021. During 2014-2021, 251 varieties/hybrids of the oilseeds have been notified comprising 42 of groundnut, 63 of soybean, 58 of rapeseed-mustard, 13 of sesame, 33 of linseed, 5 of niger, 12 of sunflower, 11 of safflower and 14 of castor. High genetic potential of the newly developed varieties/hybrids of nine annual oilseeds such as rapeseed-mustard (3.0-3.5 t ha^{-1}); groundnut (3.5-4.0 t ha^{-1}), soybean (2.2-2.8 t ha^{-1}), castor (3.0-3.5 t ha^{-1}), sunflower (2.0-2.5 t ha^{-1}), sesame (1.0-1.5 t ha^{-1}), safflower (1.0-1.2 t ha^{-1}) can be exploited to further enhance the realized productivity at the farmers' fields.

Box 7: Canola Quality Indian Mustard: Pusa Double Zero 31

Indian mustard variety Pusa Double Zero Mustard 31 has low erucic acid (0.76% in oil) and glucosinolates (29.41 ppm in seed meal) content in comparison to >40.0% erucic acid and >120.0 ppm glucosinolates in other popular varieties. Around 0.5 million tons of canola oil being imported in our country is from transgenic gobhi sarson (*Brassica napus*) varieties and being sold at very high prices (more than Rs. 250 kg^{-1}). The release of this variety has attracted the farmers and seed as well as oil industry for its production and marketing. In a short span of time of its release its breeder seed indent has reached to more than 5.0 q leading it to top five indented varieties of Indian mustard in the country.

Table 6. Milestones in oilseeds improvement

Year	Milestone
1967	T-13: First Sesame variety tolerant to lodging released for UP and MP.
1974	Durga mani: First variety of Indian mustard (*B. juncea*) resistant to *Orobanche* root parasite released.
1976	GCH-3: World's first castor hybrid released in India.
1979	First 'National Research Centre (NRC)' on Groundnut was established at Junagadh (Gujarat).
1980	Kalika: First sesame variety developed through mutation.
1982	IGP-76: First variety released for all Niger growing areas. BSH-1: First Sunflower hybrid released in India. TL-15: First Summer variety of Toria (*Brassica campastris var. Toria*) for high altitude of Himachal Pradesh released.
1984	Kaushal (G 201): First high yielding early maturing (108-112 days) Virginia bunch groundnut variety released for all India cultivation.
1988	Girnar 1 (CGC 4018): First multiple diseases (ELS, LLS, rust, collar rot, *Aspegillus flavus*) resistant Spanish bunch groundnut variety with early maturity and high peg strength released.
1990	Somnath (TGS 1): First large seeded and early maturing centrally released Virginia bunch groundnut variety. Narendra Rai (NDR 8501): First variety of Indian mustard (*Brassica juncea*) tolerant to salinity released.
1991	RH 781: First variety of Indian mustard (*Brassica juncea*) tolerant to frost released.

Year	Milestone
1994	JS 335: A landmark variety of Soybean which dominated soybean cultivation for more than a decade developed. Birsa Niger-1: First Niger composite variety released. Pusa Jai Kisan (Bio-902): First variety of Indian mustard (*Brassica juncea*) developed through tissue culture released.
1996	PGSH-51: First hybrid of Gobhi sarson *(Brassica napus)* released in India GSL-2 (Gobhi sarson): First variety of Rapeseed-Mustard group of eight crops resistant to Atrazine herbicide released.
1997	Thilathara: A Sesame variety suitable for both rice fallow and upland released for Kerala. NRC7: First early maturing Soybean variety suitable for enhancing cropping intensity released.
1998	DSH-129: First Safflower hybrid released. SEJ-2 (Pusa Agrani): First variety of Indian mustard (*Brassica juncea*) with earliness in maturity released. CS 52: First variety of Indian mustard (*Brassica juncea*) tolerant to both salinity and sodicity released.
2001	Hyola PAC-401: First hybrid of Gobhi sarson with double zero quality released. TERI Unnat: First low erucic acid (<2%) & high oleic acid (60%) of Gobhi sarson *(Brassica napus)* released.
2004	TPG 41: A large-seeded Spanish bunch groundnut variety with a high O/L ratio, fresh seed dormancy, and tolerance to rust released. TG 37A: A high yielding Spanish bunch groundnut variety having wider adaptability released for all India.
2005	Pusa Karishma: First variety of Indian mustard (*Brassica juncea*) with low erucic acid (<2%) content released. Narendra Swarna Rai 8: First variety of Indian mustard (*Brassica juncea*) with very high oil content (46%) released.
2008	The NRCHB-506: First mustard hybrid was developed in India. Girnar 2: A high yielding Virginia groundnut variety suitable for Kharif season released for North-Western India.
2009	NRCRM was elevated to Directorate of Rapeseed-Mustard Research (DRMR).
2015	Shubhra: First sesame variety for tolerance to delayed shattering. DSb21: First Soybean variety resistant to Rust released for Southern India.
2016	Pusa Double Zero Mustard 31 (PDZ-1) and RLC 3: First two varieties of Indian mustard (*Brassica juncea*) with double zero quality (<2% erucic acid and <30 PPM glucosinolates content) released.

Year	Milestone
2018	NRC127: First Kunitz Trypsin Inhibitor (KTI) free marker-assisted selection derived soybean variety developed by an introgressing null allele of KTI in *cv* JS 97-52, ISH-185: CGMS based safflower hybrid released.
2019	Girnar 4 and Girnar 5: For the first time, high oleic acid (upto 78%) containing two groundnut varieties centrally released. ISF-1: First high oleic (70% oleic acid) safflower variety released.
2021	NRC 147: Release of first high oleic acid soybean variety; NRC 132: Release of first lipooxygenase 2 free soybean variety.

3.7. Sugarcane

Sugarcane is cultivated on an area of about 5.0 Mha, which is about 3% of cultivated land in the country. India ranked second among sugarcane growing countries of the world by contributing 18.01% in area and 19.76% in the production of sugarcane during 2018. During 2019-20, India produced 404.74 Mt of cane, 27.39 Mt of sugar and 13.81 Mt of molasses. India became the largest sugar producer during 2018-19 (33.16 Mt) which accounts about 17.6% of the total sugar produced in the world.

Improved sugarcane varieties have made a major contribution in increasing yield from 36.4 t ha^{-1} in 1947-48 to 80.5 t ha^{-1} during 2019-20 and sugar recovery from 9.91% to 10.84% in the same period (the highest being 11.01% during 2018-19). Since 1947, a total of 2,795 'Co-clones' have been evolved by the ICAR-Sugarcane Breeding Institute led to the identification of 566 Co and Co-allied varieties for different agroclimatic zones. AICRP-Sugarcane came into existence in 1982 which facilitated the multi-location evaluation of improved varieties. In independent India, 134 varieties have been developed and notified for cultivation in the country. Co 740, Co 1148, Co 6304, Co 6907, Co 7717, BO 91, CoJ 64, CoC 671, CoS 767, CoSe 92423 are worth mentioning varieties that have contributed to expanding the sugar industry and sustaining the sugarcane cultivation in the country. Among the recent varieties, Co 0238 and Co 86032 are mega varieties with 2.77 and 0.89 Mha, respectively in subtropical and tropical India (Bakhshi Ram 2021).

Box 8: Co 0238: A Wonder cane

The variety Co 0238 has revolutionized the sugarcane cultivation in sub-tropical India and covers about 84% area in the sub-tropical region with 53.4% of the total sugarcane area of India. As a result, 19.7 t ha^{-1} and 2.44 per cent improvement in average cane yield and sugar recovery, respectively of five sub-tropical states of Punjab, Haryana, Uttarakhand, Uttar Pradesh and Bihar.

Table 7. Milestones in sugarcane improvement

Year	Milestone
1949	Co 740 developed, contributed significantly to sugarcane area expansion and sugar production.
1952	ICAR-Indian Institute of Sugarcane Research (IISR) was established at Lucknow.
1962	Establishment of world sugarcane germplasm collection centre at Kannur, Kerala.
1967	Sugarcane variety Co 1148 developed, ruled north India for 40 years and occupied 80% area in subtropics during the mid-1970s and 1980s.
1974	National Hybridization Garden (NHG) on sugarcane established at Coimbatore, Tamil Nadu.
1999	Establishment of National Distant Hybridization Garden facility, Agali, Kerala.
2000	Variety Co 86032 released which occupied more than 1.0 Mha in the peninsular zone.
2009	Variety Co 0238 released, which occupied more than 2.79 Mha in north India.
2020	Government permitted for direct fermentation of sugarcane juice for bioethanol production.

3.8. Cotton

In India, cotton is cultivated on about 13.0 Mha area with the production of about 37 million bales (about 6.3 million tons). India accounts about 36-38% of the global cotton acreage and 25% of production. More than a third of the world's fabric needs and over 60% of clothing demand in India are met by cotton. Cotton provides 59% of raw material to the textile industry and comprises 29.1% of total textile exports. Cotton contributes 4.9% to the value of agricultural output while the textile industry contributes about 4% to the GDP. In terms of exports, raw cotton is exported to the tune of 50-70 lakh bales while the textile industry is the largest exporter of cotton yarn (26.7%). By 2030, India's projected cotton lint requirement is 8.95 Mt @ 47 metre cloth per capita. At present, 6 million tons of cotton lint is available @ 34-meter cloth per capita. In order to meet the projected demand by 2030, the average productivity of cotton is to be increased to 746 kg lint/ha from the present ~450 kg lint ha^{-1}.

India is unique in terms of growing all the four cultivated species of cotton (*desi* diploid cottons - *Gossypium arboreum* and *G. herbaceum*), the American upland cotton (*G. hirsutum*), and the Egyptian extra-long-staple cotton (*G. barbadense*). The systematic research on cotton was initiated in 1967 under AICRP cotton. So far 385 cotton varieties and hybrids recommended for commercial cultivation in different cotton growing zones. Among them, 269 are varieties (176 *hirsutum*, 68 *arboreum*, 21 *herbaceum* and 4 *barbadense* varieties) and 110 are hybrids (70 intra-specific *hirsutum* hybrids, 19 inter-specific and 21 diploid hybrids. World-class cotton varieties and hybrids such as Suvin, DCH 32, TCHB 213, DHB 105, LHH 144, LRA 5166, Anal, Surabhi, Sumangala, Suraj,

MCU5, MCU 7, MCU 13, SVPR-2, SVPR-3, L-799, L-761, L-1060, CSHH-29, CISA-310, CISA-614, CCH 2623, HHH 287, Abhadita, NHH-44, HD 324, DHH 11, H4, H6, H8, AAH 1, Srinandi, RG 8, RAJ DH 9, GN-Cot-25, G-Cot-19, PKV Hy-2, PA-255, Phule Dhanwantry, Phule Anmol and scores of others with a higher yield, special features and compatible with low-cost production technologies were among the released over the years suiting to textile needs and ushering higher net returns to the farming community across the country. Notable among them is MCU 5 variety belonging to the superior long-staple group released in 1968 in Tamil Nadu which made a breakthrough in improved fiber quality and recorded high seed cotton yields (2.5 t ha^{-1}) combined with wide adaptability. A significant breakthrough in quality cotton was achieved with the release of 'Sujata' variety in 1969, capable of being spun to 100s count. 'Suvin' (*G. barbadense*), an extra-long staple (ELS) variety released in 1974, was capable of being spun to 120s count and was considered as one of the best quality cottons in the world (Santhanam and Sundaram 1997). Mega cotton variety 'LRA 5166' released in 1982 by ICAR-CICR made a remarkable achievement in large-scale adoption in the south and central zones under both irrigated and rainfed conditions and this became a ruling variety in many cotton-growing states for more than two decades. In recent years, ICAR-CICR released promising varieties with good fibre quality such as 'Subiksha' in 2018, 'Sunantha' in 2020. Another variety 'Suraksha' in 2021, which has a fibre quality of 32 mm length and has wider adaptability for south and central zones.A turning point in the Indian cotton breeding program is the release of the World's first hybrid (H 4) in 1970 which is of long-staple category with good uniformity and was developed at Surat in Gujarat State (Basu and Paroda 1995). This was followed by the release of the world's first interspecific 'Varalaxmi' hybrid (*G. hirsutum* x *G. barbadense)* spinnable to 80s count and was released from Dharwad in Karnataka State. An outstanding achievement was the release of the first *desi* cotton hybrid G. Cot DH 7 from Surat in 1984. This was followed by another improved *desi* cotton hybrid DDH 2 from Dharwad. Among the *hirsutum* varieties developed by ICAR-CICR, 'Surabhi' released in 1997 with good fibre length of 32 mm occupied large area in Tamil Nadu. 'Sumangala' was released in 2001 with a yield potential of 30q/ha under irrigated conditions. 'Suraj' a long staple variety with a high ginning out turn (40%) and high yield potential of 28-30 q ha-1 was released in 2008 and is still the most sought-after variety for organic cotton production in the south and central zone. Among desi cottons, interspecific *desi* cotton hybrid, G. Cot. DH 9 (*G. arboreum* x *G. herbaceum)* released in 1990 and high yielding *G. herbaceum* cotton genotype G. Cot. 21 released in 2001 proved to be well adapted to coastal areas of Gujarat. Bt cotton in India has proved to be a game-changer as its area witnessed a sharp rise after 2002 (Jayaraman 2002). The Genetic Engineering Approval Committee (GEAC) approved the commercial cultivation of three Bt cotton hybrids of Mahyco (MECH 12, 164 and 184) in 2002. Later, RCH-2 hybrid of Rasi Seeds was approved in 2004. Cotton area got a boost from 7.7 Mha area in 2002-03 to 13.3 m ha area by 2020-21 with >93% share of Bt cotton hybrids (ISAAA 2020) (Fig. 4). ICAR-CICR developed and released nine.

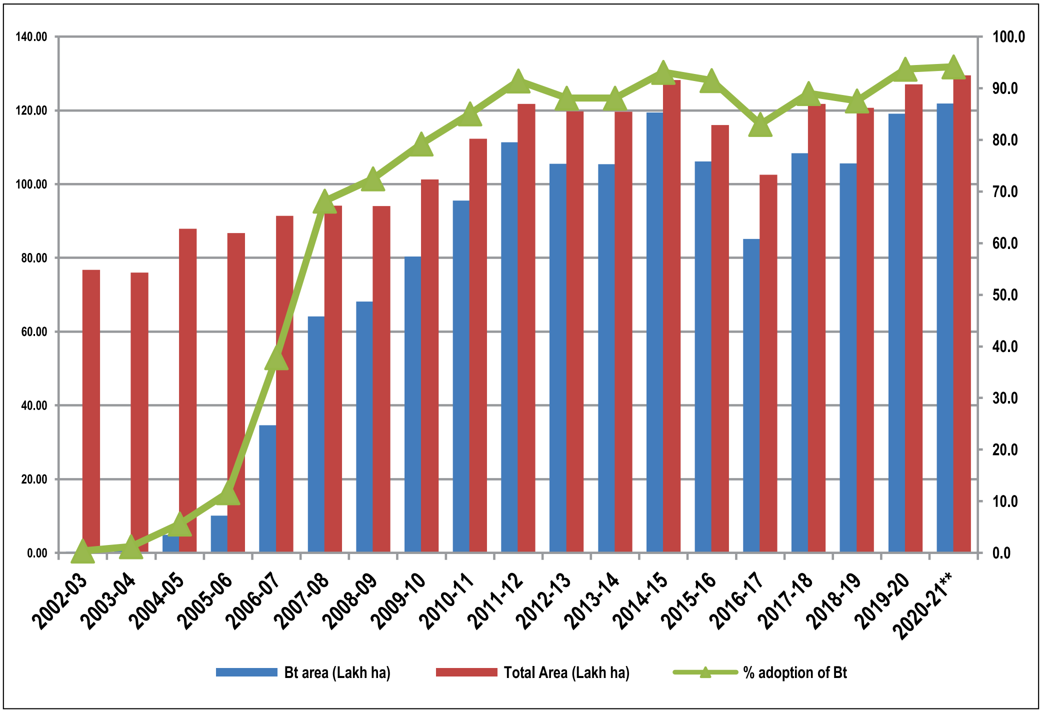

Fig. 4. Area under cotton and Bt cotton in India

Box 9: Great Adoption of Bt Cotton by Indian Farmers

The Bt cotton containing Cry 1Ac Mon 531 event that confers resistance to Lepidopteron pests of cotton, was commercialized in India in 2002 after stringent assessment for bio-safety and profitability studies. Subsequently, Bollgard II containing cry1Ac and cry2Ab MON 15985 event was approved in 2006. The area under Bt cotton increased from 0.29 lakh hectares in 2002-03 to 11.13 Mha (91.4% of the cotton area) in 2011-12 making Bt cotton unarguably the fastest technology adopted by Indian farmers. During 2020-21, around 12.29 Mha (94.1%) of the 12.95 Mha under cotton is under Bt cotton along with associated agro-techniques propelled India to become the world's largest producer and the largest exporter of raw cotton. The insecticide usage for the control of bollworms declined from 9410 metric tonnes in 2001 to 121 Mt in 2013 (Kranthi 2014). It also improved the socio-economic status of 6 million farm families.

Table 8. Milestones in cotton improvement

Year	Milestone
1950	Government launched Grow More Cotton Scheme.
1950	*Gossypium herbaceum* variety 'Jayadhar' released (cultivated even today).
1966	Establishment of Directorate of Cotton Development.
1967	Establishment of All India Coordinated Cotton Improvement Project.
1968	Finest quality *Gossypium hirsutum* variety 'MCU 5' 60 counts released.

Year	Milestone
1968	J34-a medium staple high yielding early maturing variety of Punjab (developed at PAU, Ludhiana) was a market reference variety for lint price fixation.
1970	World's first Hybrid 'H-4' released (highest yield with superior fiber traits).
1972	World's first Inter-specific tetraploid hybrid 'Varalakshmi' 80 counts released.
1974	Finest Indian variety ever of *Gossypium barbadense* 'Suvin' 120 counts released.
1976	Establishment of ICAR- Central Institute of Cotton Research, Nagpur.
1976	Bikaneri Narma and its selections 'F414' and 'H 777' identified for adaptability and high yields in North India.
1978	World's first GMS based hybrid 'Suguna' released from ICAR-CICR.
1980	Hybrid 'H-6' with superior fiber quality of 60 counts released.
1981	Inter specific tetraploid hybrid 'DCH 32' 80 counts released which is still cultivated.
1982	Highly adaptable *Gossypium hirsutum* variety 'LRA 5166' released (high adaptability).
1983	World's first Inter-specific diploid hybrid 'DH 7' released.
1983	Highly adaptable hybrid 'NHH 44' released for rainfed conditions.
1989	*Gossypium arboretum* variety 'AKA 8401' 40 counts released.
1992	Early maturing compact variety 'LRK 516' released.
2000	Launch of Technology Mission on Cotton with four other four sub-schemes.
2002	Bt cotton approved for commercial cultivation.
2010	Bt hybrid cotton occupies 90% area under cultivation.
2020	Release of Bt cotton varieties and Bt cotton occupies more than 93% area under cotton.

3.9. Jute

The raw jute sector supports the livelihood of around 4 million farm families and also provides direct employment to 0.37 million workers in organized mills and diversified activities in jute trading. India is the largest producer and consumer of jute and jute products. About 85% of jute production is consumed in the domestic market, mainly for sacking (Saha and Hazra 2008). Government of India, under the Jute Packaging Materials (Compulsory Use in Packing Commodities) Act 1987, has made it mandatory that 100% of food grains and 20% of sugar are to be packed in jute sacks produced of jute grown in the country. During 2019-20, the jute was grown in an area of 6.8 million ha with a production of dry fibres of 9.5 million bales (1.71 Mt) with the average productivity of 2.53 t ha^{-1}. In the year 1950-51, the country had around 0.57 Mha jute area with an annual production of 3.31 million bales of 180 kg each and productivity of 1.04 t ha^{-1}, which was insufficient to cater the need of the jute industries in the country. Up to early seventies, the increasing demand of jute fibre as raw material was satisfied through the increase in the acreage of the crop in the country. As a result, the area almost doubled from 0.57 M ha in 1950-51 to 1.08 Mha in 1970-71. The production of raw jute also almost doubled from 3.31 million bales in 1950-51 to 6.19 million bales in 1970-71. The productivity, however, stagnated around

1.05 t ha^{-1}. The jute area marginally decreased from 1.30 Mha in 1980-81 to 1.02 Mha in 1990-91 but the productivity increased sharply by almost 50% to 1.63 t ha^{-1}, leading to increased production of 9.23 million bales. The area further dipped by 17% during 2000-01 to 2010-11 but the production stabilized around 10.6 million bales. The credit goes to rise in productivity by 17% during the same period due to the introduction of new varieties in the production system supported with improved location-specific technologies.

After the partition of India in 1947, the major jute growing area went to East Pakistan (now Bangladesh), whereas the jute industries remained in the eastern part of India. The major challenge for Indian jute breeders was to develop varieties suitable for new areas having wider adaptation. After 1947, research on jute were carried out initially at Rice Research Station, Chinsurah, Hooghly of West Bengal from 1948-52. The Jute Agricultural Research Institute came into existence at Barrackpore, West Bengal during 1953 and was renamed as Central Research Institute for Jute and Allied Fibres in 1990. The concerted breeding efforts in post-independent India resulted in the development of 47 varieties of jute. The release and commercial cultivation of jute variety JRO 524 in 1977, converted the existing white jute area to tossa jute area. TJ 40 released in 1983, was the first commercial tossa jute variety developed through mutation breeding approach. Another milestone in 2004 was the development of MT 150 the first kenaf variety suitable for paper pulp. JRO 204, a high yielding tossa jute variety with premature flowering resistance and better fibre quality was released in 2007. JRO 524 and JRO 204 occupy more than 70 percent of the jute area of the country. Scientists from ICAR- CRIJAF in collaboration with ICAR-National Institute for Plant Biotechnology (NIPB) successfully accomplished whole-genome sequencing of *Corchorus olitorious* cv. JRO-524 (Navin) with a draft genome of 377.3 Mbp, which is a popular Indian tossa jute variety (Sarkar et al. 2017). This will pave the way to develop innovative varieties of jute using gene and molecular marker technology.

Table 9. Milestones in jute improvement

Year	Milestone
1948	Jute research in India started at Rice Research Station, Chinsurah, West Bengal.
1953	Jute Agricultural Research Institute came into existence at Barrackpore, West Bengal.
1954	First jute varieties JRC 212, JRC 321 and JRO 632 were developed.
1977	Development of tossa jute (*Corchorus olitorius)* variety JRO 524 (Navin), which is cultivated across India and replaced 90% *capsularis* jute because of high yield and shorter duration (120 days) and premature flowing resistance.
2007	Development of high yielding variety of *olitorius* jute JRO 204 (Suren), which replaced JRO 524.
2017	Whole Genome Sequencing of a leading Indian tossa Jute Variety JRO 524.

3.10. Fodder crops

The major cultivated fodder crops in India are sorghum, maize, bajra, cowpea in kharif season, and oats, lucerne, berseem in rabi season. Among the perennial crops Bajra-Napier hybrid, Guinea grass, perennial lucerne, perennial sorghum, Stylosanthes, Desmenthus are popular in different parts of the country. Twenty major fodder crops are cultivated in around 9.0 million ha which has almost remained static for the last 3-4 decades. An additional 48 m ha of wastelands and degraded soils, 12 Mha pasture lands have the potential to be used for increasing forage resources. Grazing-based livestock production is also vital as nearly 30 pastoral communities in hilly or arid/semiarid regions are dependent on these lands. The demand and supply scenario in fodder crops shows a deficit in both green and dry fodder, with varying estimates by different agencies. Recent estimate indicates 23% deficiency of green fodder and 14% of dry fodder (Roy et al. 2019) in India.

Forage Research gained momentum in post-independent India after the establishment of ICAR-Indian Grassland and Fodder Research Institute in 1962 and AICRP on Forage Crops in 1970. Since then, more than 210 varieties of fodder crops were developed and recommended for cultivation in different zones/ specific farming situations with focus on high yield, quality, biotic, and abiotic stress tolerance as well as the specific need of the zone/location and fitting in various cropping situations.

The lucerne improvement programme started in the late sixties resulting in many popular cultivars such as 'Chetak', 'Sirsa -9', 'Anand-2', 'Anand-3', 'RL-88' 'Co-3 and Co-4, etc. Variety Mescavi was the first release of Berseem as an introduction. At IARI, New Delhi, Dr M S Swaminathan and the group were successful in developing a tetraploid variety 'Pusa Giant Berseem' using colchicine-induced polyploids. At PAU, Ludhiana a series of varieties such as Bl-1, BL -2, BL 10, BL 42, BL 43, etc. were developed using introduction and mutation breeding which had a longer duration and provided extra cut of green forage. At IGFRI, varieties such as Wardan, Bundel Berseem 2, Bundel Berseem 3 were developed by selection/polyploidization. One single cut variety JBSC-1 developed by IGFRI was notified in 2019 with potential to fit in different cropping sequences. In Oats, Kent the most popular variety was released as an introduction in 1975 which became very popular. By combining the desirable attributes of sudan grass (*S. sudanense*) through hybridization, a superior hybrid variety of fodder sorghum SSG 59-3 was developed with low HCN content and good digestibility in 1978. In the early eighties, single-cut forage sorghum varieties, like PC-6, HC 136, MP Chari were developed with low HCN content and better quality. Perennial sorghum varieties COFS-29 and COFS-31 became very popular because of multi-cut nature, high yield, good quality and persistence. One composite 'African Tall' and another variety 'J 1006' were developed and became very popular to revolutionize the fodder maize for biomass as well as silage. Systematic efforts led to the development of several varieties of fodder crops. The current thrust is on the development of dual-purpose varieties suitable for intercropping with maize, sorghum as well as resistance to root-knot etc. Several varieties of apomictic perennial grasses were developed such as Marwar Anjan, Bundel Anjan 1, Bundel Anjan 3, Bundel Anjan-4 in *Cenchrus ciliaris*; Marwar Dhaman, TNCS 265, Bundel Dhaman 4 in *C. setigerus*; CAZRI 30-5, RLSB-10-5 in *Lasiurus sindicus*, Bundel Dhawalu Ghas 1 in *Chrysopogon fulvus*; Bundel sen ghas 1 in *Sehima nervosum*. PGG-1, PGG-9, Bundel Guinea 2,4, Co-3 in Guinea grass., Marvel-8, Marvel-09-4, JHD 2013-2 in *Dichanthium* annulatum. An interspecific hybrid between bajra and napier grass became the most popular fodder crop, now cultivated throughout India as it combined high quality and faster growth of bajra with the deep root system and multi-cut habit of napier grass. Concerted research work led to the release of several popular varieties. TNAU bred varieties such as CO-4, CO-5, CO-6, PAU bred NB-21, PBN 342, BAIF bred BNH 10,11,14, MPKV bred RBN 9, RBN 13 became extremely popular throughout the country.

Table 10. Milestones in fodder improvement

Year	Milestone
1962	Establishment of Indian Grassland and Fodder Research Institute, Jhansi.
1970	Inception of All India Coordinated Research Project on Forage Crops.
1975	The first forage cowpea variety Kohinoor was released.
1978	The first Oat variety "Kent" was notified.
1978	Forage Sorghum variety "MP Chari" was released.
1978	Fodder cowpea variety EC 4216 developed, erect type, suitable for intercropping.
1982	The ruling variety of Berseem "Wardan" was developed.
1983	BN hybrid grass variety BN hybrid-3 was developed.
1983	Fodder Maize variety "African Tall" was developed.
1985	Fodder Bajra variety "Giant Bajra" was developed.
1987	Multicut perennial Guinea grass variety PGG-9 (a hybrid between sexual clone x apomictic clone) notified.
1996	Perennial Lucerne variety "RL-88" was developed.
2001	First perennial Sorghum variety CO FS 29 was developed.
2004	First interspecific hybrid involving Berseem and other *Trifolium* species using embryo rescue reported.
2006	Oat variety JHO 2000-4 released with high protein (interspecific hybrid involving *Avena maroccana*)
2007	First Sen grass variety Bundel Sen ghas-1; First Dhawalu grass variety Bundel Dhawalu grass-1.
2007	Obligate sexual and apomictic interspecific hybrid between pearl millet and a new cytotype (2*n*=56) of apomictic Pennisetum *squamulatum.*
2008	First Bajra Napier Hybrid variety "CO-4" was developed.
2009	Developed the process for Ploidy manipulation in guinea grass utilizing a Hybridization-supplemented Apomixis-components Partitioning Approach (HAPA) leads to development of World's largest Ploidy series in *Panicum maximum* 3X, 4X, 5X, 6X, 7X, 8X, 9X and 11X.

Year	Milestone
2010	First tri-species hybrids (GOS) between *Pennisetum glaucum*, *P. orientale* and *P. squamulatum* developed.
2014	Bajra Napier Hybrid variety "CO (BN) 5" was notified as a ruling variety in India.
2019	First interspecific variety *Pennisetum glaucum* x *Pennisetum squamulatum* (BBSH-1); Dhaman grass variety Bundel Dhaman ghas-1 were released.
2021	First multi-cut summer forage Bajra varieties ADV0061 and HTBH 4902 released.

4. Way forward

4.1. New breeding strategies

4.1.1. Genome editing

Precise genome editing has great significance in crop improvement programs. Different crops have been benefitted by genome editing through the use of engineered nucleases *viz*., Zinc Finger Nucleases (ZFNs) mega-nucleases, Transcription activator-like effector nuclease (TALENs), and recently introduced Clustered regularly interspaced short palindromic repeats-CRISPR-associated system (CRISPR-Cas), etc. The rapid technological breakthroughs and examples of successful exploration for crop improvement have provided a great, novel, and valuable platform for biotechnologists, geneticists, and plant breeders to work in a team for greater gains in creating novel variability in traits of interest and eventually assisting in enhanced and sustainable crop production. The emphasis is being given to incorporate genome editing in crop improvement programmes. Recent advances in the development of a genome editing technique using CRISPR/Cas9 are providing hope for developing and cultivating new varieties of agricultural crops. The Government of India in its recent notification in 2022 provided the exemption to genome edited plants falling in the categories of SDN 1 and SDN 2, which are free of exogenous introduced DNA. This arrangement will accelerate the development of varieties using genome editing technologies.

4.1.2. Genomic selection

With the substantial reduction in cost and high throughput techniques based on single nucleotide polymorphism (SNP) enabled genotyping a large number of plants in a short time and has created the unique opportunity to harness the tools of genomics for enhancing the genetic gains at whole genome levels. Instead of following the traditional estimation of breeding value from phenotypes, the calculation of genomic estimated breeding value (GEBV) helps to select the best lines at different stages of the breeding programme. Genomic selection may be considered as an advanced form of MAS with high reproducibility and in this case simulation strategy is followed to predict the expected phenotype of progeny based on its genotype (Spindel et al. 2018). In our country, genomics-assisted breeding is yet to be started extensively. Few recent initiatives such as excellence in breeding (EiB) platform of a consultative group of international agricultural research (CGIAR) and Indian Council of Agricultural Research (ICAR) led consortium through financial support from Bill and Melinda Gates Foundation (BMGF). The consortium is aiming for the 'application of next-generation breeding, genotyping, and digitalization approaches for improving the genetic gain in Indian staple crops. However, the initiatives are still in the infant stage.

4.1.3. Accelerating the genetic gain through speed breeding

Food, fodder and fibre production needs to increase in the future in order to meet the demand of the increasing human population. The development of new improved cultivars with higher yield and resistance to major pests and diseases are needed quickly to meet the increasing demand. In order to accelerate the breeding program, the concept of recently developed 'Speed Breeding' method which uses environment controlled growth chambers that can accelerate plant development for research purposes, including phenotyping of adult plant traits, mutant studies, and transformation developed in wheat and other crops offers great scope for improvement in other crops as it can reduce the generation time, shorten the breeding cycle, enabling rapid development of advanced stable lines, mapping populations, screening for identification of donor sources for trait(s),hasten backcrossing and pyramiding of traits, mutant studies and faster development of improved cultivars (Watson et al. 2018, Fiyaz et al. 2020, Wanga et al. 2021).

Speed breeding increases the number of generations per year, instead of conventional breeding methods which usually take 10-15 years as only 1-2 generations could be grown per year for most of the crop species. Thus, it has the potential to reduce the time required for cultivar development, release and commercialization (Watson et al. 2018; Wanga et al. 2021). Speed breeding facilitates to grow six generations of rice, bread wheat, durum wheat, chickpea, barley, pea; four generations of Brassica species, and two generations of groundnut per year. In case of rice speed breeding through single seed descent (SSD) is a time and cost-effective breeding method where a single seed per line in a segregating population is only advanced to the next generation. These plants are then grown in the greenhouse where several generations can be completed within a short period. In India, speed breeding is still in a nascent stage and protocol standardization is undergoing in a few institutes like ICAR-IIRR, ICAR-NRRI, ICAR-IARI, and IGKV, Raipur.

4.2. Transgenics

Despite having single genetically modified (GM) crop released for the cultivation, India stands fifth in the world for area under transgenics. The single GMO crop, cotton is developed by incorporating genes from the *Bacillus thuringiensis*. The *B. thuringiensis* is a soil bacterium harboring a gene found to provide resistance against *Heliothis* bollworm insect pests of cotton. At present, GM crops are grown globally on 190.3 Mha. However, in other parts of the world, soybean transgenics are making the highest share in the world's total GM crop area (49.4%), followed by maize (31.3%), cotton (12.6%) and canola (5.3%) (ISAAA, 2020). The most frequently used GM traits in these crops included insect resistance and herbicide tolerance. In India, two GM crops Bollgard II-Roundup Ready Flex (BGII-RRF) cotton and mustard are under regulatory consideration. The Bollgard II-Roundup Ready Flex (BGII-RRF) cotton incorporating Bt as well as glyphosate-tolerant genes is developed by Monsanto. Whereas the transgenic mustard harbouring three alien genes that enable higher yields through hybridisation is developed by Delhi University's Centre for Genetic Manipulation of Crop Plants. Both the crops have undergone all the mandated bio-safety research and open field trials. Their commercial release is yet to be made. Besides, transgenics developed by public and private institutions are ready for field trials in other crops viz, castor, rice, maize, sorghum and sugarcane. Efforts need to be continued in the development of transgenics for achieving difficult objectives of crop improvement by harnessing new science. Once the regulatory considerations are fulfilled in each case, society will derive benefits from this novel approach of crop improvement.

4.3. Diversification and value addition

Currently, research efforts on the development of value-addition are gaining attention as there has been a continuous demand for such products by the consumers. India is known for its rich genetic diversity and improvement of the genetic potential and yield is the need of the hour while retaining the original key trait such as aroma, nutrition, and grain quality. Indian rice breeding is incomplete without mentioning basmati and other aromatic rice. While basmati rice has a special market in international trade earning annually to the tune of Rs 29,849 crores of foreign exchange. Aromatic short-grain rice has a niche for the domestic market; in addition, there are several types of specialty/coloured rice such as glutinous, chakuwa, joha, black, etc. in different parts of the country. Also, there is a demand for value-added products of rice such as beaten rice/poha rice in central India, puffed rice in southern and western India, Parboiled, red, and medicinal rice in Kerala, Sticky and black rice in the north eastern part of India.

4.4. Adaptation to climate change

In the present scenario to overcome the effect of climate change farmers have already begun to make adaptations to deal with the effects of climate change. The most common form of adaptation made by the farmers is the use of new varieties that can withstand the effect of climate change. Other forms of adaptation include the use of water pumps, adjusting planting times, using natural pesticides, using organic fertilizers, and altering cropping patterns. Further, mitigating and adaptation strategies such as intercropping, alternate wetting and drying, precise farming, improved tillage, and integrated farming system, are needed to mitigate the negative effects of climate change. Rice cultivation significantly contributes to climate change. Efficient strategies are required to limit the methane emission from the rice field. The application of anaerobic methanotrops to oxidize the CH_4 seems to be an effective approach. Similarly, the development of high-yielding and climate-smart rice cultivars by using different new breeding, genomic tools, and genetic engineering need to be priorities.

4.5. Partnerships & Linkages

Consortium approach involving public-private partnership for germplasm sharing and utilization is warranted. Similarly, sharing of advance breeding lines among breeders for desired traits can lead to the development of varieties suitable for different agro-ecological conditions. Deployment of appropriate cultivars based on systematic screening for tolerance to key biotic stresses at different hotspot locations through partnerships can help avert crop failures due to location-specific pests and diseases. Partnership programs for the dissemination of management strategies in various programmes have paid rich dividends in recent years. Linkages with NBRI, PPV&FRA, NBA, DBT, DST, APEDA, DAC, IMD, ISRO Remote Sensing Application Centres, and CGIAR institutes can go a long way in fostering research and development.

4.6. Policies

India has a constitutionally empowered National Food Security Act, 2013 to protect the poor and needy consumers from food deficit and food crisis. In the realm of flaring global prices, while taking into consideration, the need for ensuring food security in the country, the need of the hours is reformulating of policies so as to strengthen the efficiency in supply and demand sides in agricultural sector in India. This can indeed lead to faster growth and greater environmental sustainability of agriculture. The reforms in minimum support price (MSP) determination and implementation, decentralization of the revamped public distribution system (PDS), and introduction of food stamps, essential commodities and storage according to size of inventory of the processing units, etc may serve larger policy goals in the agricultural sector. The most important target is to reduce the costs of procurement, distribution, and storage operations. Achieving this goal will help to reduce the government's budgetary expenses to a great extent. Another important policy issue is de-linking of the procurement price from the MSP. The MSP, thought to provide protection against price risk at the harvest, should be decoupled from its primary purpose of augmenting the farmer income. At the same time, PDS could be slowly eliminated and to ensure food for poor expansion of a food coupon system can be implemented. The food coupon system will allow the poor to purchase food at the prevailing market prices. In the new regime of IPR, the exchange of genetic material for the research purpose should be made more liberal and very clear guidelines in benefit sharing to the partners. To sustain the food and nutritional security, support of the government as well as strong private industry is required in the form of strengthening both conventional as well as innovative breeding technologies.

5. Conclusion

In post-independent India, the development made during and after Green Revolution has transformed Indian agriculture from a 'ship-to-mouth' status in the 1960s to a 'right to food' situation at present. In today's scenario of food sufficiency, goal is shifted from cereal-intensive food security to nutrient-rich diet security to ensure nourishment and combat malnutrition. The goal of 'Zero Hunger' by 2030 can be achieved with sustainable development. Despite witnessing Green, Yellow, and Pulse Revolutions, and having attained impressive food production of 314.51 Mt in 2021-22, India has to continue advancement for increasing crop productivity to sustain food security. Newer methods of harnessing the heterosis, speeding up the breeding processes, and insulating crop varieties against diseases and insects are to be adopted for accelerating the genetic gains in staple crops. The priority is being given to improving the productivity and stability of rainfed crops like pulses, oilseeds, and millets, and more efficient and sustainable use of increasingly scarce land, water, and germplasm resources. Intensive research efforts are needed to make the crops nutritive and resilient to climate change. Considerable progress has been made in the basic understanding of natural phenomena. However, the acquired in-depth knowledge helping to understand the scientific facts is yet to be explored effectively for crop improvements. The gap between the advent of new techniques and their appropriate implementation is widening. Integration of different approaches and science branches seems to be an efficient way to close this gap. More notably, integrated omics approaches, available resources, data-centric intelligence, and translational and implementation strategies are being extensively employed for crop improvements. Continuously increasing the number of omics facilities like phenomics, proteomics, ionomics, and high-throughput sequencing in different Indian states indicates technological adaptation and capacity-building efforts in the country. Similarly, the development of speed breeding platforms for different crops is ensuring the demand-based timely delivery of crop breeding products. Efficient exploration of scientific development needs timely implementation of participatory approaches in research and strengthening well-structured extension activities. Equal participation of scientist, extension workers, and farmers are the far most important aspect for the verification of technologies and their sustainable implementation.

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Prime Minister Shri Narendra Modi visiting the plant phenomics facility at IARI, New Delhi

6
Chapter

Achievements in Horticulture in Independent India

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Summary

Horticulture has been a major contributor towards the substantial progress made towards food and nutrition security in India since Independence, the much noticeable after 2005. In the recent years, horticulture sector has become a driver of economic growth and slowly taking shape of an organized industry with key linkages to seed business, value-addition and export leading to job-full growth. Horticulture provides an opportunity for much needed diversification and intensification for adequate nutritious food and augmenting the income of the farmers. Horticulture research in India initiated in 1954, with the establishment of Division of Botany at IARI. Over years, several institutions and AICRPs were operationalized with the research agenda relevant to the national plans and priorities for dedicated development in horticulture. Today, horticultural research is conducted through 23 Institutes/Directorates/NRCs, 13 AICRPs and 6 Network Projects/Outreach programmes and is one of the most organized R&D setups in the NARES. The Horticulture in India comprises of diverse crops and commodities i.e., fruits including nut & plantation crops; vegetables including potato, tuber crops, mushroom; ornamental plants; spices, and medicinal and aromatic plants, honey bee rearing, bamboo, etc. has emerged as major alternatives for diversification and are contributing 31% to the agricultural GDP. Research on developing new varieties and management aspects of the horticultural crops over the past 75 years has contributed immensely to the growth of this sector. At present this sector is increasingly moving towards industries and commercialization, However, newer challenges such as Emerging pests and diseases, declining and degrading land and water resources, climate change, scarcity of water resources, natural calamities, high costs of agricultural inputs and transport, competing use of land and water and decline of investment in agriculture are emerging needing immediate action. Promotion of crop diversification in small-holder horticultural farming had been successful in many Asian countries and technology being size neutral effective technology transfer paid quick dividends.

1. Introduction

After independence in 1947, the immediate priority was to attain food self-sufficiency in staple crops like wheat and rice. The Green Revolution brought the food security through technological interventions and intensive use of inputs such as high yielding varieties of seeds, chemical fertilizers, pesticides and expansion of irrigation canal networks. During 1980-90, when gains of Green Revolution were plateauing and the luxury of area expansion under field crops gradually drying up, a vigorous search for alternative sources of growth in agriculture sector started. The high-value horticulture crops were identified as important source for growth in farm income. Accordingly, VIII Five Year Plan (1992-97) allocated Rs. 1000 crores for the first-time giving priority to this sector. This policy push has helped in achieving a compound annual growth rate (CAGR) of 4.82% in Horticulture, above the target of 4% set by National Agricultural Policy in 2000. Horticulture production increased 13-fold from 25 Mt during 1950-51 to 331 Mt during 2020-21 surpassing food grain production (Ministry of Agriculture, 2021). With 18% area, the sector contributes about 33% of the gross value added in the agricultural GDP. Currently, India is the second largest producer of horticultural crops next to China contributing 11.4 and 11.8% to world's fruit and vegetable baskets, respectively. India is the largest producer of ginger and okra amongst vegetables and ranks second in production of potato, onion, cauliflower, brinjal and cabbage. Amongst fruits, the country ranks first globally in production of banana (36.7%), papaya (43.6%) and mango (40.4%), ranks second in cashew and third in citrus. During 2020-21, India exported fruits and vegetables worth Rs. 9941 crores in spite of the global pandemic. This sector is being considered as a driver of economic growth and gradually turning into an organized industry with key linkages to seed business, value-addition and exports. It is also well established that horticulture is to play a key role in doubling the farmer's income along with meeting the much-needed nutritional security. It is strongly believed that the consistent and rapid increase in production and availability of horticultural crops shall over period of time translate into bridging the gap between the nutritional security of the country vis-à-vis global average.

2. Milestones in horticultural research

Systematic horticulture research in India was initiated in 1954, when the Division of Botany, ICAR-IARI was established for carrying out systematic research on fruit, vegetable and ornamental crops. Over years, several independent institutions and programmes were launched with research agenda relevant to national plans and priorities for the horticulture development including 10 Central Institutes, 6 Directorates, 7 NRCs, 13 AICRPs and 6 Network Projects / Outreach programmes. In addition, a few R&D establishments of crop/ commodity boards and private sector are providing research support to Indian horticulture. Other R&D establishments include CSIR (CIMAP, NBRI, CFTRI, RRLs), DBT, DRDO, IITs, BARC do conduct research of different horticultural crops. Besides, a large number of organizations have also been established to promote the horticulture development in the country by Govt. of India, which includes the National Horticulture Board, APEDA, NCDC, NAFED, NHRDF, SFAC, Bee Board, Coffee Board, Tea Board, Rubber Board, Coconut Development Board, Spices Board, Bamboo Board *etc*. Research and extension activities over the years led to development of many useful technologies in the field of crop management, release of varieties, plant protection schedules, post-harvest technologies and value-addition.

Table 1. Milestones in research and development of horticultural crops

Year	Milestone
1927	L-49 (Sardar Guava) Guava variety was released by GKFRS, Pune.
1942	Government of India Established the Coffee Board through Coffee Board Act-1942 under Ministry of Commerce and Industry at Bengaluru.
1947	Rubber Board was established under Ministry of Commerce and Industry through Rubber Board Act-1947 at Kottayam, Kerala.
1949	Central Vegetable Breeding Station at Kullu Valley was established, for seed production of temperate vegetable crops. Central Potato Research Institute initially established at Patna later shifted to Shimla, Himachal Pradesh in 1956. Kufri Ganga-late blight resistant, Kufri Neelkanth-purple colour and Kufri Lima-early, tolerant to hopper and mite burn are some promising varieties developed by CPRI.
1954	Establishment of Tea Board in Kolkata under Ministry of Commerce and Industry through Central Tea Board Act 1953.
1956	Division of Horticulture at IARI established.
1958	Coorg Honey Dew 1st gynodioecious variety of papaya was released. Establishment National Agricultural Co-operative Marketing Federation at New Delhi.
1963	Central Tuber Crops Research Institute was started at Thiruvananthapuram, Kerala for research on crop improvement in tuber and root crops. Sree Harsha, Sree Athulya and Sree Apoorva triploid and high yielding cassava varieties were developed.
1966	Directorate of Cashewnut and Cocoa Development was established at Cochin, Kerala. Establishment of Directorate of Arecanut and Spice Research at Calicut, Kerala.
1967	Establishment of Indian Institute of Horticultural Research at Bengaluru with major focus on fruits and vegetable crop improvement.
1968	AICRP on Tuber Crops was started for research networking and extension activities in root and tuber crops. Kufri Jyothi variety of potato was released for commercial cultivation, which is still grown on a large area.
1970	Division of Fruits and Horticultural Technology was created at IARI. Release of Pusa Seedless grape variety. Pomegranate variety Ganesh was released by GKFRS, Pune.
1971	Initiation of All India Coordinated Vegetable Improvement Project (AICVIP). AICRP on Fruits was initiated to work on mango, grape, citrus, banana, papaya and pineapple. AICRP on Floriculture was established to carry out nation-wide interdisciplinary research by linking SAUs with ICAR institutes. Later upgraded to Directorate of Floricultural Research. AICRP on Spices was initiated at IISR, Kerala.

Year	Milestone
	Mallika-1st regular bearing mango variety was released by IARI. 1st Public sector hybrid in vegetable crops Pusa Manjari and Pusa Meghadoot of bottle gourd were released for commercial cultivation.
1972	The Central Institute for Subtropical Horticulture (CISH) was started as Central Mango Research Station at Lucknow, Uttar Pradesh.
1973	First release of private sector hybrids in tomato (Karnataka) and capsicum (Bharat) to the farmers by M/s Indo-American Hybrid Seeds, Bengaluru.
1974	Central Plantation Crops Research Institute (CPCRI) was established at Kasaragod, Kerala. VTLAH1, VTLAH2 and VTLAH3 early, dwarf and high yielding arecanut hybrids were developed.
1977	Establishment of National Horticultural Research and Development Foundation by National Agricultural Co-operative Marketing Foundation at New Delhi.
1979	Amrapali-mango variety suitable for HDP was released by IARI
1981	Coconut Board was established through Coconut Development Act-1979
1984	National Horticulture Board (NHB) was set up by Government of India on the basis of recommendations of the "Group on Perishable Agricultural Commodities", headed by Dr. M.S. Swaminathan.
1985	National Research Centre on Citrus was founded at Nagpur. Parbhani Kranti variety of okra resistant to YVMV was released which revolutionized okra cultivation in India.
1986	Project directorate of vegetable research at IARI. Directorate of Cashew research was founded with headquarters at Puttur, Karnataka.
1987	Spice Board was constituted under Spice Board Act-1986 with Headquarters at Kochi, Kerala.
1992	PDVR headquarters was shifted to Varanasi from IARI New Delhi.
1993	Establishment of National Research Centre on Banana, Udhayam (ABB) variety was released in 2005
1994	Establishment of National Research Centre for Onion and Garlic at Nasik, later in 2008 upgraded as Directorate of Onion and Garlic Research and shifted to Pune. Central Institute for Temperate Horticulture was established at Srinagar, to carryout research activities in temperate horticultural crops.
1996	Establishment of National Research Centre on Orchids at Gangtok, Sikkim. Nematode resistant variety of tomato Pusa-120 was released.
1997	Establishment of National Research Centre on Grapes at Manjri, Pune. Manjari Medika and Manjari Naveen are some promising varieties were released in 2017.
1998	Centre for Protected Cultivation Technology was created IARI, to demonstrate technologies of protected cultivation in horticultural crops.
1999	Indian Institute of Vegetable Research was established at Varanasi, Kashi Krishna Black Carrot variety was released.

Year	Milestone
2000	National Research Centre on Seed Spices was established at Ajmer. NRC on Arid Horticulture was elevated to full-fledged Institute as Central Institute for Arid Horticulture (CIAH), Bikaner, Rajasthan. Maru Samridhi new Lasoda and Maru Gaurav new Karonda, Goma Kirti in Ber varieties were developed.
2001	Establishment of National Research Centre on Litchi at Muzaffarpur, Bihar. Gandaki Sampada and Gandaki Lalima are promising varieties released.
2004	Arka Kalyan onion variety was released by IIHR, Bengaluru.
2005	Establishment of National Research Centre on Pomegranate, Solapur, Maharashtra.
2006	To recognise the scope for development of horticulture in NE region, Central Institute of Horticulture was established at Medziphema, Nagaland.
2013	India's first triple disease resistant tomato F_1 hybrid Arka Rakshak was released for commercial cultivation.
2015	1st Biofortified variety of cauliflower Pusa Beta Kesari was released by IARI-RRS Katrain which is rich in β-carotene.
2017	Promising biofortified variety of pomegranate 'Solapur Lal' was released rich in Zn, Fe, Vit C and anthocyanins was released by NRC on Pomegranate. Biofortified Sweet potato Bhu Krishna (rich in anthocyanins), Bhu Sona (rich in β-carotene) were released by CTCRI-RRS Bhubaneswar.

The major landmarks of research in horticulture that supported the growth of the sector in this country include the following;

Advanced propagation techniques have been developed in case of fruit crops (tissue culture with virus indexing in banana (Selvarajan et al. 2011); shoot tip grafting, micro-grafting and micro-budding in citrus (Karunakaran et al., 2014) and potato (aeroponics) (Bag et al. 2015), that are helping in large scale production of disease-free (freedom from virus(es), viroids, bacteria, nematodes) planting material.

Canopy management practices have been standradized in different temperate, tropical and sub-tropical fruit crops. Rejuvenation technology for restoring production in old and senile orchards of mango, litchi, cashew, guava, ber and aonla has been standardized. High density planting technology of fruit crops has been standardized in mango (Ram et al. 1996), guava (Singh et al, 2005), banana (Biswas and Kumar 2010), citrus (Ladaniya et al. 2020), pineapple (Radha et al. 1990), pomegranate (Pal et al. 2014), papaya (Ranjan et al. 2018), cashew (Yadukumar et al. 2001) and coconut (Maheswarappa et al. 2013); employing dwarfing and semi-dwarfing rootstocks in mango (Reddy et al. 2003), citrus (Sonkar et al. 2002), guava (Sharma et al. 1992), litchi (Dhakar and Das 2017), apple (Rana and Bhatia 2003), canopy architecture modifications, understanding the rhizosphere dynamics and nutrient source–sink relations and use of bio-regulators, mechanization increased the farm productivity.

Standardization of tissue nutrient standards, micro-irrigation and fertigation techniques for better WUE, NUE and drought mitigation (Namara et al, 2007) have contributed to the improved farm productivity and profitability, besides improving cropping intensity in low rainfall regions. DRIS and tissue nutrient guides are available for different crops and locations, inter-cropping and multi-storied cropping systems have been proposed for coconut, arecanut, *ber* and *aonla*. Besides, Horti-silvi-, horti-pastoral, horti-agri etc.farming systems have also been developed to enhance farm profitability on sustainable basis.

Development of hybrid varieties and disease resistant vegetable varieties developed by ICAR like Kufri Jyothi and Kufri Chandramukhi of potato, Arka Rakshak in tomato, Pusa Mukta and Pusa Subhra cauliflower for black rot resistance, Pusa Sawani and Arka Anamika of okra, Pusa Sadabahar and Arka Meghana of chilli, Arka Manik of watermelon and Kashi Kanchan of cowpea have immensely contributed to environmentally safe management of diseases across the country. Out of 72 vegetable varieties identified during the last five years (2016-20) through AICRP (Veg) trials, 7 are resistant to important diseases, viz., tomato to ToLCV, brinjal to bacterial wilt, okra to YVMV and pea to powdery mildew. While, Pusa 120, Pusa hybrid 2 & Pusa Hybrid 4 have tolerance to rootknot nematode.

Genetic improvement for abiotic stresses, namely, in early cauliflower group variety Pusa Kartiki, Pusa Ageti cabbage, garden pea variety Arka Chaitra, low chill varieties of apple, peach and pear suitable for subtropical temperatures are under commercial cultivation. Salinity in grape, mango and citrus is being tackled using suitable rootstocks. Flooding tolerance in tomato has been induced using brinjal cv. Arka Neelkant as a rootstock and has been widely demonstrated. Recently, varieties have been developed in crops suitable for drought prone arid areas, viz., Kachari (AHK-119), Snapmelon (AHS-82), Khejri (Thar Shobha) and cassava (Sree Reksha, 8S501). Salinity tolerant varieties in sweet potato (Bhu Krishna, Bhu Kanthi, Bhu Ja, Bhu Swamy, Bhu Sona) have been developed. These efforts have brought marginal, waste and arid lands under cultivation.

Good Agricultural Practices (GAP) are now developed for perennial fruit and plantation crops, tree and seed spices and a variety of high-value medicinal and aromatic plants like safed musli, lemongrass, palmarosa, senna, anise, cardamom, cinnamon, saffron *etc*. Further, area under protected cultivation is also increasing due to sound technology development in several high-value, off-season flower and vegetable crops.

To reduce drudgery in farm operation several machines have been developed in farm mechanization, namely, pit digging, fruit harvesters, grading and cutting machines, driers, sorters and pulpers, which are now being commercially employed. Patents have obtained on different technologies for production of alcohol from cassava, cassava starch based biodegradable plastics, fermented cassava flour and hand operated cassava-chipping machine. Production technology for high yielding oyster, medicinal and blue oyster mushroom species have been standardized and commercialized.

For export promotion, post-harvest produce handling protocols have been developed in different commodities. A low cost environment friendly cool chamber was developed for on farm storage of fruits, vegetables and flowers. A number of value-added and novel products have been developed in coconut, mango, guava, jackfruit, aonla, litchi, different vegetable crops, potato, tuber crops, mushroom etc.

3. Salient achievements in important horticultural crops

In general, horticultural crops are prone to natural vagaries and emerging pests and diseases. Salient research achievements in overcoming few of these production challenges and gains obtained through research in meeting market demand are given below.

3.1. Fruits

3.1.1. Commercialization of Amrapali and Mallika: Hybrids which changed the contour of mango farming

Fruits of Amrapali variety of mango in farmers' field.

Amrapali – a unique mango hybrid (Dashehari x Neelum), is precocious, distinctly dwarf, highly regular and prolific bearer was released in 1979. It is suitable for high-density planting owing to its dwarf stature. Mallika is semi-vigorous and hence can be planted at 6-8 m spacing. Amrapali responds well to pruning and thus is ideal genotype for establishing high-density orchard. The current acreage under this variety is over 2,00,000 ha in the country, besides it is being commercially grown in several neighboring countries like Bangladesh, Nepal and Bhutan. It has the highest area of over 73,000 hectares in Odisha spread in eight districts of which prominent are Keonjhar, Dhenknal, Angul and Kashipur Block of Raigada. The other prominent states growing Amrapali are West Bengal, Jharkhand, Bihar, Uttar Pradesh, Madhya Pradesh, Uttarakhand and Tripura. Farmers in Odisha have registered this mango as '***Udyan Fresh***' and since 2012 are regularly marketing their produce in Azadpur Fruit and Vegetable *Mandi* in New Delhi. In West Bengal, it is occupying an area of 15,000 ha. in the tribal districts of Bankura, 24 Parganas, Malda, Murshidabad, Purulia, Birbhum, etc. In Bankura, a Tribal women SHG has established 1,500 ha during last 10 years to achieve livelihood security of 150 Shabar tribe members where over 500 orchards have been raised through MGNREGS since 2010. They are now even exporting the quality produce to Bangladesh and Nepal. Similarly, in Jharkhand it is grown commercially in the districts of Ranchi, Simdega, Gumla, Latehar, Hazaribagh, Dumka, Sahibganj and Godda. The present estimated area under Amrapali is about 23,000 ha. During 2019, the farmers associated with PRADAN -an NGO sold Amrapali worth Rs. 20 crores.

Fruits of Mallika variety of mango.

In 1971, a hybrid Mallika (Neelam x Dushehari) was released. It is is semi-vigorous and hence can be planted at 6-8 m spacing. The fruits of Mallika are big (300 g) and have good pulp content 72%. Fruits are sweet (TSS 24^0Brix), fibreless firm pulp with appealing flavour and good shelf-life (6-8 days). Mallika is semi-vigorous and hence can be planted at 6-8 m spacing. At present its area in the country is over 45,000 ha with maximum area in Karnataka (20,000 ha) followed by West Bengal (8,000 ha), Gujarat (5000 ha), etc. Karnataka is exporting fresh Mallika mangoes to the USA, parts of the European Union, UAE, Kuwait, Japan, Malaysia, Singapore and South Korea, while Gujarat is exporting it to EU countries along with Kesar.

3.1.2 Dogridge rootstock of grape

The grape rootstock Dogridge (*Vitis champinii*) was developed to overcome the adverse effects of drought and salinity, but also to improve the yield and quality of major commercial scion varieties. In addition, the raisin recovery from the grapes harvested from the vines grown on Dogridge rootstock is higher to the tune of 25% compared to own rooted vines. Yield gain was in the range of 5-10%, while reduction in cultivation costs was in the range of 10-15% across major grape growing regions of Maharashtra and Karnataka. There were other intangible benefits such as improved quality of the berries and reduction in the total water requirement for the crop. Today, more than 90% of the area under grape cultivation in India is on Dogridge rootstock. Employing this rootstock, training to Y trellis, developing sub-canes and proper scheduling of growth regulators have increased BC ratio both in domestic and export grapes to the extent of 2.3:1 and 5.26:1, respectively. Employing Dogridge rootstock, training to Y trellises, developing sub canes and proper scheduling of growth regulators has increased the productivity from 10-11 t ha^{-1} during 1990-91 to 22 t ha^{-1} during 2018-19. The total value of grape crop raised under this technology currently is Rs 9,456.0 crores. Exports of fresh grapes earned a foreign exchange of US$ 334.91 million (Rs. 2,335 crores) while exports of raisins earned US$ 26.217 million during 2018. Nearly 90% of these exports are based on the fruits obtained from grapes cultivated on Dogridge rootstock.

Grape crop raised on Dogridge rootstock, training to Y trellis, developing sub canes and timely scheduling of growth regulators

3.1.3. Improved varieties and crop regulation technology of pomegranate

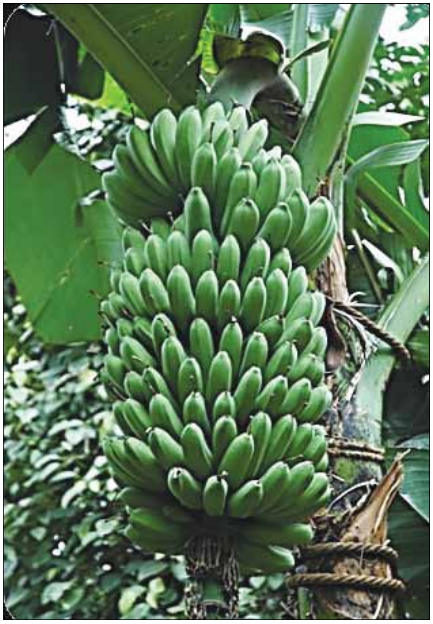
Fruits of Bhagwa variety of pomegranate.

MPKV, Rahuri has developed Bhagawa and Super-Bhagwa, which were tested under AICRP Arid zone fruits and found to be superior over existing varieties like Ganesh and Arakta both in terms of yield and fruit quality. It has recorded in case of Bhagawa that a higher fruit weight (320.6 g) with attractive bright red colour of fruit rind in comparison to ruling variety Ganesh (297.80 g). It possessed a higher mean weight of aril per fruit (220.80 g) and higher Juice recovery from 100 arils (27.6 ml) compared to Ganesh (23.60 ml). It is the most widely adopted pomegranate variety in the country. Recently, a biofortified variety Solapur Lal possessing higher contents of iron, zinc and vit C has been developed (Saroj and Kumar, 2019). Bhagwa has replaced the earlier ruling high yielding variety Ganesh. The popularity of this variety and its impact can be witnessed through tremendous increase in pomegranate area under cultivation (122.91%), production (279.15%), productivity (70.12%) and export (382.17%) as compared to those of 2003-04. Today more than one lakh families are earning livelihood from this variety in India. Further, employing crop regulation during *mrig*, *hasth* and *ambia* bahar has ensured availability of pomegranate fruits throughout the year. Management strategies for major diseases like bacterial blight disease and wilt complex of pomegranate have been instrumental in popularizing this crop.

3.1.4. Improved varieties and agronomy of banana

Several new varieties bred with a specific biotic or abiotic stress tolerance have become popular leading to wider adoption and increased production of this crop over years. For example, popular varieties like Kaveri Haritha are tolerant to *Fusarium* wilt (Foc race 2), Kaveri Saba is a drought tolerant variety and suitable for cultivation in saline sodic soils (pH ranging from 8.8 to 9.0) and Kaveri Kanya is tolerant to Foc race 1. Further, unique landraces, namely, Manoranjitham and Hill bananas, which were nearing extinction in the natural habitats were rejuvenated. Facilitated Hill Banana Growers Federation in acquiring GI tag for the Hill bananas (Virupakshi and Sirumalai) (Rani and Kumar 2013).

A slight reorientation of planting geometry using optimized clump management coupled with fertigation increased 40% plant population per unit area resulting in 30% increase in productivity and 25% reduction in water and fertilizer inputs. The B:C ratio increased from 2.5:1 to 3.5:1. Over the past decade, this technology has spread to 2.0 lakh ha (>30% of total area) in states like Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh and Tamil Nadu.



Superior quality bunch of banana.

During the past three decades, the area and production has increased substantially in banana and India has emerged as the largest producer of banana in the world meeting the domestic demand and nutritional security. The main impact of improved varieties can be seen as increase in the national acreage by 7.5%, production by 6.8% and productivity by 17.2% of banana in the country, which has put the nation in top slot contributing to 21% of the total banana produced in the world with an annual business of more than Rs. 60,000 crores. Recently, India's export in banana is steadily increasing with the help of technology awareness. ICAR-NRCB under the PPP mode along with APEDA has successfully accomplished the export of Nendran. Further, Sea protocol for long distance transport of traditional bananas like Nendran and red banana have been standardized.

3.1.5. Temperate horticulture

In India, temperate horticulture crops are grown in Himalayan states in the north and north-east. It plays a vital role in providing nutritional and economic security of the region. Horticulture in these states forms the backbone of economy by providing direct or indirect employment to about 8-10 million people and generating revenue to the tune of Rs. 10,000 crores annually.

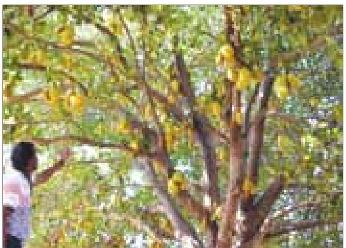
Among temperate horticultural crops, apple, pear, peach, plum, kiwi fruit, apricot, cherry, almond and walnut in fruits are important with apple, walnut and pear sharing major area, while in vegetables, temperate cultivars of cole crops, bulb and root crops; capsicum, peas, high value leafy vegetables like lettuce, parsley, celery, Chinese cabbage *etc*. are commercially cultivated in India. In floriculture, tulip, lilium, alestromaria, carnation and gerbera and in medicinal and aromatic plants, *Lavender*, *Lavendine*, *Geranium*, *Dioscoria*, *Podophyllum*, *Pyrethrum*, *Mentha*, *Artemisia* etc. are becoming increasingly significant in the recent years. A very high value and low volume crops like saffron and *kala zeera*, which are exclusively grown in this region, too are commercially important.

Other research achievements that have transformed horticulture in these regions include: High Density Plantation in apple increased the productivity from 10-15 t ha^{-1} to 50-60 t ha^{-1} with better quality produce; Intensive saffron production technology enhanced the productivity of from 2.5 to 7.5 kg ha^{-1}; New walnut varieties have enhanced yield (4 t ha^{-1}) and have better quality with high export potential.

3.1.6. Exploring natural diversity and promoting custodian farmers

Natural populations of cross-pollinated fruit crops are highly heterogeneous in nature resulting in a considerable variation in their yielding abilities, fruit quality and maturity parameters. This provides enough opportunity for clonal selection of promising strains for diverse purposes. ICAR has been making efforts to link such native fruit biodiversity to livelihood security- empowering the custodian farmers. Jackfruit variety 'Siddu' and tamarind variety 'Ravindra' have proven success of this strategy. Due to this effort, about 75% of the earning would go to the custodian farmer(s) providing them additional livelihood security.

Tamarind farmer's variety Ravindra



Tree and arils of farmer's variety Siddu jack fruit

3.1.7. Indigenizing oil palm

A bearing tree of oil palm under Indian conditions

Oil palm is likely to play a major role in the future in augmenting the supply of vegetable oil in the country as it is the highest oil yielding perennial crop. Looking at its potentiality, Government of India has been promoting this crop in order to bridge the gap between consumption and domestic production of edible oil. In comparative terms, yield of palm oil is 5 times the yield of edible oil obtainable from traditional oilseeds. ICAR has provided technological impetus with improved varieties, good planting material, irrigation and proper management strategies. Three tenera hybrids with high oil yield were developed that are being cultivated in Andhra Pradesh, Tamil Nadu, Maharashtra and Goa with yield potential of 7-8 t oil ha^{-1} yr^{-1}. Recently, dwarf high yielding hybrids with production potential of 6-7 t oil ha^{-1} yr^{-1} have also been developed. Five new seed gardens have been established in Andhra Pradesh, Karnataka and Mizoram with annual production potential of 35 lakh sprouts. Further, technology for oil palm hybrid seed production was standardized to produce quality tenera hybrid seeds. With all these efforts, oil palm has spread to an area of 3.31 lakh ha in 15 states by 2019.

3.1.8. Technology-led import substitution

As per the statistics of Seednet, GoI, 2019, India imports 7 lakh apple, 1 lakh Kiwi, 2 lakh date palm and 1 lakh oil palm planting material every year. Therefore, ICAR has been laying stress in technologies to substitute this import. To that effect, low chill apple and peach varieties have been developed; technologies for cultivation of exotic fruits like walnut, durian, kiwi, dragon fruit, passion fruit, avocado, etc. have been standardized and are being commercially adopted, multiplication technology for date palm has been developed and oil palm hybrids suitable for our subtropical regions have been bred. Similarly, in flower crops, varieties suitable for polyhouse cultivation of rose (Arka Swadesh,) and gerbera (Arka Pink) have been bred to substitute imported planting material saving the cost of production.

Artificial LED lighting for off-season production of dragon fruit

3.1.9. Post-harvest management of mango enhanced income of tribal farmers of Odisha

Post-harvest treatment of mango and their marketing after packaging

In eastern tropical regions of India, mango is the leading fruit crop and shares about 1/5th of total area and production of mango. Among eastern Indian states, Odisha covers the largest area under mango (2.1 lakh ha) but its productivity is the lowest (4.0 t ha^{-1}). Mango is also being cultivated by tribal farmers of Odisha, however substantial post-harvest loss (20%) primarily due to improper ripening, fruit fly infestation, and post-harvest diseases like anthracnose and sooty blotch causing huge economic loss to growers. ICAR started a training and handholding the farmers of the region. Proper adoption of post-harvest protocols, grading, packaging, and transport in suitable containers substantially reduced post-harvest losses (5-10%), while increasing shelf life and fruit quality. These interventions led the tribal farmers to enhance their income by 25-30%. Tribal growers could realize higher value for their produce with a net profit of Rs. 40,000/- from one-acre mango cultivation.

3.2. Vegetable crops

3.2.1. Arka Rakshak, F_1 Hybrid of tomato

Bumper pesticide free production of Arka Rakshak production in Karnataka and NE states

The production potential of this crop is generally challenged by Tomato Leaf Curl Disease (ToLCD) transmitted by white fly (*Bemisia tabaci*), bacterial wilt (*Ralstonia solanacearum*) and early blight. At times, these diseases are capable to incur economic yield losses up to 70-100%. To address this major problem, ICAR has bred a triple-disease (ToLCV + BW + EB) resistant tomato F_1 hybrid, Arka Rakshak. The hybrid has enormous yield potential (19 kg/plant; potential yield of 100 t ha^{-1}). The fruits are firm, medium in size (75-80 g) with attractive deep red in colour. Besides, the excellent keeping quality (15-20 days) makes it an unmatchable choice for long distance markets. This hybrid has been adopted in 26 states across the country covering an estimated area of 7,720 hectares. Many farmers have recorded a crop yield of 19 kg per plant (100 t ha^{-1}) through adoption of precision farming methods and have even realized a net profit of Rs. 20 lakhs per acre. On an average tomato grower in the country have realized a net profit of Rs. 3 to 5 lakhs per acre.

3.2.2. Improved varieties of potato

ICAR-CPRI has released 66 potato varieties for different states/ regions, which presently cover 80-85% of the total potato production of the country and successfully adapted a temperate crop to its present form of sub-tropicalization. Four varieties, *viz.* Kufri Jyoti, Kufri Bahar, Kufri Pukhraj, and Kufri Chipsona 1 together contribute around 75% of total area under potato in the country. Over the years the variety yields increased from 20-25 t ha^{-1} (Kufri Jyoti, Kufri Jeevan of 1960's) to 35-40 t ha^{-1} in recent varieties along with special traits like resistance to diseases and pests (Kufri Sahayadri is highly resistant to potato cyst nematode and Kufri Karan resistant to late blight, viruses: PALCV, PVY, PVX, PLRV, PVA, PVM & potato cyst nematode), abiotic stresses (Kufri Thar-3 which is drought tolerant: 20% water saving) and biofortification (Kufri Manik is rich in micronutrients like Fe and Zn along with s and carotenoids).


Aeroponic multiplication of potato seed tubers

Traditional seed production system has the limitation of repeated exposure of initial disease-free seed stocks to soil and insect pests which results in accumulation of pathogens accompanied by deterioration in quality of produce by the time it reaches the end user. Therefore, ICAR-CPRI developed a programmed air mist-based potato culturing technique based on aeroponics technology. It shortens the span of quality seed production by 2 years. The aeroponic system technology has revolutionized potato seed industry in the country. The institute has licensed this technology to several private firms like Shekhon Biotech, Bhatti Farms, Sandhu Farms, Siddhi Vinayak Agri, Sun Grow Seeds etc., to produce one million mini-tubers by aeroponic system. After four successive multiplications, it shall make available 70,400 tons of seed potatoes in addition to the conventional system.

3.2.3. Improved processing varieties of horticultural crops

Total post-harvest losses in fruits and vegetables as per the recent ICAR studies ranges from 6 to 16% (excluding losses in retailing). Presently, only 2.2% of fruits and vegetables are processed in the country. India's exports of processed fruits and vegetables were Rs. 7,373.77 crores in 2018-19 (APEDA) suggesting a huge potential in future. Thus, processing sector is being seen as a game changer to reduce post-harvest losses, for price stabilization, value addition and to tap foreign markets. ICAR has been working to develop varieties that are suitable for processing in various crops. Recently two hybrids of tomato (Arka Apeksha and Arka Visesh) suitable for ketchup and paste; onion variety Arka Yogith suitable for dehydration; potato variety Kufri Frysona suitable for French fries; turmeric variety IISR Pragati for cucurmin extraction; pomegranate variety Solapur Anardana suitable for anardana preparation; grape variety Manjari Medika suitable for juice making have been developed. Demand for processing quality potato increased from 0.97 to 2.68 million tons during 2005-06 to 2010-11. Potato farmers are estimated to have earned additional Rs. 342 crores during these five years because of growing processing potatoes. Gross and net income for Kufri Chipsona 1 was higher than the average of potato farm by 22 and 30%, respectively and the benefit-cost ratio of Kufri Chipsona 1 was 1.91, while it was 1.61 for the average of all potato varieties grown on the farmers' fields in UP. Kufri Frysona variety has strengthened the French fries chain in collaboration with M/s. McCain's Food India Pvt. Ltd., Gujarat.

3.3. Flower crops

3.3.1. Arka Prajwal, a high yielding tuberose variety

ICAR-IIHR has developed this high yielding single floret type variety possessing white flowers with pinkish tinge on buds. The individual flowers are bolder compared to local single variety. The average loose flower yield of this hybrid is 17 t ha^{-1} $year^{-1}$ and is about 49% higher than the existing local variety. The flowers have a better shelf-life (7 days) compared to other varieties (4 days). It is a dual-purpose variety for both loose and cut flower. It has great potential and demand in market as loose flower, cut flower and for concrete extraction. It is estimated to occupy 38% of the total tuberose area in the country (2006-2016).

3.3.2. Floricultural exports

The transformation of Indian floriculture from pushcart transportation to chartered flight transportation is phenomenal. During the year 2018-19, India exported floricultural products worth Rs. 571.41 crores (APEDA 2020). Floricultural exports from India comprises of fresh cut flowers (to Europe, Japan, Australia, Middle East and USA), loose flowers (for expatriate Indians in the Gulf), cut foliage (to Europe), dry flowers (to USA, Europe, Japan, Australia, Far East and Russia) and potted plants (limited to very few countries).

A farmer in Karnataka reaping the benefits of tuberose variety, Arka Prajwal

Specifically, an improved packing technology for jasmine with thermocole packaging with gel ice and aluminum foil lining was developed, which has reduced the post-harvest losses from 30 to 10%, the shelf-life of flowers has increased up to 72 h and the flower colour has been retained for longer time. The technology played an important role in promoting the export of jasmine flowers to different markets.

3.4. Spices, plantation and tuber crops

3.4.1. Turmeric varieties with high curcurmin content

Varieties possessing high levels of curcumin, viz., IISR Sudarshana (7.9%) IISR Prathibha (6.2%) and IISR Alleppey Supreme (6.0%) compared to earlier varieties Suvarana (4.0%) and Suguna (4.7%) have been developed providing incremental consumer value.

3.4.2. Improved varieties, agronomy and value-addition in plantation crops

The coconut, arecanut and cocoa are important plantation crops of India, influencing the livelihoods of over 25 million people in the country. They also support the national agrarian economy, with an annual contribution of Rs. 14,200 crores to the national GDP and foreign exchange earnings of about Rs. 2,440 crores. ICAR-CPCRI is custodian to the world's largest germplasm on coconut, arecanut and cocoa. ICAR-CPCRI hosts International Coconut Gene bank for South Asia (ICG-SA). Root (wilt) disease caused by phytoplasma is causing debilitating conditions in coconut in southern parts of Kerala. Tolerant varieties such as Kalpa Raksha, Kalpa Sree and Kalpa Raj as well as Kalpa Sankara hybrid could produce economic yield through integrated management practices.

High-density multi-species cropping systems of coconut and arecanut with high-value intercrops are capable of producing 1.5 to 3-fold income from the farming. Coconut-based cropping system, using multi-species cropping of coconut with pepper, banana, nutmeg, pineapple, ginger, turmeric and elephant foot yam generated a net income of Rs. 3.7 lakhs ha^{-1}, which is 150% higher than that of coconut monocrop (Rs. 1.4 lakhs). Arecanut-based cropping system with cocoa, banana and black pepper as component crops generated net returns as high as Rs. 8.8 lakhs ha^{-1}, which is 132% higher than that of arecanut monocrop (Rs. 3.80 lakhs).

ICAR-CPCRI has commercialized the protocol for hot and fermentation processing of Virgin Coconut Oil VCO. Another beverage from coconut is the inflorescence sap, popularly known as '*neera*'. Technology for the collection of unfermented coconut sap has been developed referred to be *Kalparas*. Value-added products such as *Kalparasa* and coconut sugar, virgin coconut oil, extruded products from coconut, snow ball tender nut, coconut chips and vegan coconut delicacy, coconut sugar based dark chocolate and drinking chocolate could make the sector profitable and small enterprise friendly. It has been demonstrated that a farmer tapping 15 coconut palms for *Kalparasa* could earn on an average net profit of Rs. 45,000 a month, while a tapper can earn about Rs. 20,000 per month.

3.4.3. Improved tuber crop varieties

About 40% of the total area of cassava in the country is under improved varieties *viz.,* H-226, H-165, Sree Apoorva, Sree Athulya, Sree Pavithra, Sree Swarna, Sree Jaya, Sree Vijaya and Sree Reksha, which have spread to the states of Tamil Nadu, Andhra Pradesh, Kerala, Telangana, West Bengal and North Eastern states. The overall economic impact of the adoption of improved varieties has been estimated to be Rs. 10,005 million per annum. Similarly, area under improved varieties of sweet potato, *viz.,* Kishan, Sree Kanaka, Bhu Sona, Bhu Krishna, Bhu Swami, Bhu Ja, and Bhu Kanthi, was 23% and the economic impact was calculated at Rs. 2608 million per annum. Varieties have spread in the states like Odisha, Uttar Pradesh, Karnataka, Kerala, Andhra Pradesh, West Bengal and North Eastern states. These improved varieties are high yielding, resistant to various biotic, abiotic stresses and also rich in nutrition (β-carotene more than 8-14 mg/100 g, anthocyanin content of 80 mg/100 g). Besides additional income, they are contributing towards household food and nutritional security.

3.5. Mushrooms

Presently, India contributes about 0.4% of the total world production of mushrooms and productivity in the country has almost doubled, while production has registered a more than 36-fold increase during last decade. Several promising varieties of cultivated mushrooms were released by ICAR in button mushroom, paddy straw mushroom, *shiitake* mushroom, milky mushroom, oyster mushroom and macrocybe mushroom. Among them, the first non-browning button mushroom variety, DMR-NBS-5 is widely accepted across the country contributing 32% of the total button mushroom production in the country.

3.6. Pest and disease management in horticultural crops

3.6.1. Disease forecasting and management strategies for potato late blight forecasting

Late blight is the most devastating disease of potato because of its fast spread resulting in wipe out of entire crop in a few days if proper preventive measures are not adopted. The average losses caused by late blight have been estimated to the tune of 15% annually. A computerized late blight forecasting system known as JHULSACAST (Singh et al., 2000) was developed for Uttar Pradesh for forecasting first appearance of late blight. It has predicted appearance of the disease before its actual appearance in UP during the last 13 years. Studies have shown that prophylactic fungicide sprays help in protecting the crop with a minimal crop loss (<10%) using recommended spray schedule even in epiphytotic years as against 30-40% losses in crop that was not protected prophylactically. ICAR-CPRI has developed a pan-India late blight forecasting model named Indo-Blightcast. The expected reduction in crop losses by the use of Indo-Blightcast (Singh et al. 2016) in last five years would have been 35.8 million ton of potatoes valued at Rs. 3580 crores (@ 7.16 Mt annually).

3.6.2. Environmentally safe management of biotic and abiotic stresses in horticultural crops

Pesticide residues have always been a major concern in horticultural crops. However, of late, focus is on novel techniques to manage these stresses. RNAi based nanoclay dsRNA formulation has been developed against late blight of potato and management of potato cyst nematode. *In vitro* bio-immunization technology for *Fusarium* wilt TR4 tolerant banana has been successfully demonstrated. Biopriming for protecting ginger seed rhizomes has been patented. Vegetable grafting to avoid soil-borne diseases such as bacterial wilt in tomato, nematodes in capsicum and *Fusarium* wilt in watermelon have been developed. Traps have been designed for invasive pests like *Tuta* in tomato. Diagnostics kits like dip sticks (Lateral flow immune-strip) for BBrMV and CMV in banana (Selvarajan et al. 2020), lateral flow technology for potato viruses, NASH detection for Banana Bunchy Top Virus/ Banana Streak Virus and Real-time LAMP assays for viruses in spices have been developed. UAV & AI technologies are now being used for pest & disease surveillance/ management especially for detecting damage symptoms of rhinoceros beetle, leaf eating caterpillar, root (wilt) disease and sooty mould associated with spiraling white fly infestation of coconut and other plantation crops. Bio-pesticides like ICAR-FUSICONT with strains of *Trichoderma* and *Pseudomonas* for management of panama wilt of banana and nutrient solubilisers like Arka Microbial Consortium for better nutrient mobilization and *Penicillium pinophilum for* potash and phosphorous solubilization developed for pomegranate have been commercialized. In addition, food safety and referral laboratories have been established in major horticultural institutes to monitor pesticide residues.

4. Way forward

The horticulture sector is plagued with some persistent problems like unavailability of quality planting material; threats of emerging insect pests and diseases and nutrient deficiencies; increased frequency of abiotic stresses like salinity and drought, flooding, hailstorm and high temperature; lack of post-harvest handling along with processing infrastructure. Poor processing and lack of storage infrastructure is a deterrent for farmers as prices crash in glut season; insufficient investments and absence of organized and regulated marketing system, besides, conventional handling of horticultural produce are other drawbacks, which result in poor and uncertain monitory returns to the growers.

Further, from food shortage to food surplus, India endeavors to create revolution in horticulture. Horticulture has emerged as an important business opportunity for growers, processors, retailers and exporters. Under these circumstances, we need to look for disruptive technologies to deal with the challenges of future. Research that enables growers to adopt innovative practices and technologies, lowering the costs of production are the need of the hour. Cost reduction can be achieved through deployment of novel technologies, which allow more efficient use of inputs, including water, nutrient, energy and labour. The power of artificial intelligence, unmanned aerial vehicles, GIS and remote sensing should be pursued for inducting precision in farming, smart agro-engineering tools and gadgets to enhance efficiency of nutrient and water use, plant protection interventions and to develop location-specific precision farming regimes. Promotion of weather-resilient crop varieties, vigilant bio-security system and strengthening climate risk information should be accorded top priority to minimize crop losses because of natural disasters. Emphasis on use of renewable and alternate energy sources, application of sensors and nano-technologies, safe and natural farming in identified agro-ecological zones for efficient resource management, intensive and alternate production systems like vertical farming. Genome sequencing initiatives in ICAR of major crops like mango, coconut, pomegranate, oil palm and potato shall come handy in their breeding efforts. Challenges are for brining precision in crop improvement using Omics and Gene Editing tools, production systems with more application of use of AIs, space and GIS technologies too.

5. Conclusion

To achieve the greatest impact from investments in research and innovation, there is a need for coordinated strategic approach by all stakeholders to achieve a balance of both short- and long-term goals. It is expected that current research programs of ICAR would lead to a technology driven growth for safe production of nutritious food, better environmental and nutritional security, higher profitability and self-reliance in horticultural crops and thereby rise to make India *Kuposhanmukt* and *Atmanirbhar*. Besides, this sector has enormous potential for meeting much needed eradication of problems of rural poverty, unemployment, livelihood opportunities, malnutrition and nutritional security.

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7
Chapter

Achievements in Livestock and Poultry Production in Independent India

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Summary

Since independence, livestock production in India has improved significantly in terms of milk, meat and fiber (wool). The well-designed research programs and concerted scientific efforts have made it possible for animal sector to touch the new horizons. The development of high yielding crosses of different livestock species *viz*. cattle (4), sheep (5), pig (9), chicken (6), Japanese quail (6), Guinea fowl (3) and turkey (2) have played pivotal role in augmenting animal production. Molecular genetics approaches have helped in pathways analysis and identification of gene(s) related to production/disease resistance traits. Biotechnological interventions such as transgenesis, gene knock down using RNAi technology, gene editing using CRISPR/Cas9, etc. are opening new vistas of improving production and/or quality of products. The country-wide genetic selection and breeding programs under AICRP/ Network projects have increased the production of milk, egg, meat and fiber and helped in conservation of native germplasm. So far, 202 breeds, livestock (177), poultry (22) and dogs (3) have been gazette notified. Feed costs about 70% of animal production, therefore, in order to reduce the cost of animal feed, more than 30 alternative feed resources with appropriate supplementation level were identified along with intensifying the efforts for improving nutrient availability and feed efficiency. In order to mitigate methane production in ruminants, several products such as *Harit-dhara*, Tamarin plus, *Avivatika*, etc. were developed. Livestock products technologies have enriched the food basket with a wide range of products and so far about 66 products have been commercialized. The investigations have yielded vital genetic and management clues for climate resilience in animal production. Still, there exists a wide gap between demand and availability of animal products and feed resources.

1. Introduction

Livestock is the integral part of Indian agrarian society. Livestock (including poultry) sector contribute directly through milk, meat, egg, wool and fiber production as well as provide employment to about 18.8% of the Indian population and livelihood to two-third of rural community. These animals have played crucial role in the evolution of crop cultigens and expansion of agriculture system by providing the draught power for agricultural works and contributing to the soil fertility. It is estimated that 30% of the total protein requirement for human-beings is derived from the animal husbandry. The poultry sector has undergone a paradigm shift in the structure and operation transforming from a mere backyard activity into a major commercial agri-based industry over a period of five decades. Animal husbandry is one of the fastest growing sectors contributing over 25.6% to Agri-GDP (gross domestic product) and 4.11% to overall GDP. India is the highest milk producer (198.4 million tons, Mt), 3rd largest producer of eggs (114.5 b) and 6th largest in poultry meat production (4.34 Mt) in the world. The current production of livestock and poultry has increased several folds in comparison to 1950-51 *viz.* 11.7 times in milk, 62.4 times in eggs, 1.33 times in wool and 4.62 times in meat (since 2000). Besides, with 14.16 Mt fish production in 2019-20, India is the second largest fish producing country. Honey production in the year 2021 in India was 1.25 lakhs Mt. The milk group has greatest share (66.5%) in value of output of livestock at current price basis followed by the meat group (23.27%), whereas share of egg, wool & hair and hide & skin were 3.13%, 0.05% and 0.58%, respectively (BAHS 2020). The country has witnessed three revolutions; viz. white revolution for milk production in 1976-96; silver revolution for egg and poultry production in 2000, and red revolution for meat production in 1980-2008. In spite of spectacular growth in animal sector there exists a wide gap between demand and availability of meat and eggs in India. The present per-capita per annum availability of egg is 86, which is far below the ICMR recommendation of 180 eggs. Similarly, for meat per-capita per annum availability is 6.45 kg against the recommendation of ~11 kg meat per annum. The gap in demand and availability generate pressure on resources and demand intensification of R & D to augment productivity in order to alleviate hunger and malnutrition.

In the post-independence era, the scientific breakthroughs and technology interventions have played key role for continuous and sustainable growth in the livestock (Table 1) and poultry sector (Table 2). Development of high yielding livestock and poultry breeds, nutritional interventions and advanced reproductive technologies were instrumental in augmenting production and productivity in India. High density SNP chips were developed for future application in genomic selection in indigenous livestock and poultry. The government policies and schemes also supported the large-scale breeding and dissemination of the high yielding/ improved germplasms throughout the country. The feed technologies have also helped in reducing the cost of animal and poultry feed along with augmenting nutrient availability and improving the feed efficiency. A number of alternate feed resources, supplements and additives were identified and standardized for formulation of low-cost rations as well as for substitution of antibiotic growth promoters in feed. The feed formulations and practices were also standardized for mitigating methane emission and stress especially during summers. The assisted reproductive technologies (ARTs) such as artificial insemination (AI), estrus synchronization, embryo transfer technology (ETT), ovum pick-up & in-vitro fertilization (OPU-IVF), and animal cloning were standardized and perfected for faster multiplication and maximum utilization of superior germplasm. The development of new generation vaccines diagnostics and drugs, and innovative surgical procedures have led to reduction in morbidity and mortality losses and thus enhancing the overall production from livestock and poultry species. The well- structured research programs of ICAR played pivotal role in technology driven progress in livestock sector in the country. During 1962 to 1999, ICAR established 19 research institutes in different parts of the country to address the research, innovation and technology requirement for improving animal health and production. Two major animal science institutes i.e., IVRI (1989) and NDRI (1923) were established in pre-independence era which now have the status of deemed universities.

Table 1. Milestones in livestock production

Year	Milestone
1971	AICRPs on buffalo, sheep, goat, pig and poultry initiated.
1985-87	Frieswal Project (1985) and AICRP on cattle (1987) launched.
1980-82	Karanswiss and Karanfries declared as high yielding crossbred cattle.
2008	Breed Registration process in India was initiated by ICAR-NBAGR, Karnal.
2009	Initial registration of 129 livestock and poultry populations as extant breeds.
2015	Registration of variety/lines initiated by ICAR-NBAGR, Karnal.
2017	Annual "Breed Conservation Award" by ICAR-NBAGR, Karnal initiated.
2019	Gazette Notification of AnGR initiated by DARE/ICAR, Govt. of India.
2016	Development of prolific Avishaan sheep for higher mutton production by ICAR-CSWRI, Avikanagar.
2016-18	Release of high yielding crossbred varieties of pig.
2019	Frieswal cattle was declared as breed.
2020	SNP chip for indigenous livestock & poultry developed by ICAR-NBAGR.
2021	Mission Zero Non-Descript AnGR of India initiated by ICAR-NBAGR.
1970	Urea treatment of poor-quality roughages specially straws.
1980	Feeding of bypass protein.
1990-95	Development of 'Dag Cure' for treating the Dagnala disease (Selenium toxicity).
1992	Feeding of protected (bypass) fat in high yielding animal.
1997-03	Development of the mineral mapping of the country.
2010-15	Development of nutraceuticals from agricultural wastes.
2010-15	Development of 'Memnaprash' a milk replacer for lambs/kids by ICAR-CSWRI, Avikanagar.
2015-17	Development of Feed block making machine.
2004	Network project on mitigation of methane emission.
2015-20	Development of anti-methanogenic product '*Harit Dhara*' and 'Tamarin Plus' by ICAR-NAINP, Bangalore

Year	Milestone
2015-20	Development of an encapsulated Lactobacillus based formulation for the modulation of beneficial microbes in GIT in canine, cattle and buffaloes.
2015-20	Development of Lactobacillus based probiotic culture for neonatal health.
1939	First time Artificial Insemination performed in India.
1943	First buffalo calf through artificial insemination (AI) was born.
1987	The first embryo transfer calf in India was born in ICAR System.
2003-04	Development of a simple & cost effective device 'Crystoscope' for heat detection in dairy animals by ICAR-IVRI, Izatnagar.
2009	Buffalo cloned for the first time in the world by Hand-guided cloning by ICAR-NDRI, Karnal.
2009-21	Production of cloned buffalo calves using different cells ICAR-NDRI, Karnal and ICAR-CIRB, Hisar.
2013-14	Foetal extractor developed for large ruminants.
2018	AI technology in goats using frozen semen was commercialized by ICAR-CIRG, Makhdoom.
2021	Preg-D- urine based early pregnancy detection kit for cattle and buffalo was released by ICAR-CIRB, Hisar.
2019-20	AI technique with reduced sperm count per dose in buffalo/cattle developed by ICAR-CIRB, Hisar.
2015	Launching of 'Meat on Wheels' by ICAR-NRC on Meat, Hyderabad.
2015	TTIs based meat quality indicator for temperature abuse during storage.
2016	FSSAI certification as National Referral Laboratory for ICAR-NRC on Meat, Hyderabad
2021	mRNA based method for species identification in animal by-products.
2021	Development of field level kits for species identification of pork.

Table 2. Milestones in poultry production

Year	Milestone
1962	Exotic poultry breeds imported to improve egg and broiler production.
1977-on-wards	High yielding layer and broiler strains developed and released by ICAR institutes/ SAUs.
1989-on-wards	Release of backyard chicken varieties.
2014	Mission on village poultry under AICRP (Poultry breeding).
2020	Conservation of chicken through PGC standardized.
2021	Transgenic chicken as bioreactor developed for production of therapeutics (Human interferon alpha 2b) in eggs.

2. Animal genetic resources

India is a rich repository of animal genetic resources distributed widely over the diverse agro-climatic regions of the country with a total population of 536.76 million livestock and 851.81 million poultry (20th livestock Census, 2019). The livestock wealth of India includes 193.46 million cattle, 109.85 million buffaloes, 148.88 million goats, 74.26 million sheep, 9.16 million pigs and other species like horses and ponies (3.42 lakhs), camels (2.52 lakhs), mules (0.8 lakhs), mules and donkeys (1.24 lakhs), yak (0.58 lakhs), mithun (3.86 lakhs). The avian species includes 807.89 million fowls, 33.51 million ducks, 10.41 million turkeys and other poultry. Globally, India possesses largest buffalo population (49%), second largest population of cattle and goat, 3rd of sheep, 4th of duck, 5th of poultry and 6th of camel. Farmers of marginal, small and semi-medium operational holdings (area less than 4 ha) own about 87.7% of the livestock.

2.1. Characterization and registration of breeds

So far, 180 breeds of livestock (cattle 50, buffalo 19, goat 34, sheep 44, pig 10, horses/ponies 7, donkey 3, camel 9, yak 1, dog 3) and 22 poultry (chicken 19, duck 2, geese 1) have been gazette notified.

Large proportion of non-descript animals of different species indicates that the characterization and inventorization of animal genetic resources of India is still incomplete. After establishment of National Bureau of Animal Genetic Resources at Karnal by ICAR, phenotypic characterization of domestic animal diversity of India has been accelerated. A system of registration of livestock and poultry breeds was initiated by ICAR in 2008 with the initial registration of 129 livestock and poultry populations as extant breeds. A total 73 new breeds were registered from 2010 to 2021.

2.2. Conservation of Animal Genetic Resources

Most remarkable achievement was revival of Krishna Valley cattle in Maharashtra and Karnataka states. The number of this cattle breed was reduced to only 400 when NBAGR initiated an *in-situ* conservation program and after 12 years of continuous efforts the number has increased to 10,000.

Conservation of Punganur cattle was taken up under National Agriculture Technology Project (NATP) by NBAGR, Karnal during 2000-2004 in collaboration with SVVU, Tirupati. For *ex-situ* conservation, semen doses and somatic cells are being cryo-conserved at National Gene Bank, NBAGR, Karnal and so far, semen doses of 24 breeds of cattle (163108), 12 breeds of buffalo (59,703), 5 breeds of goat (12584), one breed each of sheep (8375) and camel (928), 3 breeds of equine (1750) and a breed of yak (460), totaling to 227362 semen doses of 47 livestock breeds have been cryo-conserved.

3. Genetic improvement of animal genetic resources

3.1. Cattle

Frieswal declared a breed on November 3, 2019

The crossbreeding of indigenous cattle breeds with exotic cattle breeds like Holstein Friesian, Jersey, Brown-Swiss was started in India as early as 1875. Subsequently, it was expanded into AICRP on cattle with five centers *viz.* IVRI, Izatnagar and CCS, Haryana used Hariana cattle; MPKVV, Rahuri and JNKVV Jabalpur used Gir; ANGRAU, Lam used Ongole as base foundation for crossbreeding programme. Karan Swiss and Karan Fries were developed at NDRI, Karnal, and Sunandini (Non-descript x Brown Swiss) was developed under Indo-Swiss project at Kerala. The prestigious "Frieswal Project" launched on 23rd May 1985 by ICAR in collaboration with Military Farms with the objective to evolve a national milch cattle breed having 4000 kg milk with 4% butter-fat in a mature lactation of 300 days. The outcome of project was a stable cross "Frieswal" with 62.5% (HF) and 37.5% (Sahiwal) inheritance. IVRI, Izatnagar developed Vrindawani (Hariana x Brown Swiss x Jersey). Performance profiles of four crossbreds have been summarized in Table 3.

Table 3. Performance of crossbred cattle developed at ICAR Institutes

Trait	Frieswal	Karanfries	Karanswiss	Vrindavani
Daily Yield (kg)	15.11± 0.06 (41.0 best yield in a day)	10.26±0.06 (46.5 best yield in a day)	8.9±0.2 (44.0 best yield in a day)	16.58±0.16 (35.0 best yield in a day)
300-d Lactation Yield (kg)	3628.00±12.32 (7000 highest MY)	3083.35±22.12 (6939 highest MY)	3316.0±82.0 (7096 highest MY)	3220±41 (7187 highest MY)
Average Fat %	3.9	4.2	4.52	4.30
Lactation Length (Days)	322.02 ± 0.78	320.52±2.26	328±80	337.73±2.29
Age at first calving (Days)	965.36 ± 2.18	1012.17±3.61	1038±5.6	1012±9.3
Service Period (Days)	119.76± 1.81	149.97	156	149±4.55
Dry Period (Days)	164.59± 2.17	197	170	99.65±5.75
Calving Interval (Days)	440.30± 2.12	402.04	404	425±4.87

3.2. Sheep

Cape Merino, an exotic fine wool breed, was crossed with local breeds and 4000-5000 crossbred sheep were produced around Pune for superior quality wool production (National Commission on Agriculture, 1976). Nilgiri, a fine wool breed of sheep was evolved in the Nilgiri Hills of Tamil Nadu. Crossbreeding of indigenous sheep with Romney Marsh was undertaken both in plains and hilly areas. Hisardale, a fine wool breed with about 75% exotic inheritance, was evolved by crossing of Bikaneri ewes with Merino rams at Government Livestock Farm at Hisar (Haryana Agriculture University, 1983). Kashmir Merino was evolved by crossing Gaddi, Bhakarwal, Rampur Bushair, Poochhi, Kamah and Gurez with Merino. Sheep breeding work under AICRP for fine wool was started in 1971 at CSWRI. The breeds involved were exotic fine-wool breeds- Soviet Merino and Rambouillet, and the indigenous breeds-Gaddi, Nali, Chokla, Patanwadi, Nilgiri and Bonpala. The new strains of sheep were named as Avivastra, Nali-synthetic, Chokla-synthetic, Nilgiri-synthetic, Patanwadi-synthetic and Gaddi-synthetic.

Crossbreeding to improve mutton production involved exotic mutton breeds- Dorest and Suffolk and indigenous breeds were Malpura, Sonadi, Muzzaffarnagari, Nellore, Mandya, Deccani and Madras Red. Avimaas (Mutton Synthetic) lambs attained 25 kg body weight at 130 days. Rambouillet was superior to other exotic breeds in crossbreeding experiments. Awassi was crossed with native Malpura sheep at CSWRI, Avikanagar in 1994; the crossbred (AM) exhibited improvement in body weight and feed efficiency.

3.2.1. Avishaan: A prolific sheep developed at ICAR-CSWRI

A crossbreeding scheme was started in 1997 to introgress the prolificacy gene *FecB* from small sized prolific sheep breed 'Garole' of Sunderban area of West Bengal into non-prolific large size mutton sheep breed 'Malpura' of Rajasthan and Garole x Malpura half-breds were produced with twinning percentage of 50%. The *FecB* gene carrier Garole x Malpura halfbreds males were backcrossed with Malpura dam to produce the GMM having 25% Garole and 75% Malpura inheritance. Later, in 2008, Patanwadi inheritance was introduced to increase the availability of milk to newly born lambs. In this crossbreeding programme, GMM having Fec^{BB} gene was used as sire and Patanwadi as a dam breed to produce triple indigenous breed cross with 12.5% Garole, 37.5% Malpura and 50% Patanwadi inheritance in which *FecB* gene has been introgressed successfully.

Avishaan ewes produced 46% more mutton compared to monotocus Malpura

The high performing triple breed cross "Avishaan" was released by CSWRI on 4th January, 2016. Avishaan exhibited high prolificacy (74.4%), litter size (1.8) and annual lambing

(94.5%). Body weights at 3 and 6 months averaged 16.5 and 27.9 kg, respectively, with post weaning and adult survivability above 98% with *FecB* gene inheritance.

3.3. Goat

Crossbreeding in goat with exotic breeds was started to increase milk, meat and mohair production. Exotic breeds such as Alpine, Saanen and Toggenberg were used for improved milk production and Angora for Mohair production. Alpine and Toggenberg were crossed with Sirohi for improving the milk and reproduction performance of the local breeds. Saanen breed showed better performance with both the indigenous breeds than Alpine. Saanen and Malabari cross showed an improvement of 128% in milk yield over Malabari. Saanen×Beetal crosses (75% exotic inheritance) were the best, showing 103.4% improvement over purebred Beetal (AICRP 1985). Alpine × Sirohi and Toggenburg × Sirohi exhibited higher lactation yield than Sirohi. Subsequently, it was observed that purebred selection was more effective than crossbreeding.

For improving growth and meat production, Jamunapari and Beetal were used as improver breeds to cross with Black Bengal, Assam local, Sirohi and Sangamneri. Beetal × Black Bengal cross performed better than Jamunapari × Black Bengal cross. The combining ability of four important indigenous breeds was analysed in the PL-480 project involving Jamunapari, Black Bengal, Barbari and Beetal breeds. Indian goat breeds do not produce mohair; however, crossbreeding of Sangamneri and Gaddi with Angora breed yielded mohair. Crossbreds with 87.5% exotic inheritances were found to be the best for mohair production under Indian conditions. However, crosses had higher mortality and mohair production was uneconomical (AICRP 1985).

Overall, the crossbreeding did not prove viable as the crossbred were not stable and could not sustain the production in subsequent generations. Majority of goat breeds and non-descript goats in India carry A, B, E and F alleles at αs1-casein locus. Allele A (0.68 to 1.00) and B (0.098 to 0.23), associated with better casein yield, had higher gene frequencies. Allele F was observed in Beetal, Marwari, Chegu and non-descript goats of MP in less than 1% of population. Furthermore, the null allele (β-CnO) of β- casein, which is associated with no synthesis of α-S2 casein protein having higher frequency in Norwegian goats and crossbreeding may result in inheritance of this allele into indigenous goat breeds. Alpine and Saanen goats from France showed αs1-cnE and αs1-cnF allele frequencies as 0.34 and 0.41, respectively. Togenburg, Appenzeller and Verzasca breeds of Switzerland had αs1-cnF frequency was 0.69, 0.44 and 0.62, respectively. Indian goats have higher frequency of A and B alleles indicating better allelic combination for the higher milk protein yield.

3.4. Pig

Exotic breed pigs were imported in India in IV-five-year plan (1970-1971) with the launch of AICRP on pig and the main objective was studying the performance of purebred exotic pigs under existing managemental conditions and stabilizing their performance in different agro-climatic conditions of the country. Consequent to slow progress of genetic improvement in indigenous pigs and higher demand for pork, crossbreeding of native pigs with exotic boars gained momentum in different parts of the country. The ICAR-National Research Center on Pig and the centres of AICRP on Pig developed nine high yielding crossbred pig varieties suitable for different agro-climatic condition of the country as given below.

1. Rani (50% Hampshire: 50% Ghungroo) developed at NRC on Pig, Guwahati attains 75 kg body weight at slaughter (8 months) with 1.98 cm of back fat thickness with litter size 9-10.
2. Asha (50% Duroc:25% Ghngroo: 25% Hampshire) developed at NRC on Pig, Guwahati attains 80 kg lean pork at slaughter age of 8 months with 1.75 cm back fat thickness with litter size 8-9.
3. HD-K75 (Hampshire 75%; local 25%) developed at AAU Guwahati attain 74 kg body weight at slaughter age of 8 months with 2.58 cm of back fat thickness and litter size 8-9.
4. Jharsuk (50%Tamworth: 50% local pigs) developed at BAU, Ranchi attains 80 kg body weight at slaughter age (8-10 months) and litter size 8-12 with two farrowing/year.
5. Mannuthy White (75% Large White Yorkshire: 25% Desi) developed at KAU, Mannuthy attains 94 kg body weight at slaughter age (10 months) with 2.10 cm of back fat thickness and litter size 8-9.
6. Lumsniang (50% Niang Megha: 50% Hampshire) developed at ICAR-RC for NEH Region, Barapani attains 90-100 kg body weight at 12 months of age and litter size 8-9.
7. TANUVAS KPM Gold (75% Large White Yorkshire: 25% Desi) developed at TANUVAS, Chennai attains 80 to 85 kg body weight at 8 months with litter size 8-9.
8. SVVU-T17 (75% Large White Yorkshire: 25% Desi) developed at SVVU, Tirupati attains 85 kg body weight at slaughter age of 10 months with litter size 8-9.
9. Landlly (75% Landrace: 25% Gurrah) developed at ICAR-IVRI Izatnagar attains 85-95 Kg body weight at slaughter age (8 month) with litter size 7-9.

Average litter size at birth of crossbred varieties ranges from 8-10 compared to 5-6 in indigenous pigs. Average body weight at slaughter age (8 months) in indigenous pigs is 40-50 kg, whereas the crossbreds attain 75-90 kg at slaughter age. Assuming rearing of one indigenous sow with average litter size of 5.5 and average body weight of 45 kg/animal, a farmer can produce approximately 250 kg pork in one year and earn Rs 25000 by selling of pig @ Rs. 100 kg^{-1} of pork. On the other hand, keeping improved crossbred sow with average litter size of 9.5 and average body weight of 75 kg/animal, a farmer produces about 700 kg pork and earn Rs. 70000 per year.

3.5. Poultry

Poultry is one of the major sectors of agriculture in India. ICAR has pivotal role in shaping up both organized and un-organized poultry sectors through its research programmes including AICRP and Poultry seed projects and producing highly skilled manpower for manning the Indian poultry sector. Specialized breeding programmes have resulted in development of high yielding poultry strains, which have revolutionized the Indian poultry sector.

Both the ICAR Institutes along with AICRP Centres have developed many high yielding backyard chicken varieties such as Vanaraja, Gramapriya, Srinidhi, Janapriya, Vanashree, CARI-Shyama, CARI-Nirbhik, CARI-UPCARI, CARI- HITCARI, Pratapdhan, Kamrupa, Narmadanidhi, Jharshim, Himsamridhi, etc., for enhancing backyard poultry production in the country. These high yielding chicken varieties lay 130-140 eggs and attain 1.5 kg body weight at 12-14 weeks of age and are best suited for hot and humid climate. CARI-Nirbheek has been enlisted by the FAO as a bird suitable for backyard poultry. Some of these varieties are enlisted as Low Input Technologies (LIT) under National Livestock Mission (NLM). The Institutes / AICRP Centres also developed commercial layer varieties such as Krishilayer, ILI-80, ILM-90, ILR-90 and Atulya (290-315 eggs) and commercial broiler like B-77, CARIBRO-Dhanraja, CARIBRO-Vishal, IBL-80, IBB-83, Krishibro, etc. (~2 kg at 7 weeks), for intensive/semi-intensive poultry production in the country. Standardized package of practices developed by the institutes together with the high yielding strains have contributed to spectacular growth rates in layer, broiler and backyard poultry production. Furthermore, the turkey and Japanese quail backyard population in India has increased by ~49% and 564% in 2019 (20th Livestock Census) as compared to 2012 (19th Livestock Census). Genetic improvement and popularization of the diversified poultry species such as duck, Japanese quail, turkey, Guinea fowl has also been undertaken. Every year, both the ICAR Institutes/ AICRP and Megaseed project centres are supplying >30 lakhs improved chicken germplasm including parents to the different stakeholder. During last 10 years, ICAR has supplied more than 2.5 crores of backyard chicken germplasm from which around 2 lakhs farmers every year across the country are benefitted. The estimated profit by the improved low input technology birds was found to be Rs. 883.70 lakhs in last five years.

4. Genetic improvement of indigenous germplasm

4.1. Cattle

The ICAR-Central Institute for Research on Cattle (CIRC), Meerut has been implementing the Indigenous Breeds Project (IBP) under the All India Coordinated Research Project (AICRP) on Cattle for the conservation and genetic improvement of important indigenous cattle breeds of the country. Under the IBP, initially Hariana and Ongole breeds of cattle were undertaken for improvement. The genetic improvement of Ongole cattle was initiated in collaboration with Livestock Research Station at Lam under Shri Venketeshwara Veterinary University, Andhra Pradesh from 1988 to March 2014 and 73 bulls were evaluated through field progeny testing (FPT). Draft studies undertaken on Ongole animals indicated that draught power of Ongole varied from 0.60 to 0.72 HP. Genetic improvement of Hariana cattle was initiated in collaboration with the CCS Haryana Agriculture University, Hisar (1989 to 2009). Hariana bullocks had capacity to pull moderate load of 8 quintals for about 2 hours without any serious effect on the physiological status.

Since 2010, genetic improvements of Gir, Kankrej and Sahiwal breeds in their home tracts have been undertaken in IBP in collaboration with State Agricultural/Veterinary Universities and ICAR institutes. About 16500 Gir, 10500 Kankrej and 3400 Sahiwal cows from the farmers/Organized herds have been covered under the project and 5490, 2743 and 1003 improved female calves of respective breeds were produced. The elite females had average lactation yield of 3238, 3553 and 3393 kg in Gir, Kankrej and Sahiwal, respectively showing overall improvements in respective breeds as 36.73, 24.33 and 20.02%, during 2010 to 2020.

In 2018, ICAR-CIRC established a herd of Frieswal cow by selecting elite Frieswal cows as bull mother farm for the production of young male calves for testing in the Field Progeny Testing (FPT) Programme at four different centres with coordinating unit at CIRC, Meerut. The young bulls are reared at Bull Rearing Unit at Meerut for collection, storage and distribution of semen. The ranked bull semen was also used at the bull mother farm maintained at ICAR-NDRI, Karnal for the production of young bulls. The Field Progeny Testing programme resulted in an increase of average first lactation 305 days milk yield of the Frieswal progenies by 67.76% in KVASU, 41.95% in GADVASU, 12.41% in BAIF and 36.07% in GBPUA&T unit.

4.2. Buffalo

Network Project on Buffalo Improvement (NPBI) was started by ICAR in the year 1993 with ICAR-CIRB Hisar as the coordinating unit. The main aim of this project was to ensure the sustained maintenance of nucleus herds as bull mother units and production of improved germplasm on large scale for use in buffalo improvement program by establishing linkages with institutions. Important breeds of buffaloes *viz*. Murrah, Nili-Ravi, Bhadawari, Jaffarabadi, Surti, Pandharpuri and Godavari were included under NPBI programme for their genetic improvement. The elite herd of breedable Murrah, Nili-Ravi, Jaffarabadi, Bhadawari, and Surti buffaloes along with semen freezing laboratories were established under NPBI for the production of genetically superior young bulls of these breeds.

High genetic merit male and female calves of Murrah breed are being used for production of future elite parents at ICAR-CIRB, Hisar. So far, 19 sets of Murrah bulls had been tested under the NPBI. The performance of the nucleus herd has increased from 1820 kg/lactation in 1993 to 2586 kg in 2020 (42% increase). A total of 33 progeny tested bulls have been produced under the project with highest genetic superiority of 18.75%. The project has achieved reduction in age at first calving in Murrah buffalo by 8 months i.e., from 50.7 months in 1993 to 42.8 months in 2020, calving interval by 50 days and service period by 112 days.

Nili-Ravi and Bhadawari breed Centers are functioning as conservation and improvement units and Jaffarabadi and Surti breed Centers are concentrating on field progeny testing along with maintaining the elite herd for bull production and testing. So far 9 sets of the Nili-Ravi bulls have been progeny tested under the NPBI. The performance of Nili-Ravi

Nucleus herd has been increased from 1885 kg during 2001-02 to 2679 kg during 2018-19 (42% increase in SLMY). A total of 10 progeny tested Nili-Ravi bulls have been produced under the project with highest genetic superiority of 25.07%. Calf mortality has been reduced from 13.2% to 3.3% in 2019-20. The performance of Jaffarabadi Nucleus herd has been increased from 1814 kg during 2001-02 to 2245 Kg during 2019-20 (24% increase in SLMY). Total 9 progeny tested Surti bulls have been produced under the project with highest genetic superiority of 19%. Significant reduction in AFC of Surti buffaloes has been recorded from 49.75 months in 2003-04 to 45.29 months in 2019-20. Performance of Bhadawari herd has increased from 1029 kg in 2003-04 to 1286 kg in 2019-20 (25% increase in SLMY).

4.3. Sheep

An All India Coordinated Research Programme (AICRP) on sheep breeding was launched by the ICAR in 1971, which was later converted to Network project on Sheep Improvement and Mega Seed Sheep Project in 1990 with four farm-based units on four indigenous sheep breeds *viz.* Marwari, Muzzafarnagri, Deccani and Nellore; and two field units on Madras Red and Magra sheep. The growth traits since inception have remarkably improved to achieve body weight at 3 months which was earlier achieved at 6-month of age and the weight which was earlier achieved at 12 months is now achieved at 6-month age; thus, improving the mutton production, and reducing the marketable age as also the cost of rearing. Improvements in survivability and reproductive performance have also yielded extra lambs, thus yielding more mutton more return. Weight at birth was improved up to 28% (2.5 to 3.3 kg), at 6 months improved up to 86% (Malpura; 14.0 vs 26.0 kg) and at 12 months improved up to 65% (19 kg to 32 kg in Marwari sheep) since inception (1975 *vs.* 2020). The overall survivability (96%) and lambing % (88%) have improved by 22% and 20%, respectively since inception.

4.4. Goat

All India Coordinated Research Project (AICRP) on Goat Improvement in 1971 was started with the main objective of improving the performance of goat for milk, meat and fiber (Pashmina) production in different parts of the country. Crossbreeding and selective breeding approaches have been undertaken to improve the productivity performance of goats. Selective breeding approach was undertaken to improve the performance of indigenous breeds in their home tract. This is being practiced at CIRG, Makhdoom for increasing the milk production in Jamunapari (63%) and Barbari goats (85.4%) since 1985.

Selection for growth is continuing in Barbari and Jamunapari goats at CIRG, Makhdoom since 1985. Feedlot kids attained 33.75±1.01 kg and 41.85±0.81 kg at 9 and 12 months of age, respectively. In Jamunapari goats there was increase in body weight at 12 months from 20.32 kg to 29.60 kg indicating an improvement of 45.67%. In Barbari goats an increase in body weights from 18.52 kg to 24.44 kg at 12 months with improvement of 31.96% over the years, was observed. The Pashmina yield varies from 78 g in first clip to 227 g in the third clip. Chegu and Changthangi goats showed an annual Pashmina production of 132 g and 214 g, respectively, with an average fiber diameter of 12.4 micron. Selection based on greasy fiber weight and fiber diameter combined into an index is likely to provide maximum genetic progress in improving Pashmina production.

The genetic trends obtained for weight at all ages were positive in Jamunapari goat (0.144 kg/year at 9 months of age and 0.199 kg/year at 12 months of age) (Rout et al. 2018). The genetic trend for birth weight was positive but almost constant in nature. There was an increase in mean milk yield of 0.25 kg/year, 0.70 kg/year and 0.72 kg/year at 90 days, 140 days and total milk yield, respectively, in Jamunapari goats (Rout et al. 2017).

Barbari Female

Jamunapari Male

4.5. Pig

Out of 9.06 million of pigs in the country (Livestock Census, 2019), a larger proportion (78%) is indigenous and non-descript. They are smaller in size, well adapted to hot and humid climate and comparatively have better disease resistance. An AICRP on pig was started during IV Five Year Plan (1970-1971), initially with four Centres that increased to 16 centres covering 7 indigenous pig breeds. Recently, 6 centres of the Megaseed project were also included in the AICRP. At present, there are ten registered pig breeds in the country (Ghungroo, Niang Megha, Agonda Goan, Tenyi Vo, Nicobari, Doom, Zovawk, Gurrah, Mali and Purnia). Presently, conservation of these indigenous breeds is being done at the institute and AICRP centers by collecting superior, true-to-the-breed animals from their breeding tract and further propagating through selective breeding. Litter size at birth and weaning showed continuous improvement over the years. Growth rates and body weights at 32-weeks were also increased significantly. Litter size at weaning and weight at 8-months also showed an overall genetic gain of 7% to 15% in different indigenous breeds. However, genetic improvement of indigenous breeds through pure breed selection has been slow.

4.6. Poultry

AICRP on poultry breeding started in 1971, initially has two components i.e., poultry for egg and poultry for meat. Later, another component on rural poultry was added. Poultry for eggs had an objective to produce a strain cross layer with production target of 220 eggs (hen housed) in 500 days. Subsequently over the years, the target was revised to 235, 250, 270, 280, 290 and 300 eggs in 500 days/72 weeks of age with good egg size. In the XI plan the target was revised with the objective to evolve high yielding strains/strain crosses with average production performance of 305 eggs in 72 weeks (hen housed) and more than 52 g egg weight at 40 weeks of age. The poultry strains developed under AICRP have achieved the targets of annual egg production of more than 300 eggs with Athulya (ILM 90) had average annual production of 315 egg and CARI-Priya had an average of 301 eggs with better adaptability to tropical climate.

Poultry for Meat had initial target to produce a broiler weighing 1500 g at 10 weeks of age with an FCR of 1:2.5, which was later revised to 1200 g at 8 weeks of age. In the XI plan, the target was revised to evolve a commercial broiler with at least 1700 g body weight at 6 weeks or 2000 g at 7 weeks with feed efficiency of less than 2.0 and less than 5% mortality up to 5 weeks of age using conventional breeding. The targets were achieved as the CARIBRO-Dhanraja developed at ICAR-CARI attained 2100 g at 7 weeks with FCR of 1.7. The commercial cross IBL-80 developed at GADVASU, Ludhiana (erstwhile PAU) also attained 2.0 kg at 7 weeks.

4.7. Camel

Camel is a multipurpose animal as it can be used for milk, meat, wool, transport, race, tourism, agricultural work, decoration for ceremonial functions, and camel dance for amusement. Though camel numbers have decreased however, retention of female population in higher numbers is likely due to rising interest of rearing camel for milk purpose. ICAR-NRC Camel established on 20th Sept 1995 has taken an important initiative to establish camel milk as a human health adjuvant and camel as milch animal. Finally, combined efforts of NRCC and other government and non-government organizations have resulted in devising an operational standard for camel milk in November, 2016 by FSSAI and to recognise it in food category that promoted production and marketing of camel milk. The lactational yield of four camel breeds *viz*. Bikaneri, Jaisalmeri, Kachchhi, Mewari were 1223.45, 1284.66, 1802.35 and 1442.35 Kg, respectively. The lactation length in corresponding breeds were 338.18, 367.18, 435.67 and 367.71 days. The daily milk production average is estimated to be between 3-10 L during a lactation period of 12-18 months. The yield could increase to 20 L per day under improved feed, husbandry practice, water availability and veterinary care. Several value-added camel milk products have been developed to promote consumption of camel milk and milk-products. Annual fiber yield from an adult camel amounts to 840 g and its blending products with sheep wool have good market value. A model for camel eco-tourism has been developed at NRCC for promoting the camel.

4.8. Yak

Yaks play multidimensional socio-cultural-economic role for the pastoral nomads, who rear yaks in high altitude Himalayan ranges, mainly for earning their nutritional and livelihood security. ICAR-NRC on yak established in 1989 works for conservation and improvement of yak for higher productivity and profitability in the country. The only breed of yak in India i.e., "Arunachali" was registered in 2018. The institute has developed

> NRC on yak has the privilege to produce First ET calf of yak named "MISMO" which was born on 27th June 2005 and later, first yak calf born through OPU-IVF on 27th July 2017 was named "NORGYAL"

complete feed block, area specific mineral mixture and AI technology with frozen semen (average conception rate 65%) for sustained Yak production and rapid multiplication of superior germplasm. The first yak calf through AI was born on 7th July, 2006 in the institute. Selection of superior yak bulls and their maximization through AI technology is being practiced. This technology has been propagated and frozen yak semen straws are regularly distributed to AH Departments of yak rearing states for genetic improvement and reduce inbreeding. The protocol for production of embryo through in-vitro fertilization (IVF) of octytes retrieved with ultrasound guided ovum pickup (OPU) technique in yak is a significant development towards conservation and multiplication of elite yak germplasm in the country. The protocol for induction and synchronization of oestrus in Yak "Ovsynch protocol" was developed. Fifty-one varieties of fodder species received from FAO were tested at different altitude and seed setting was found reasonable for Dactylis, Vicia and Agrostis spp; three varieties of Salix were found to be suitable in this region. Number of products from yak milk *viz.* Yak milk whey beverages, Cheese, Functional paneer, Flavoured *Churkam,* Yak Mozzarella etc. and carpets/wall hangings, foot mats, jackets and other garments have been developed at the institute.

4.9. Mithun

Mithun (*Bos frontalis*) or "gayal" is a unique bovine species playing central role in improving livelihoods of indigenous tribes of NEH region and symbol of prestige for local tribes. It is the state animal of Arunachal Pradesh and Nagaland. ICAR-National Research Centre (NRC) on Mithun, located at Medziphema, Nagaland, is the only Institute in the world fully dedicated to R&D and extension on this rare bovine. It is phylogenetically distinct from other *Bo*s species: however based on phylogenetic analysis of mitochondrial genome of mithun, it has been found that Gaur and mithun have common origin from an extinct *Bos* species.

> ICAR- NRC on Mithun has sequenced the genome (~300 gb) and annotated it for evolutionary and genetic studies. First ETT calf named "BHARAT" was born on 27th March 2012 and second calf 'PRITHVI' on 11th May 2012. The first calf "MOHAN" was born from cryopreserved embryo on 12th May 2012.

Traditionally, mithun is being reared under a free-range forest-based ecosystem with almost zero input but having great liking for salt feeding. Mithun is mainly reared for meat purposes and often slaughtered for high-quality organic meat during marriage ceremonies, religious festivals etc., therefore popularly called as *'Ceremonial Cattle'*. Being low in fat, mithun meat is good for human health. The ideal age of slaughter is 4-5 years with dressing as 58-62%. Mithun can produce 1-1.5 kg/day of milk which is rich in fat (8-13 %), solids-not-fat (18-24%) and protein (5-7%). Mithun milk has higher unsaturated fatty acids, amino acids, Vitamin A, D and E, minerals (Ca and Mg) and lactoferrin compared to cattle and buffalo milk. Based on the calorific value, 1 kg of mithun milk is equal to 2 kg of cow milk. The institute developed area-specific mineral mixture, low-cost complete feed block and designed a salt dispenser for mithun. The AI technology and estrus synchronization protocol were developed multiplying superior germplasm. Value-added products from mithun milk were developed.

5. Interventions for improving livestock and poultry

5.1. Molecular and biotechnological interventions

Large volume of information has been generated on molecular genetic studies in different livestock and poultry species. A number of genes sequence data have been generated, submitted to NCBI database, accession numbers acquired and phylogenetic analyses carried out in livestock and poultry species. The population structure estimates using DNA marker such as RAPD, microsatellite, AFLP, SNP have been generated for inter and intra-population studies. Candidate genes associated with different performance traits like growth (Growth hormone, Growth hormone receptor, IGF-1, IGF-2, IGFBP, myostatin, TGFs, Ghrelin, lectin, etc.), milk production traits (Casein genes, beta-lactoglobulin, etc.) meat quality genes (calpains, calpstatin, myostatin, etc.), wool quality gene (keratin type I, keratin type II gene, etc.), immunocompetence genes (MHC genes, cytokines and chemokine genes, TLRs, Lysozyme, etc.) have been studied. Expression analysis of various genes and transcriptome analysis using microarray/RNA-seq in different tissues/organs under different treatments and/or pathogenic challenges have been carried out to decipher the pathways and genetic milieu under different biological processes and/or disease disposition.

5.1.1. Transgenic chicken as bioreactor for production of human interferon alpha 2b in eggs

At ICAR-DPR, Hyderabad, the transgenic cassette was transferred to the chicken genome through sperm mediated gene transfer (SMGT) method. A total of 4 transgenic birds (2 female and 2 male birds) were produced, where the efficiency of production of transgenic birds has been 5.4%. Transgenic birds lay eggs containing human interferon alpha 2b. Around 40-50 mg human interferon alpha 2b was isolated from each egg. The interferon alpha was found to be glycosylated indicating the biological activity and also showed its antimicrobial activity in HEK293 cell culture.

5.1.2. Application of RNAi technology for augmenting body growth/egg quality

Knock down chicken was developed by silencing myostatin gene through RNAi. The body weight at 6 weeks of age was enhanced by 26.9% in knock down chicken (Bhattacharya et al. 2016). Further, to minimize cholesterol contents in egg and serum, RNAi approach was adopted to knock down Acetyl-CoA carboxylase (ACACA) and sterol regulatory element binding transcription factor 1 (SREBP1) genes. shRNA constructs were developed at ICAR-DPR, Hyderabad, which showed lower level of ACACA and SREBP1 protein in serum of the knock down birds. The inheritance of shRNA constructs was also analysed through back crossing. The serum total cholesterol and LDL cholesterol were significantly lower by 26.8 and 31.3%, and 56.3 and 26.4%, respectively in ACACA and SREBP1 knock down birds compared to the control birds. The egg total cholesterol and LDL cholesterol content was significantly lower in both ACACA and SREBP1 knock down birds by 14.3 and 13.2%, and 10.3 and 13.6%, respectively compared to the control birds (Prasad et al. 2022).

5.1.3. Genome edited Nicobari chicken developed by CRISPR/Cas improves egg production

Exon-1 and exon-2 of Inhibin alpha gene has been edited by CRISPR/Cas in Nicobari indigenous chicken breed. The efficiency of production of transgenic birds were 21.7 and 7.6% for exon-1 and exon-2, respectively while the efficiency of production of inhibin alpha edited birds was 13% for exon-1 fragment. The egg production upto 72 weeks of age was significantly higher by 95.3% in edited birds as compared to the control birds (250 vs 128 eggs). The number of pause days was lower in the edited birds as compared to the control birds (100.5 vs 224 days) indicating higher persistency of egg production in edited birds compared to that of control ones (0.7 *vs* 0.4 eggs/day). Internal egg quality parameters like Haugh unit and yolk colour index were higher by 19.8 and 17.5%, respectively in the edited birds compared to control.

5.1.4. Genomic Selection

National Bovine Genomic Centre (NBGC) at ICAR-NBAGR Karnal has been launched in 2017 for implementing genomic selection (GS) in indigenous cattle using high throughput sequencing data. The accuracy of genomic prediction in dairy cattle exceeds 0.8 for production traits and 0.7 for fertility, longevity, somatic cell count, and other traits. GS involves two steps i.e., firstly effect of each SNP marker is estimated in a reference population. Secondly, genomic breeding values (GEBV) of young animals are calculated by using marker information, and subsequently ranked for selection.

NBGC-IB, NBAGR Karnal has developed the HD-SNP chip for indigenous cattle (608K); Buffalo (603K); Backyard poultry (610K); Goat (605K) markers and; Medium Density DNA Chip of Camel (180K).

5.2. Nutritional interventions

In livestock production system, feeds being the major input cost (70%), needs special attention and necessitates to manage the feed resources efficiently to sustain the present growth rate. The R&D in the area of Animal Nutritional and Feed technology also occupy the central place in the journey towards science led increase in animal production in independent India. With the growing demand for milk, meat and animal products the country is facing a shortage of 13.3%, 31.7% and 27.5% of dry fodder, green fodder and concentrate, respectively. Grasses from pastures, forest areas and wastelands/ fallow lands are the major sources of natural vegetation available for livestock feeding. There are four major types of grasslands in India *viz.* arid, semi-arid, sub-mountainous and temperate regions. Estimates of feed availability indicate that availability of feed resources in terms of dry fodder, green fodder and concentrates are 435, 920 and 57 million tons, respectively. Fodder crops are the plant species that are cultivated and harvested for feeding the animals in the form of forage (cut green and fed fresh), silage (preserved under anaerobic condition) and hay (dehydrated green fodder). The estimated potential availability of fodder on the basis of DM, CP and ME is 1,15.95, 148.17 and 1.058 million tons, respectively. The crop residues like straws, stovers, sugarcane tops, tubers and roots are the major feed resources for feeding of the Indian livestock across all ecosystems. At national level, of the total 718.57 million tons of dry matter available, crop residues account for 64.38 %.

Oil cakes and meals obtained as by-product after extraction of oil from oil seeds are valuable source of protein for livestock feeding. Major oil seed crops grown in India *i.e.,* groundnut, rape and mustard, soybean, sesame, safflower, sunflower, castor, linseed, and niger utilized for feeding of livestock. Substantial quantities of about 4-5 million tons of unconventional cakes from castor seed, karanj seed, neem seed, jatropa seed, rubber seed, etc. are also potentially available. Fruits and vegetables wastes constitute another important animal feed resource but due to high moisture (80−90 %), high soluble sugars (6−64%) and crude protein (10−24%) contents they are highly perishable which restricts their full utilization. Molasses and sugarcane bagasse are the two major by-products of sugar industries. In India, only 10% of molasses is diverted to the animal feed industry for manufacturing the compounded livestock feed.

5.2.1. Balanced feeding for optimizing productivity of animals

Balanced feeding optimizes growth, milk yield, egg production, reproduction and prevent metabolic disorders and is required for assessing true genetic potential of the livestock and poultry. The feed requirements of livestock and poultry species at different ages, stages of production and physiological stages were formulated as total nutrient requirements by adding maintenance requirement according to body weight and lactation requirement as per milk yield. Dry matter intake at 2% of body weight and 1/3rd of milk yield. Animals should be provided appropriate amount of mineral mixture supplementation and appropriate supplements and additives should be added for maintenance of rumen and animal health. The balanced ration yield about 30% extra profit through increase in milk production and optimized feeding.

5.2.2. Mineral mapping of India

Mineral mapping and prioritisation of most limiting minerals in different states/ regions has led to the formulation of area specific mineral mixture (ASMM). Further, for improving the bio availability of trace minerals, protocol for preparing chelate / organic minerals for zinc, copper and selenium have been developed and validated. State-wise mineral deficiency has been presented in Table 4.

Table 4. State-wise mineral deficiency

State	Mineral Deficiency	State	Mineral Deficiency
1. Arunachal Pradesh	Na, K, Mg, Cu, Mn	11. Madhya Pradesh	P, Zn, Mn, Fe
2. Assam	Ca, P, Mg, Cu	12. Rajasthan	Ca, P, Cu, Zn
3. Sikkim	Ca, P, Cu, Mn	13. Gujarat	Ca, P, Zn
4. Tripura	Ca, P, Cu, Zn, Mn	14. Punjab	Ca, P, Cu, Zn
5. West Bengal	Ca, P, Cu, Zn, Mn	15. Haryana	Ca, P, Cu, Zn, Mn
6. Bihar	P, Mg, Cu, Zn, Mn	16. Himachal Pradesh	Ca, P, K, Cu, Zn
7. Uttar Pradesh	Ca, P, Cu, Zn, Mn, I	17. Maharashtra	Ca, P, Mg, Cu, Zn, Fe
8. Uttaranchal	Ca, P, Cu, Co	18. Karnataka	Ca, P, Mg, Cu, Zn
9. Tamil Nadu	Ca, P, Cu, Zn, Co	19. Kerala	Ca, P, Mg, Cu, Zn, Mn
10. Odisha	Ca, P, Cu, Zn, Mn	20. Andhra Pradesh	Ca, P, Cu, Zn, Mn

Source: ICAR-NIANP, Bengaluru

5.2.3. Alternate feed resources

Unconventional feeds such as neem seed cake, karanja seed cake, castor seed cake, sal seed meal, mahua seed cake, ambadi cake, mustard cake and cottonseed cake explored were found to have moderate to high protein content but have one or more anti-nutritional factors. Hence, suitable detoxification methods have been developed for processing such feeds to safely include at 5-10% level in the concentrate mixture of ruminant diets. Apart from these, several more such by-products such as ayurvedic herbal residues, areca sheath, sugar cane dry trash, sunflower heads, maize cob and sheath, groundnut haulms, fruit residues - apple, grape, mango, citrus fruit by-products, banana fruit by-product, pineapple fruit residue, jack fruit residue, etc. have been evaluated.

5.2.4. Alternative feed ingredients for broiler and layer chicken diets

More than 30 alternate agro-industrial feed resources have been evaluated for cost-efficient poultry feed formulation. Feed ingredients like *bajra* (pearl millet 50%), tannin-free *jowar* (sorghum, 50%) or *korra* (fox tail millet 60%) and *ragi* (finger millet 15%) may be replaced in commercial broiler and layer diets containing required levels of nutrients with net economic benefit. Quality protein maize (QPM) can be used as an effective alternative for conventional maize in both broiler and layer diets yielding better weight gain, egg production and feed efficiency. Soybean meal can be partially replaced with guar meal (upto 10% with Non-Starch Polysaccharide degrading enzymes), DDGS (rice origin upto 10%), sesame/til cake (upto 12%), double zero mustard cake (upto 18%) and detoxified karanj cake (upto 3 and 8% in broiler and layer diet, respectively) in the diet of broiler and layer chickens. The anti-nutritional factors, mycotoxins and residues in feed have also been effectively ameliorated. The overall economic impact of alternate feed resources was estimated to be Rs. 1750 crores.

The FCR in broilers was over 2.8 in 1970s which has been improved to 1.6 at present leading to an estimated cumulative saving of about 14 mmt poultry feed worth Rs. 250 billion. Similarly, the feed consumption/egg has been reduced by 7 g translating into a net saving of Rs. 10.5 b per year.

5.2.5. Methane emission and mitigation strategies

Ruminants are one of the leading methane contributors among the different anthropogenic sources and on an average dispense 80-95 Tg methane every year due to ruminant enteric fermentation , globally and about 9 Tg in India as per 20th livestock census (Livestock Census 2019). Enteric methane database for the prevailing feeding regimes in different states developed by ICAR-NIANP revealed that Buffalo and indigenous cattle contribute 45.1% and 31.4%, respectively, to the total methane pool from Indian livestock. Researches at ICAR institutes on ameliorative measures through dietary approaches has shown that it is possible to reduce the methane production by 10-20%.

Feeding interventions: Desirable reduction of 15-21% in enteric methane emission can be achieved by the feeding of more digestible feeds such as legumes, concentrate, grains, etc. Most promising results obtained at NDRI, Karnal by feeding balanced ration to the dairy animals under field condition has shown the reduction in methane emission by 10-15% with subsequent increase of 10-12% in milk yield. Sea weed products also reduced methane emission by almost 15%.

Tree leaves and plant secondary metabolites: Many plant secondary metabolites (PSMs) such as tannins, saponin and essential oils have anti-methanogenic property (Bhatta et al. 2015, 2016). Tree leaves such as Moringa leaves, Neem leaves, Jack leaves and organic acids have shown promising results in reducing enteric methane. These interventions have reduced methane emission by 10-15% in growing and lactating animals. Ionophores in the dairy ration reduce methane emission in heifers and nitrous oxide emission from dung of dairy animals.

Alternate H_2 sinks: Use of salts containing sulphur is also capable of reducing methane emission from dairy animals to the tune of 12-15%.

5.2.6. Feed technology

For efficient use of feed resources, technologies such as fodder block, pellet making, extrusion, complete feed block (total mixed ration) have been developed at ICAR institutes and adopted by feed industries. These technologies have helped in improved nutrient utilisation besides aiding in ease of transportation and storage. For better protein and fat utilisation in rumen of dairy animals, bypass nutrient technologies have been developed. Technologies of formaldehyde treatment of oil cakes to improve bypass protein value and preparation of bypass fat with vegetable oil and calcium hydroxide have been adopted by the feed industries.

Use of exogenous enzymes and vitamins in animal feed: Several enzymes like phytase, cellulase, proteinase, etc. are being used to obtain more animal produce at cheaper cost. Supplementation of vitamin E can be useful against oxidative stress in periparturient dairy cows. Utilization of phytate phosphorus was increased in chicken gut through supplementation of microbial phytase (500 FYT kg^{-1}) or with surfeit levels of vitamin D3 (2400 to 3600 ICU kg^{-1}).

Area specific mineral mixture (ASMM) for dairy animals: ASMM technology is available for the formulation of mineral mixtures as per the recommendations of BIS for different species i.e., cattle, buffalo and goat to supplement major and trace minerals such as Ca, P, Mg, Fe, Zn, Mn, I and Co, etc. There are two types of formulations of mineral mixture, one is with salt and the other is without salt, can be mixed in the concentrate mixture @ 2 kg/100 kg (without salt) and @ 3 kg/100 kg (with salt). It can also be supplemented @ 50 g/day/ adult animal mixed in feed or in water. Anionic mineral mixture developed at NDRI Karnal given to pregnant cows/buffaloes at least 3 weeks before parturition helped in meeting the increased demand of Ca and maintaining blood Ca. Vitamin E is additionally added to alleviate oxidative stress in periparturient dairy cows. Thus, supplementation of this special kind mineral mixture is effective for the prevention of hypocalcemia, minimizing the occurrence of milk fever and other metabolic disorders. Dose of 100 g/animal from 3-4 weeks before calving may be given along with concentrate feeds. Overall, 35% increase in profitability has been recorded through increase of 14% in milk production and 70% reduction in cases of milk fever by the use of Anionic mineral mixture.

Feeding strategies for enhancing functional/designer food production: The CLA content was increased by 300% in milk by dietary manipulation (Tyagi et al. 2007). Green fodder increases the CLA, vitamin A and E contents in goat milk (Tyagi et al. 2008). Buffaloes fed with mustard oil and cake in the diet enhanced 185% CLA in milk and milk products (Kathirvelan and Tyagi 2007). Supplementation of hen's diet with a higher amount of Se resulted in production of Se enriched eggs for better human nutrition.

Gut microbiome and dietary probiotics and prebiotics: Subsequent to the studies conducted at ICAR institutes, novel supplements like probiotics, prebiotics, gut acidifiers, emulsifiers are being used for improving nutrient utilization in gut. It was also concluded that the incorporation of Mannan oligosaccharides (MOS) and *Lactobacillus acidophilus* in diet either individually or in combination as symbiotic was found to improve the performance in Murrah buffalo calves (Sharma et al. 2018). Gut microbiome of indigenously developed commercial broiler, backyard cross, and Kadaknath as well as Guinea fowl exhibited the higher proportion of bacterial moieties conferring disease resistance rather than growth or fat deposition (Saxena et al. 2015, Vineetha et al. 2016, Harshini 2021). Vinay (2019) concluded that faecal origin probiotics served as a potential candidate for augmenting neonatal gut health and designing probiotic consortium for Murrah buffalo calves.

Ameliorating mycotoxins in poultry diets: Toxic effects of aflatoxin (300 µg kg^{-1}) were alleviated by incorporating poly unsaturated fatty acid-rich vegetable oil, activated charcoal, ascorbic acid, liver tonic, etc. in broiler diet. Vegetable oils rich in unsaturated fatty acids (soybean or sunflower oil) could be used to completely alleviate aflatoxin in broiler diet. Dietary supplementation of *Spirulina* (0.02%), herbal vitamin C, MOS partially alleviated, while vegetable oil (3%) completely alleviated the ill effects of aflatoxicosis (300 ppb) in commercial broilers.

Make feed software: A window-based user-friendly software developed at CARI, Izatnagar for formulation of low-cost poultry ration using locally available feed ingredients. The software helps the feed manufacturer and poultry farmers for least cost ration preparation for poultry.

6. Assisted Reproductive Techniques (ARTs)

The ARTs include several advanced reproductive technologies such as artificial insemination (AI), multiple ovulation and embryo transfer (MOET), *in-vitro* fertilization (IVF) and sperm sexing. These technologies have brought significant genetic improvements and productivity of the animals. However, the application of these technologies in indigenous dairy cows has been relatively slow.

6.1. Artificial Insemination (AI)

Tremendous progress has been achieved in semen cryopreservation and artificial insemination (AI) techniques that enable a single bull to be used simultaneously in several countries for up to 100,000 inseminations per year. The AI programme was first started in India at the Palace Dairy Farm, Mysore in the year 1939. In 1942, a Centre to study problems associated with AI was started at IVRI, Izatnagar and later on 4 regional stations were started at Bangalore, Kolkata, Patna and Montgomery (now in Pakistan). AI in buffalo gained importance in later years and the first buffalo calf was born through AI in 1943 at Allahabad Agricultural Institute, Allahabad. Presently, about 30% of the total breedable bovines are covered under the AI program. AI is currently used in breeding programs of ICAR, central and state govt farms and schemes of government. AI with frozen semen has also been standardized in Goat but in sheep it is practiced with refrigerated semen. In Pigs, AI with chilled semen is being practiced. Overall conception rate of AI is about 30-35%, which necessitates more intensified R&D efforts for improving the AI technology.

6.2. Multiple Ovulation and Embryo Transfer (MOET)

In this technique, genetic contributions of both the male and female are utilized simultaneously. The first embryo transfer calf in ICAR system was born in 1987 at ICAR-NDRI Karnal. ICAR-CIRC, Meerut, in a pilot study on MOET in cattle, initiated the embryo transfer technology at Military dairy farm, Meerut for multiplication of Sahiwal cattle. ICAR-NDRI Karnal and CIRC Meerut are working on augmenting production of indigenous livestock.

6.3. Ovum Pick-up and *in-vitro* Fertilization (OPU-IVF) Technology

A technique for *in-vitro* embryo production (IVEP) has been developed for utilization of the indigenous cow oocyte / gamete pool for enhancing the maternal contribution to genetic improvement. Ovum Pick-Up (OPU) is the only means for collecting oocytes from live animals of known pedigree; further this technique also enables repeated collection of oocytes from live animals on a weekly or biweekly basis over a long period of time. When using *in-vitro* procedures, average rate of blastocyst formation is around 30-40% and calf production is 10-15%.

India's first female Sahiwal calf named 'Holi' born through OPU-IVF in 2007 at ICAR-NDRI, Karnal

6.4. Semen sexing

A total of 12 semen stations in different states *viz.* Gujarat, Haryana, Kerala, Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, Telangana, Uttar Pradesh, Uttarakhand, Punjab and Himachal Pradesh have been established. The use of sex-sorted semen will not only enhance milk production but also crucial in limiting population of male cattle/ stray cattle. At parallel, ABS Technology (website genusabsindia.com) claims to make available sexed semen of Sahiwal, Gir and Red Sindhi bulls in India. The use of sexed semen of exotic breeds is becoming popular in states like Punjab, Haryana, Kerala and West Bengal. However, the high cost and poor pregnancy rates are the limiting factors.

6.5. Animal cloning

A decade ago (2009), India created a history in the field of animal cloning research by the birth of world's first cloned riverine buffalo using an economical and simple animal cloning technique called handmade cloning at ICAR-NDRI Karnal. Using simplified buffalo cloning technology, several cloned buffaloes were produced in the country using different types of somatic cells. The technology developed in India is less demanding

Multiple copies of elite Murrah bull (M-29)

in terms of equipment, skill and time. At CIRB and NDRI, so far, 15 cloned bulls from superior males and one re-clone calf have been produced. The first cloned bull 'Hisar Gaurav' born in 2015 at CIRB, Hisar has already produced more than 15,000 doses of semen. These semen doses have been used both at CIRB as well as at farmers' herds to produce 62 pregnancies which are growing normally, similar to progenies of bulls born conventionally. Also, the semen of these cloned bulls had fertility attributes equal to those of normal bulls.

6.6. Other reproductive technologies/products

Early pregnancy diagnosis kit (Preg-D) for cow and buffalo: A Urine based test has been developed at ICAR-CIRB, Hisar which can detect pregnancy at farmers' doorstep as early as 30 days after insemination.

Spermoscope: ICAR-CIRB, Hisar, developed and commercialized a handy and portable field microscope- 'Spermoscope' for the evaluation of sperm motility in field conditions.

Low sperm count for AI: Standardized low dose up to 10 million sperms per straw without affecting fertility for semen of Sahiwal, Karan Fries and Murrah Bulls in field condition.

7. Livestock products technology

Achievements of ICAR in Animal Products Technology research, education and capacity building since independence and their applications have played a vital role in accomplishing remarkable progress in augmenting milk, meat and egg yields and quality characteristics through breed improvement programs, nutrition and management programs; hygienic meat production and handling practices; extension of shelf life and microbial quality; value-added products; utilization of tough meat; economic formulations; byproducts utilization; human resource development etc. Technologies for meat speciation, cell-cultured meat and traceability have been initiated. Molecular tools like primers from mitochondrial D Loop gene (629 bp), mitochondrial cytochrome b gene for Goat (617 bp), 12SrRNA (322 bp) for pig and DNA biomarker (12 species) for species identification in meat samples were developed. Restructured meat products, functional products, and products with extended shelf life were developed. Formulations were standardized for ready-to-fry shelf stable meat-based snacks and ready-to-cook/ reconstitute dehydrated meat cubes. Ready to reconstitute instant soup mix from spent hen meat was developed. Several technologies on the efficient utilization of slaughter co-products were optimized and important products like heparin, insulin from buffalo pancreas, meat meals, quality lard, gelatin from bone and Neatsfoot Oil, deserted poultry sleeves etc. were developed. Studies on production and evaluation of multifunctional food ingredients from poultry by-products have been initiated and protein isolation protocol for chicken liver has been standardized. A strip-based indicator sensor was developed, which inside the packaged meat, changes its colour from yellow to blue upon deterioration in meat quality. Time Temperature Indicators (TTIs) based on the enzyme-substrate complex for monitoring meat quality and safety during temperature abuse in storage conditions was developed. The gender-specific primers from amelogenin

(AMELX) and SRY genes were found effective in determining the sexes in indigenous cattle as well as in buffalo, sheep and goat. An innovative protocol for inactivation of *Salmonella typhimurium* (ST) on dressed chicken carcass which can be applied to dressed chicken carcass in actual processing conditions was developed at ICAR-CARI, Izatnagar.

Country's first NABL accredited laboratory for Meat Species identification has been established as per ISO/IEC 17025:2017 at NRC on Meat. More than 400 samples have been tested for forensic evidence as well as for regulatory agencies. ICAR-NRC on Meat has been identified as a National Referral laboratory for quality analysis of meat and meat products by the FSSAI, GoI and has been identified as a Nodal Institute for Foods of Animal Origin under the Network for Scientific Cooperation for Food Safety and Applied Nutrition by FSSAI. ICAR-NRC on Meat has been granted copyright for first 'Database' for meat traceability in India. Meat on wheels– a mobile unit for the popularization of clean meat production and value-added meat processing was designed.

7.1. Value addition to meat

A combination of meats such as mutton and chicken were evaluated to compliment desirable characteristics of one with the other to produce quality meat products such as sausages, kababs, patties, and nuggets. The incorporation of chicken meat and byproducts in mutton sausages and kababs resulted in better quality products with economic advantage. The demand for value-added meat products is growing steadily. The meat products could be classified as per the criteria like the extent of particle size reduction, degree of comminution and type of processing, etc. According to the 2021 economic census, food processing industries grew at an average annual rate of 9.99% for the five fiscal years ending in 2018-19, overtaking agriculture (growing at a rate of 3.12% per year) and manufacturing (growing at an annual rate of 8.25%). Frozen and chilled meat is being exported to more than 54 countries in the world and has crossed the value of Rs. 3500 crores.

7.2. Traceability model for Indian buffalo meat industry

Farm-to-fork traceability in buffalo chain was successfully achieved by identification of animals using ear tagging, registration of farms and abattoirs, and systematic updating of information pertaining to animals, farm and abattoir in the traceability database being developed at NRC on meat. The traceability model developed showed that it is possible to maintain farm to fork traceability of buffalo meat by proper documentation of the system and regular update of the information.

7.3. Technologies for value added meat products

Processing of meat or further processing is primarily done to add value to meat, provide variety and convenience to the consumers, provide employment, better utilization of low-value cuts and by-products from slaughterhouses, extend shelf-life, facilitate incorporation of non-meat ingredients, better marketing and distribution, better profit and scope for export.

Emulsion-based meat products: Emulsion is made by grinding or chopping the meat added with common salt (NaCl) to a fine meat homogenate forming the matrix in which fat is dispersed. Several products like nuggets, functional nuggets, sausages, meat balls, meat petties and croquettes are popular and marketed.

Enrobed products: Enrobing is the process of making "further processed products" by applying an edible coating, and it brings several advantages such as value addition, versatility to consumers, and improvement of nutritive value. The products like enrobed eggs and enrobed/ coated meat products are very popular.

Recipes for products: Recipes for restructured meat products and cured and smoked meat products, heritage products (like Kebbabs, curries, pickle, soups), shelf stable ready-to-eat meat products, fermented meat products and functional foods were standardized and commercialized.

7.4. Innovative approaches in processing of poultry eggs

The innovative strategies entail improvements with inclusion of eggs and other nutrient rich ingredients through innovative egg processing techniques with focus to enhance the nutrient contents of the developed products and to enhance the storage stability under ambient storage. Development of innovative products includes value-added eggs products with cereals like raghi or millets, for blending the egg-based protein with cereals, for formulating nutrient enriched egg products. Such innovative approach can open newer avenues of utilizing eggs especially in summer season when egg prices are lower as well as for generating employment. Egg products like Japanese quail pickled egg, salted chicken egg, egg rasmalai, instant emu egg noodle, etc. have been developed and commercialized.

7.5. Value-added dairy products and technologies

Indian dairy industry contributes around 23% of global milk production, with 35% level of processing and valued at Rs. 11356 billion in 2020, which is expected to grow at the rate of 15.4% during 2021-26. With changing scenario in demography, consumer preference for quality products; "Product diversification" is the key for long-term sustainability of industry.

Dairy Beverages as Healthy Drinks: With growing demand for pasteurized or UHT processed liquid milk, to fortify milk with micronutrients like calcium, iron, zinc, vit. A and vit. D without altering the organoleptic quality of fluid milk, the beverages like Flavoured milk or drink in combination with natural fruits juices or pulps, high milk protein drinks, fermented dairy beverages with unique microbial starter and herb-milk beverage have been developed. Likewise, whey a major by-product of dairy industry (1 Mt annually) containing 50% of milk nutrients is converted into beverages. The manufacturing technology can be adopted at small or industrial scale/start-ups without any newer addition to existing infrastructure. Hands-on-training imparted to entrepreneurs resulted in effective utilization of whey at small scale processing units.

Innovative Traditional Dairy Products (TDPs): These are important part of our religious ceremonies, festivals and occupy a prime position in the processed dairy products market. According to an estimate, about 30-35% of the milk is converted into TDPs the market size of which is three-time bigger than liquid milk and 100-200% value addition is achieved by converting raw milk into TDPs. However, TDPs manufactured at small and medium enterprises suffer from the problem of non-uniformity, poor shelf-life, higher calorific value, and lack of mechanization. Several dairy giants have ventured into the commercial production of TDPs with an aim to capture the market opportunities among the Indian diaspora globally. Long-life and convenient ready-to-make mixes for paneer, milk cake, *rasmalai, basundi*, *kheer, payasam*, *kunda*, have been developed for such enterprises. Considering the growing demand of ghee as cooking medium within the country and middle-east nations, technology for low cholesterol ghee and Arjuna herbal ghee is launched. Manufacturing technologies for several region-specific TDPs like *chhanapodo, bhapadahi, mishtidoi, doda barfi, halwasan,* and *lalpeda* etc. were standardized. The technology of convenience mixes including ready-to-make rasmalai mix, paladapaysam, *kheer mohan* and improved texture dahi were transferred to industry and start-ups.

Composite Dairy Foods-Fusion Trend: Health foods have been developed using judicious blends of milk/milk constituents and cereals/plant commodities, into convenient, long-life forms with proven health benefits to consumers. Therapeutic virtues of herbs are harnessed by suitably incorporating their bioactive-rich fractions in products like fermented milk, ghee, and sweets. Packages for milk-millet/coarse cereal-based composite dairy products in the form of weaning, complementary foods, beverages; smoothie, extruded snacks, gluten-free pasta and vermicelli mix, high fiber dairy desserts, etc. have been developed.

Probiotic Dairy Products as Immune Enhancer and Improving Gut Health: A collection of indigenous strains of probiotic organisms and a number of products namely; probiotic ricotta cheese, probiotic edam cheese, probiotic yogurt, probiotic composite oat beverage, and probiotic dried formulations have been developed at NDRI Karnal and several of cultures have been sold to companies that are conducting clinical trials for their validation of health benefit.

7.6. Innovative and Novel Packaging Technologies for extended Shelf-life of Products

Several emerging packaging techniques such as modified atmosphere packaging (MAP), active, intelligent, and bio-nano composite packaging in improving the packaging systems of dairy products and to extend their shelf life have been developed. Electrospun smart oxygen tags were developed for colorimetric detection of oxygen leak (up to 0.4%) into MAP trays of Mozzarella cheese. The electrospinning technique was adopted to develop

PVOH-based dual antioxidant active wrapping material for *Burfi*. An industrial method has been developed for whey protein and iron based edible coating of *Paneer* for enhancing its nutritional quality. Milk protein-corn starch composite biodegradable films containing nano clay or nanocellulose were developed and used as sealing films for trays. An on-package colorimetric freshness indicators have been developed for *Khoa, Sandesh, Dahi,* and Milk-Millet complimentary food which change their color indicating freshness status to another distinguishing color to reflect product spoilage and supplement the "best before" or "expiry dates" printed on the package label. Among the active packaging ingredients are lysozyme, sorbic acid and silver-substituted zeolite which have been successfully incorporated in packaging materials to impart antimicrobial activity in food packaging.

7.7. Meat microbiology and occupational hazards

Various foodborne pathogens namely, *E. coli, Salmonella, Campylobacter,* and *Listeria monocytogenes* have been detected. Isolation and identification of *Listeria* from clinical (human and animal) and food samples (meat and meat products) revealed high prevalence of *Listeria* species. Samples from poultry production chain (comprising of poultry droppings, feed, water, meat and environment) were screened from poultry farm settings of Maharashtra, Kerala and Telangana for *Escherichia coli* and non-typhoidal *Salmonella* (NTS) spp. ICAR NRC on Meat and IVRI, Izatnagar have been working on occupational hazards among abattoir associated personnel namely, brucellosis, leptospirosis, Q fever, chlamydiosis and hepatitis E. Rapid serological assays have been developed for the detection of Q fever and listeriosis. The PCR based protocols for detection of *Listeria monocytogenes* and *Coxiella burnetii* from foods and clinical samples have been developed. An in-house designed i-ELISA was developed for serodiagnosis of chlamydiosis in humans. The ddPCR assay was developed for the detection of *C. psittaci* which was found to be suitable for screening the samples with a lower bacterial load.

8. Climate resilient animal production

With a recorded increase in temperature by 0.2°C per decade, the IPCC (2021) predicted that the global average surface temperature would increase in between 1.8°C to 4.4°C by 2100. The air temperatures above 20-25°C in temperate climate and 25-37°C in tropical climate like in India, enhance heat gain beyond that lost from the body and induces heat stress (Das et al. 2016). The temperature-humidity index (THI) is commonly used to quantify the degree of heat stress on animals (Habeeb 2018). THI levels <70 is comfortable; 71-74, mild stress; 75-78, stressful; 79-85, severe stress and >86 is considered lethal to animals.

8.1. Cattle and buffalo

The work carried at NDRI Karnal under NICRA project exhibited that seasonal variation in skin temperature, blood flow and a physiological function in Zebu and Karan-Fries (KF) cattle indicated the better adaptability of zebu during heat stress. The hair coat of animals plays a critical role in heat and moisture transfer from the skin surface to the surrounding environment to control body temperature. Thermal imaging of the cows revealed lateral surface and the dorsal surface of the body being more sensitive to heat stress than other part of body (rear surface, forehead and udder region). Tharparkar (TH) and Gir cows did not exhibit decline in milk yield up to 76 THI, beyond which the milk yield declined by 0.41 g/day with every unit increase in THI score. Cortisol level increased during hot humid month (July-August) and was low in winter months. Overall, the seasonal variability affected the % fat in the order TH>GIR~SW(Sahiwal)>KF in the winter, and thermoneutral zone. Milk plasmin was increased significantly in the summer season in all the breeds. Green-house gas emissions were in the range of 563-757 kg CO_2 eq. t^{-1} of milk production. Water foot print ranged from 1212-1583 m^3/ton.

The peripheral blood leucocytes tanscriptomic signature of Tharparkar cattle carried out at NDRI, Karnal highlighted altered metabolic pathways under stress. Sahiwal also revealed 140 transcripts and down- regulation of 77 transcripts after heat stress. Expression studies on coat colour related genes (MC1R, PMEL, KIT and TRIP1) indicated that genes responsible for skin pigmentation were found to be highly expressed during winter followed by summer and spring in Tharparkar, Karan Fries and Murrah indicating the ability to protect from heat and UV-rays. Dermal fibroblasts play role in thermo-tolerance, and also revealed that skin of Tharparkar and Sahiwal are highly adapted to thermal stress than Karan-Fries and Murrah buffaloes. Frequency of sister chromatid exchange (SCEs) was higher in Tharparkar and Sahiwal of semi-arid region and Kankrej of arid zone. Significant effects of environmental condition were found on chromosome aberration and SCEs indicating their adaptability to the climatic conditions. The differential expression pattern of candidate genes like Neuobeachin (Nbea), Integrin Alpha-9 (ITGA9) and Thyroid hormone receptor interacting protein-11 (TRIP11) in Tharparkar compared to Karan Fries might have role in imparting better heat tolerance in Tharparker. Novel and conserved miRNAs in zebu (Tharparkar) and crossbred Karan-Fries (KF) cattle under heat stress were identified. Maternal hyperthermia was found to have a very crucial role in deciding the developmental competence of oocyte and subsequently results in poor quality embryos in Murrah.

Several nutritional supplements like chromium propionate, Vit C, Vit E, Se, Zn, Betain, etc. have been found helpful in ameliorating heat stress in animals. Dietary NDF level @ 15% above control (34.5% NDF) had significant effect on amelioration of heat stress in lactating Murrah buffaloes. Addition of molasses in feed of Sahiwal and Karan-Fries resulted in reduction of enteric methane emission which may be helpful in reduction of global warming. Different designs and materials for shelter construction have been suggested for livestock species.

8.2. Goat

Physiological relevance of metabolomics as biomarker of thermal stress in lactating goats revealed that more than 50 metabolites were identified in goat milk, among which 15 metabolites varied significantly. Metabolites like L-Valine, Palmitic acid, Pentadecanoic acid, Hexanoic acid, Eicosanoic acid, 2,5 Dimethoxy-mandelic acid and Glycerol varied significantly in cold stress. Metabolites like Myristic acid, Heptadecanoic acid and 1,3 propanediol varied significantly in heat stress. Metabolites like 3 alpha mannopyranose, Maltose, D-Allofuranose, Ethanedioic acid, and 4-tert butoxy butanol varied significantly in thermoneutral temperature and can be used as potential biomarkers for thermal stress. In a multiparametric evaluation of climate resilience potential of goat breeds of southern India conducted at ICAR-NIANP established that Salem Black breed was found to be able to cope with heat stress challenges efficiently as compared to Osmanabadi and Malabari breeds. Similar experiments conducted on Bidri, Nandidurga, Kanni Adu and Kodi Adu goat breeds revealed that Kanni Adu, Kodi Adu and Bidri breeds are showing great promise. The results indicated that as compared to individual stress, combined (heat and nutritional) stress highly significantly influenced the productive and reproductive performance of Osmanabadi bucks. When the multiple stressors exposure prolonged for longer period, the animals compromise their productive function usually in the order of growth, reproductive and immune response. Thus, the multiple stressors may be more detrimental for the productive performance in these bucks under hot semi-arid environment. It was found that when nutrition is not a limiting factor then Osmanabadi bucks were able to better cope up with heat stress. The experimental data collected on heat stressed and control group of Osmanabadi, Malabari and Salem black goats each indicated significant alteration in the rumen bacterial community at all taxonomic levels across control and heat stress groups of all the three targeted breeds. Such information may help in identifying novel strategies to relieve the effect of heat stress by manipulating or altering the ruminal microbial composition.

The transcriptome analysis of PBMCs of two indigenous breeds i.e., Kadai Adu and Kodi Adu female goats of one-year age under heat stress for a period of 45 days clearly demonstrated the distinct transcriptomic signature for imparting thermo-tolerance in both Kanni Adu and Kodi Adu breeds. In addition, the study clearly demonstrated that HSF1, HSP70, GHR, THRA, FSHR, PRLR, TLR5, and IL18 genes could serve as ideal biomarkers for reflecting the climate resilient potential of indigenous goat breeds. The epigenetic alterations due to heat stress in Nandidurga and Bidri goats revealed less epigenetic (methylation) changes in Nandidurga breed as compared to Bidri breed. A simulated heat stress model for using in climate chambers to induce heat stress to simulate the natural heat stress was developed to study the influence of heat stress on various goat breeds. The climatograph of the breed origin was developed and accordingly thirty years cardinal weather data are programmed to develop this simulated heat stress model. The model was designed in such a way to induce heat stress as experienced by the breeds during grazing condition in their natural location. The average thirty years data of temperature and relative humidity of summer season (March-April) was programmed at hourly interval from 10.00 h to 16.00 h to depict the natural heat stress experienced by the grazing animals. Therefore, the simulated heat stress model could be of practical relevance as it simulates the natural climatic condition. Further, from ethical point of view also the simulated heat stress model offers better scope to study heat stress impact in farm animals (Sejian et al. 2019).

8.3. Poultry

Heat stress causes serious losses in poultry production because it increases mortality and reduces performance of poultry. Several nutritional and managemental practices could not completely prevent the negative effect of heat stress. Introgressing some important major genes like Naked neck (Na), and Frizzle (F) into broiler germplasm may substantially improve the heat tolerance. Commercial broiler chickens exposed to cold stress (without brooding during first week of life) during winter season resulted in poor performance. The performance of broiler chicken was hampered due to heat stress whenever the THI exceeded the value of 75.0. The production performance of laying hens maintained at 29^0C with THI of 82.47 in environment-controlled house facility performed better when compared to conventional poultry house. The use of water foggers for spraying water as fine droplets in open sided poultry house during summer season reduced the THI by 2.2 units with reduced egg breakage under semi-arid conditions. Performance and egg shell quality of egg laying chicken can be maintained during summer season by supplementing fiber hydrolyzing enzymes in diet. The three indigenously developed broilers *viz*. CARIBRO-Tropicana (Naked neck and Frizzle plumaged), CARIBRO-Mritunjai (Naked neck plumaged) and CARIBRO-Vishal (Normal plumaged) exposed to three different THIs (i.e., 72, 85 and 91) for 4 hours daily for 7 days exhibited that production traits declined whereas water consumption increased at higher THIs. Respiration rate, body temperature increased at higher THIs. Glucose and ACTH levels increased whereas Na and K declined at higher THIs. Heterophil content and H/L ratio increased whereas lymphocytes content declined at higher THIs. The mRNA expression analysis of HSP-70 in liver revealed higher expression levels at later days during the exposure trials indicated the phenomenon of stress memory and acquired thermotolerance. Among the three genetic groups, CARIBRO-Mritunjai exhibited highest averages for production traits as well as tolerated heat stress in a better way.

8.4. Pre-conditioning and epigenetic thermal adaptation in poultry

Epigenetic temperature adaptation is based on the assumption that environmental factors especially ambient temperature has a strong influence on the determination of ‘set point’ for physiological control systems during “critical developmental phases” of embryonic development. Thermal regulation is regulated by alteration in cellular properties in frontal hypothalamus and this pathway is activated by Brain Derived Neurotrophic Factor (BDNF). These alterations may be modulated by the epigenetic code that determines the repertoire of transcribed proteins. During 10-14 days of incubation a higher temperature (40°C) cycle of 4 h daily were given and the thermally preconditioned chick were exposed to THI 91 for 7 days at the age of 10 days. Thermally conditioned chicks exhibited better performance in terms of body weights, weight gains, feed intake and FCR as compared to control group on re-exposure to THI 91. BDNF gene expression in brain exhibited higher expression levels in thermally conditioned chicks as compared to control group. Approximately, 2-fold increase in DNA methylation was exhibited by thermally conditioned chicks in BDNF gene promoter over the control group chicks. Overall, the thermally conditioned chicks exhibited better performance.

ICAR-DPR has developed a customized electrolyte mixture containing potassium chloride (40.0%), sodium citrate (7.5%), sodium dihydrogen phosphate (2.0%), disodium hydrogen phosphate (2.0%) and sodium bicarbonate (48.5%) for supplementation through the broiler feed. The recommended dose is 1.0 kg t^{-1} of feed and the cost of electrolyte mixture is Rs. 45 kg^{-1}. Dietary supplementation of Ashwagandha extract (0.75%), turmeric extract (0.1%) and Amla powder (1.0 %), Betain hydrochloride (0.2%), chromium @ 0.3 ppm improved the performance of birds by alleviating heat stress during summer season.

9. Way forward

The conventional approaches have tremendously helped in augmenting animal production, however, several challenges are being faced *viz.* the animal populations are reaching to a state of genetic plateau resulting into lowered genetic gains, cost of feed and other resources are escalating due to various reasons, the increasing ambient temperature and weather changing patterns are resulting into stress causing various physiological and reproductive disorders, and the changing market formats and dynamic state of public likings necessitates for diversification and innovation in animal food products and value addition. This scenario dictates the need for discovering / inventing advanced tools and technologies and applying them for improving production and health of livestock species. The advanced tools such SNP chip based genomic selection is expected to increase efficiency of selection and augment the gains. The biotechnological approaches like gene editing, RNAi, transgenesis, etc. may help in augmenting the production and quality of products even beyond the physiological barriers. The artificial intelligence-based precision livestock farming for different species is expected to be the future of livestock farming. The ARTs such as ETT, OPU-IVF/IVEP, semen sexing and animal cloning will be improvised for easier and economic application at the field level. The feed technologies and innovations for improving FCR and alternate feed resources for cheaper feed formulation is an important researchable area. The diversification in products technology and value addition along with traceability-based quality assurance would help in meeting the market demands. The advancements in different areas may be converged with the conventional tools or the different advanced tools may be applied simultaneously as technology package for bringing improvement in quality and quantity of animal produce and products.

10. Conclusion

Livestock sector has made phenomenal growth during the last eight decades with many-fold increase in production and productivity of livestock species, bringing India towards self-reliance in animal products as well increasing export potential of this sector. The concerted and interwoven R&D efforts across different disciplines of animal science have culminated into development of several innovative technologies and products, which have transformed the animal sector into industry such as dairy industry, poultry industry, feed industry, food processing and value addition industry, etc. The advanced tools and technologies are being used in different areas like animal production, health, reproduction, housing and management, livestock products development. Efforts are continuing for improving the performance of livestock and poultry through genetic and /or biotechnological interventions. Improved housing and nutritional interventions are helping in economic production with better animal welfare. The advanced reproductive technologies have tremendous potential in the faster multiplication of the superior germplasm as well as in the conservation of threatened breeds/species. Overall the R&D in animal science is striving for narrowing the gap between demand and availability with regards to animal products to alleviate the problems of malnutrition, thereby making country self-reliant besides expanding export potential in this sector.

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First AI-calf of yak born on July 7, 2006

Vanaraja

Sahiwal bull

Mithun

8
Chapter

Achievements in Fisheries and Aquaculture in Independent India

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Summary

India, with its extensive marine and inland water resources that support diverse aquatic ecosystems, possesses enormous potential to harness its fisheries and aquaculture to support the income, nutritional and livelihood security of its population. Following independence, there has been a strong commitment within the political and scientific community to pursue the above objectives through a science-centric strategy. Strong emphasis was placed on developing institutions and infrastructure that support scientific fishing and fish farming. In the form of systematic surveys and exploratory investigations, the initial goal was to characterize and document the country's fishery resources. The Zoological Survey of India, founded in 1916, was instrumental in this process by conducting extensive research on fish taxonomy and descriptive natural history. Numerous initiatives for the discovery and distribution of fish stocks were conducted, emphasizing the importance of scientific stock management. Recognizing the importance of trained manpower and the need for the sustained scientific pursuit to bring about a significant transformation in the fisheries sector, in 1947 two fisheries research stations, the Central Marine Fisheries Station (later renamed as Central Marine Fisheries Research Institute) and the Inland Fisheries Research Station (later renamed as Central Inland Fisheries Research Institute) were established. These institutions set the groundwork for the country's strong fisheries research base, which has since grown into a pan-India network of research, extension, and teaching in the subsequent decades. The primary focus was to develop expertise in fish stock assessment, fish biology, modernization of fishing craft and gear, standardization of aquaculture protocols for marine and inland fishes, disease diagnostics and management, fishery habitat monitoring and environment management, post-harvest value addition, market development strategies and so on. To cater to the need for trained manpower in the research institutes, the Central Institute of Fisheries Education (CIFE) was established in 1961, along with forming several

Fisheries Colleges in State/Central Agricultural Universities over an extended period. Central Institute of Fisheries Technology (CIFT), established in 1957, focused its research efforts on the development of harvest and post-harvest technology, thereby enabling the country to meet the growing needs of the seafood industry.

The major challenges in fish farming were systematically addressed and several breakthroughs in breeding and hatchery development of major finfishes and shellfishes were achieved during the first three decades after independence. The success of induced breeding of carps by hypophysation in 1957 and large-scale farming of Indian major carps in the 1980s revolutionized carp farming in the country. The research focus on aquaculture was intensified with the establishment of independent institutes - Central Institute of Freshwater Aquaculture (CIFA), Central Institute of Brackishwater Aquaculture (CIBA) and NRC on Coldwater Fisheries (NRCCWF) in 1987 by reorganizing the research centers of CIFRI. These institutes not only strengthened existing aquaculture technologies, but also developed cutting-edge technologies in the aspects of species diversification, strain improvement, diagnostic tools and control of aquatic diseases, modernization of aquaculture systems, feed for cultured species, and other intensive farming systems. Shrimp farming witnessed unprecedented development during the 1990s owing to the renewed research and extension focus. India's fish and fish products exports soared at unprecedented rates during the mid-1990s, making the country a major contributor to the global seafood industry. However, the issues of disease incidence started dampening the growth momentum of the sector during the early 2000s. To address these issues, harnessing the advancements in genetics and biotechnology were mooted. The National Bureau of Fish Genetic Resources (NBFGR), established in 1983 has played a notable role in the above context, apart from its mandated areas of characterizing and cataloging the diverse genetic resources for sustainable utilization and species diversification. New tools of biotechnology and genetics were developed which were utilized for stock characterization and maneuvering suitable genetic traits for fish improvement. The demand from the field also catalyzed significant advancements in developing cell lines, vaccine development, cryopreservation of fish gametes, genomics, biofertilization, bioprospecting, surrogate fish development, genetic engineering, and transgenics, among other areas.

Concerted efforts made by the fishery science fraternity spread across the NARES contributed to double-digit growth of the fisheries sector in the last few decades and currently contributing to 7.28% of the Agricultural GDP in the national economy. India presently holds the distinction of being the 2nd largest aquaculture producer and 4th largest capture fishery producer in the world. Continued growth in fish demand has necessitated many more scientific advances from across the fisheries sector. Several challenges such as depleting water resources, degraded habitats, pollution of water bodies from land-based sources, climate change, the spread of alien species, ocean acidification, excessive culture as well as fishing pressure, the emergence of new aquatic diseases, antibiotic resistance in the culture systems, etc. need focused attention in the future years. Research breakthroughs achieved in the areas of captive breeding and mass production of high-value marine fish species along with advancements in cage farming technology necessitate further advancements in the fields of precision mariculture and artificial intelligence so that greater input use efficiency and automation can be achieved. Further, there is a need to harness the potential opportunities in the areas of species diversification and value addition. High levels of wastage, as well as inefficiencies pervading the fish value chains, need to be tackled through innovative technological and logistic interventions. To address this, and to meet the future needs of entrepreneurship development and the overall sector development, effective mechanisms for technology extension must be put in place. Therefore, new perspectives for inclusive and sustainable growth as well as the scientific impetus in the fields of fisheries research and climate-smart development are being emphasized.

1. Introduction

Fisheries and aquaculture are fast-growing sectors of India's economy that support the nutritional and livelihood security of millions of dependent populations. During 2018-19, the fisheries sector contributed as much as Rs 2,129 billion to the national gross value added (GVA) which accounted for 7.28% of the GVA of agricultural and allied sectors and 1.24% of the total GVA in the triennium ending 2018-19. Estimates show that the sector grew at a rate close to 11% over the last decade surpassing most other sub-sectors of agriculture. Seven decades of Indian independence have witnessed the transformation of India's fisheries sector from one based mostly on capture to one in which aquaculture contributes two-thirds.

Even though fishing and aquaculture are age-old activities, intensive development of the sector in India was driven by well-planned research & development programmes, particularly after independence. These programmes are mostly aimed at fostering investments and technological innovations, bridging legislative and policy inadequacies and promoting local support systems that facilitate efficient harvesting/production, value chain development, and marketing activities. India presently holds the distinction of being the 4th largest producer in capture fisheries and 2nd largest producer in aquaculture in the world. India's total fish production during 2019-20 stands at 14.16 million tons (Mt), which is about 7.6% of total global fish production (Fig. 1). Fish and fish products also earn considerable foreign exchange for the country worth over UD$ 6.73 billion.

During the early few decades after independence, marine fisheries received a considerable focus in terms of capital and infrastructure development. About 70% of total fish production during the 1950s was of marine origin. Subsequently, growth in marine fish landings was brought about through mechanization of fishing and intensification in efforts through multi-day trips aided by advanced navigation, scouting, and fish-finding techniques. This led to a steady improvement in marine fish landings that rose from about 0.5 Mt to a peak of 3.9 Mt in 2012. Aquaculture picked up momentum during the 1970s with carp farming in freshwater and late 1980s with advances in shrimp farming, gradually enhancing its relative share in total fish production. India presently produces about 9 Mt through aquaculture, which is about two-thirds of the total fish production. With 6-7% average annual growth in the last three decades, freshwater aquaculture is sharing about 90% of total aquaculture production. Brackishwater aquaculture was reliant mostly on black tiger shrimp (*Penaeus monodon*) during the 1990s & 2000s but was subsequently shifted to the introduced species, white-leg shrimp (*Litopenaeus vannamei*). Mariculture is another promising segment, touted to have considerable future potential in the wake of successful demonstration of cage culture all along the coasts of the country during the last decade.

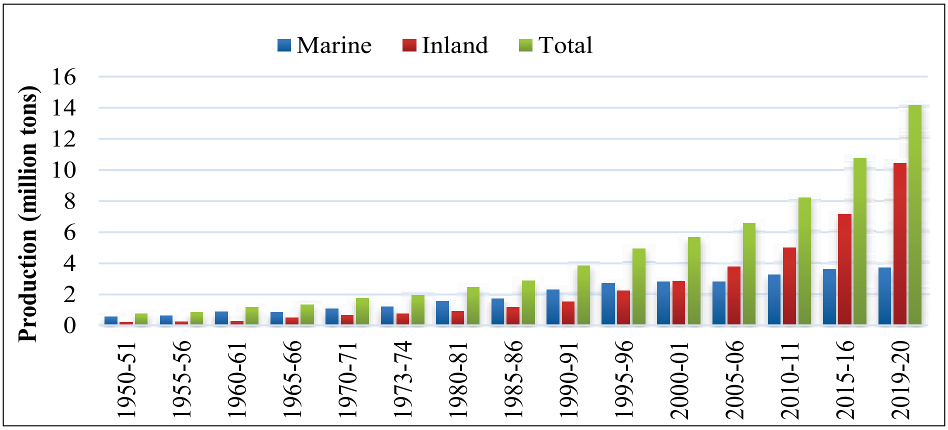

Fig. 1. Trends in fish production in India during the post-independence period

Much of the above achievements were catalyzed by sustained research and extension efforts coordinated through the research institutes and universities under the National Agricultural Research and Education System (NARES). The Indian Council of Agricultural Research (ICAR) with its eight fisheries research institutes has played a significant role in bringing about a noteworthy transformation that altered the lives of millions of fishers, fish farmers and other stakeholders across the value chain. This chapter attempts to document the key milestones as well as the major scientific achievements that aided in this transformation.

2. Milestones in fisheries and aquaculture

Post-independence fisheries research in India during its initial years focused on the biology of commercially important species, including age and growth, food and feeding, reproduction, migration, ecosystem productivity, biodiversity, estimation of fishing efforts and landings, and fisheries-related environmental studies (Silas, 2003). These studies included both marine and freshwater fishes from diverse open-water systems. The focus shifted from hydro-biology to ecosystem dynamics, primary productivity, prey-predator interactions, and so on. Adaptation and mitigation of climate change, pollution of water bodies, bioassay, bioremediation, and other aspects have also received much thoughtfulness. Innovations in harvesting and post-harvest technologies increased the efficiency of capture fisheries operations greatly in post-independent India. The most significant technological advances that have aided the evolution of fish harvest and post-harvest technology are (i) advancements in craft designs, mechanization of propulsion, gear operations, and handling of fish catch, (ii) use of synthetic components for fishing gear, (iii) satellite-based remote sensing techniques and innovations in acoustic fish detection, (iv) advancements in navigation, (v) development of preservation and processing techniques for fish, and (vi) development of quality and safety standards (Ayyappan et al. 2011).

In 1957, the breakthrough in induced breeding of carp garnered significant attention in aquaculture research. Researchers succeeded in standardizing breeding protocols, mass-scale seed production techniques, and nursery rearing and fingerling production protocols for prioritized cultivable species, resulting in increased yields (Ayyappan and Jena 2001). Following this, silver carp and grass carp were introduced, with a polyculture protocol developed later with Indian major carps. Continuing efforts in this direction led to the development of breeding and seed production technologies for other species such as catfishes, minor carps, murrels, freshwater prawns, and other species. In parallel, efforts were also made to develop improved fish strain through selective breeding, nutrient management, and disease management. Initiation of the All India Coordinated Research Projects (AICRPs) by the ICAR *viz*., Composite carp culture, and Brackishwater fish farming in the 1970s helped in validation and refinement of the packages of practices of scientific carp polyculture and farming of brackishwater species including shrimps.

Hatchery seed production of black tiger shrimp and Indian white shrimp (*Penaeus indicus*) and the development of semi-intensive farming technologies were prioritized areas that received utmost attention. The introduction of exotic *L. vannamei* in 2009 and its successful adoption in the subsequent years was made possible through concerted efforts towards environmental impact assessment studies, development of quarantine measures, biosecurity at the farm/hatchery level, adoption of better management practices (BMPs), sustainable intensification protocols, etc. The introduction of improved culture methods paved way for research on the productivity and efficiency of culture systems. Recent breakthroughs in captive breeding, seed production, and grow-out technologies of marine and brackishwater fishes such as cobia, pompano, seabass, grouper, milkfish, grey mullet, pearl spot, etc. are expected to accelerate the growth of diversified brackishwater farming and mariculture in the coming years. Efforts are also directed towards the standardization of fattening protocols for crabs and the culture of mussels, oysters, seaweeds, etc.

In recent years, several frontier areas of research have garnered considerable attention from the scientific community, including genetic engineering, cell line development, genomics, stem-cell culture, cryopreservation of fish gametes, vaccines, biofertilization, bioprospecting, etc. (Ayyappan et al. 2015). Additionally, emphasis is placed on post-harvest value addition to develop methods for preserving the quality of fish and fish products. Numerous industrial products were developed from low-valued fishes or other fishery byproducts. Significant effort was also devoted to the advancement of packing technology and the enhancement of processing machinery. As with biological and frontier science research, socio-economic and extension research has played a vital role in recent years in changing the fisheries sector. Some of the thrust areas in this realm include socio-economic evaluation of capture and culture systems and their efficiency studies, impact assessment of technologies, market and trade research, value chain studies, gender research, fisheries policy and legislation, information and communication, etc.

2.1. Achievements in capture fisheries

2.1.1. Marine fisheries

India's marine fisheries was of subsistence nature during the early 1950s producing about 0.5 Mt annually which, however, achieved remarkable development during the last six decades. The establishment of the Marine Fisheries Research Station (presently ICAR-Central Marine Fisheries Research Institute or ICAR-CMFRI) on 3rd February 1947 at Madras University, Tamil Nadu, which later shifted to Mandapam Camp, Tamil Nadu in 1949, was a significant step forward by the Government of India. The current annual production of about 3.8 Mt - a 7.5 times increase in the last seven decades is a testimony of the development made by the sector. Supported by a coastline of 8118 kilometers, an exclusive economic zone (EEZ) of 2.02 million km^2 and a continental shelf area of 0.53 million sq km, the present catch level constitutes about 71.6% of the revalidated fishery potential of 5.31 Mt, comprising 4.92 Mt from 0-200 m depth, 0.097 Mt from 200-500 m depth, 0.17 Mt of oceanic resources and 0.12 Mt from Andaman & Nicobar and Lakshadweep Island ecosystems. Research efforts in the areas of exploratory surveys, mapping for productive fishing grounds and virgin areas, biology of commercially important species, stock monitoring, judicious exploitation and conservation, environmental assessments, and mechanization of crafts and gears, besides infrastructure developments over the years have contributed to the growth in the sector. The artisanal sector contributed to most of the fish landings up to the sixties. Subsequent growth in mechanized fishing along with the motorization of artisanal crafts led to the drastic decline in the share of the artisanal sector in fish landings. Presently, the mechanized sector accounts for 83%, motorized 16%, and the artisanal sector only 1% of total marine fish catch. The growth in marine fisheries resulted in significant increases in production, employment generation, and domestic and export earnings.

2.1.1.1 Developments and adoption of harvest technologies

Mechanization of fishing craft in India occurred in four stages, beginning with the motorization of some conventional designs of traditional crafts, progressing to the introduction of more specialized motorized crafts, and finally to the establishment of a full-fledged fishing fleet. Since 1953, attempts were made to motorize many traditional vessels prevalent locally like the *Lodhia, Machuwa, Kotia* and *Satpati-Versova* type vessels (Zeiner et al. 1958). The Indo-Norwegian project established in 1953 at Kollam, Kerala with the objective of modernization of fisheries and allied activities and later operational from Cochin made a significant impact on the overall fisheries development of the country. In 1962, the project introduced 25 feet boat with 16 hp diesel engines that could use as a small shrimp trawl. The project had also introduced vessels of different length classes and suitable gears to operate from these vessels.

The Central Fisheries Technology Research Station established at Cochin in 1957, which was later renamed as Central Institute of Fisheries Technology (CIFT) contributed significantly to the harvest and post-harvest sectors of fisheries by developing vessel designs in association with Naval architects from FAO and designing and optimizing different gear designs. The institute played a major role in developing the post-harvest sector, in which the major achievements were the development and optimization of freezing techniques for export and the development of quality standards for the export items. FAO/UNDP-supported Pelagic Fisheries Project operated in two phases during 1971-1975 and 1976-79 also contributed significantly to the fisheries development. The Marine Products Export Development Authority (MPEDA), established in 1972 under the Ministry of Commerce, Government of India, has been promoting the export of fishery products from the country. FAO's Bay of Bengal Programme in the 1980s built fiberglass beach landing crafts for use off the surf-beaten shores of Tamil Nadu and Andhra Pradesh.

The ICAR-CIFT, in collaboration with naval experts from the FAO, introduced twelve standard designs of wooden fishing boats ranging in size from 7.67 to 15.24 meters for various types of fishing operations, providing a significant boost to India's fisheries mechanization programme. More than 80% of the motorized wooden fishing crafts of India's fishing fleet are said to be based on the popular CIFT design or its later derivatives. The Institute has also developed newer designs of trawl gear with improved selectivity and reduced negative environmental impacts to protect the biodiversity and environment and ensure the long-term sustainability of fishery resources. The trawl net gained substantial adoption among the fishers of all coastal states and presently is the most important gear in marine waters contributing more than 50% of the catches from the Indian waters. The harvest of prawns and shrimps from deep waters witnessed a notable jump through trawl fishing that targeted demersal fishes and mid-water pelagic fishes.

Fig. 2. F.V. Sagar Harita at deep sea

The generation of by-catch from low-selectivity fishing gears has been a matter of concern in commercial fishing. This is particularly of concern in trawl nets and proved to be destructive in terms of juvenile catches. The by-catch reduction devices (BRD) developed by ICAR-CIFT have been able to address this problem. Square mesh cod-ends, Fisheye BRD, Sieve Net BRD, Juvenile Fish Excluder cum Shrimp Sorting Device (JFESSD), etc. are some of the BRDs that were field-tested for their effectiveness. Several state governments have stipulated the use of square mesh cod ends in trawl nets to check the incidence of juvenile catches. Species that are at risk due to climate-induced changes such as sea turtles and other Endangered Threatened and Protected (ETP) species often form a by-catch in different gear systems like trawls and long lines. Field studies indicated that the use of Turtle Excluder Devices (TEDs) helps release turtles getting in the way of trawl nets and circle hooks, thereby resulting in lower mortality rates. The use of pingers acts as a deterrent to Cetacean species and results in their interaction with fishing gear like seine nets.

ICAR-CIFT has carried out extensive research to improve the fuel efficiency of fishing vessels and in 2016 developed a 19.75 m energy-efficient combination of deep-sea fishing vessels with approximately 9% fuel-saving features, which is now accepted as a standard design for India's efforts towards improving harvest from relatively less exploited deep-sea resources in the Indian EEZ. Reducing the trawling efforts and emissions, and better catch quality are other collateral gains of this innovative design.

2.1.1.2. Marine Fish Landing Estimation and Fish Stock Assessment

New fishing crafts and gears technology led to a substantial increase in landings of various resources, pushing the research initiatives on the estimation of resource-wise marine fish landings. To develop a statistically sound database on catch and effort that can aid in stock assessment exercises, pilot studies were conducted by ICAR-CMFRI resulting in the development of Multistage Stratified Random Sampling (MSRS) Design for building up a time-series database on gear-wise, species-wise and season-wise marine fish production of the country during the early 1950s to 1970s. A time-series database was generated including gear-wise, seasonal and spatial fish catch data for major commercial resources. This was supplemented with real-time fishery surveys conducted by the Fishery Survey of India (FSI). This sampling scheme is still in use for collecting marine fish landings data making it probably the longest-running sampling scheme in marine fisheries, at least among developing nations. Initial forays into stock assessment began with the estimation of growth and mortality parameters of Indian oil sardine and Indian mackerel during the 1960s. The first group of fish stock assessments included stock assessments of 14 species comprising fish, shrimp and cephalopods. Following this, stock assessments of over 40 commercially important resources of the Indian EEZ were carried out applying length-based methods. In the most recent round of stock assessments, 67 stocks of marine finfish and shellfish were assessed, and it was found that 86% were being fished within biologically sustainable levels *i.e.*, yields from these stocks are yet to attain Maximum Sustainable Yield (MSY). In addition to traditional length-based single species stock assessment models, ICAR-CMFRI has also moved into assessments using multi-species models, biomass dynamics models and ecosystem-based models.

Table 1. Milestones in marine capture fisheries research

Year	Milestone
1948	First attempt towards scientific estimation of marine fish catch.
1950	Initiation of pilot surveys across the country to assess the marine fish stock status.
1953	Launch of the Indo-Norwegian Project for modernization of fishing crafts.
1957-58	First Marine Fisheries Census was carried out.
1959	Introduction of stratified multi-stage random sampling techniques for fish landing estimation.
1962	Trawl net designs were developed for Indian conditions.
1970	The first major attempt to estimate the Potential Yield of fishery resources in the Indian Ocean region using primary productivity estimates.
1974	Purse seining in the small-scale mechanized sector started for the first time.
1977	Indo-Polish Industrial Fishery Survey for Pelagic resources.
1980	Marine Fisheries Census covering 7 maritime states carried out.
1982	Mini purse seine called ring seine was introduced.
1991-2018	Potential Yield Estimation (PYE) of the marine fishery resources from the Indian EEZ in 1991, 2000, 2011 and 2018.
1992	Tuna longlining became an established method of fishing for deep-sea fisheries.
2005-16	Marine Fisheries Census was conducted in 2005, 2010 and 2016.
2016	Energy Efficient Green Fishing Vessel *FV Sagar Harita* launched.
2021	Stock assessment of 67 stocks of marine finfish and shellfish was carried out.

2.1.2. Inland fisheries

The establishment of the Central Inland Fisheries Research Station on 17th March 1947 at Barrackpore, West Bengal which was elevated to a full-fledged institute in 1959 - the Central Inland Fisheries Research Institute (CIFRI), was a testament to the R&D thrust given by the Government of India for the development of open-water fisheries even before the independence of the country. The country's inland water resources include 29,000 kilometers of rivers, 0.3 million hectares (Mha) of estuaries, 0.19 Mha of backwaters and lagoons, 3.5 Mha of reservoirs, 0.5 Mha of floodplain wetlands, and 0.72 Mha of upland lakes, which annually contribute approximately 1.3 Mt of fish.

2.1.2.1. Riverine and estuarine fisheries

India's river systems consist of 14 large rivers, 44 medium rivers, and an infinite number of tiny rivers and desert streams. Studies have shown that the fish production of these riverine systems varies from 0.64 to 1.64 tons per km with an average of 1 t km^{-1}. With a combined length of 12,500 kms and a drainage area of 1,060,000 km^2, the River Ganga and its tributaries have garnered considerable attention from scholars since the independence of the country. Over the years, the construction of barrages in the majority of its tributaries has resulted in flow diversion, resulting in decreased fish capture and species variety loss

(Payne et al. 2004). In general, Indian major carp, followed by catfish, murrels, and other miscellaneous species, contribute to fish catches in major riverine systems, except peninsular rivers, where endemic species predominate. Extensive research has been conducted to highlight critical variables like overfishing, habitat damage, pollution, sedimentation, and water abstraction that have contributed to the catch declines over the years. While the introduction of non-selective gear with a reduced mesh size has slowed the recruitment of important commercial species, damaging fishing techniques such as dynamiting and poisoning pose hazards to biodiversity. CIFRI's spawn prospecting experiments in the 1960s resulted in the formulation of a system for riverine spawn gathering and site selection. The efficiency of shooting nets in collecting spawn in the shallow margins of flooded rivers aided in the exploitation of major carp seed resources from major riverine systems. The ICAR-CIFRI has recently re-estimated the production potential of selected stretches of Ganga. To address the declining trend of fish production, measures like ranching, habitat characterization and protection, fishing ban, and application of GIS and remote sensing technology for resource mapping are suggested. To understand the dynamics of river hydrology and ecology, since 2010 ICAR-CIFRI has studied the environmental flow of several Indian rivers such as Teesta, Cauvery, Mahanadi and Kathojodi. River ranching has been undertaken in different rivers by varied organizations from time to time as an important strategy for sustaining the fisheries of commercially-important species. Since 2016, ICAR-CIFRI has been carrying out a massive ranching programme with the release of over 4.5 million advanced fingerlings of Indian major carps in depleted stretches of the River Ganga covering states like Uttarakhand, Uttar Pradesh, Bihar, Jharkhand & West Bengal with the funding support of the National Mission for Clean Ganga (NMCG). The diverse estuary systems covering about 300,000 ha also provide a sizable portion of India's fisheries resources. The Hooghly-Matlah estuary, the largest estuary system in the country, captures approximately 66,200 tons of fish year^{-1} along a 296-kilometer stretch.

2.1.2.2. Fisheries enhancement in reservoirs and wetlands

The average annual fish yield of small, medium and large reservoirs was 49.9, 12.3 and 11.4 kg ha^{-1} yr^{-1}, respectively as against the potential yield of 100, 75, and 50 kg ha^{-1} yr^{-1} (Sugunan 1995). Considering such immense potential, the Government of India had initiated schemes for reservoir fisheries development through fingerling stocking programmes with technological backstopping from ICAR-CIFRI. With such interventions, the fish yield from Indian reservoirs in recent years increased to 190, 98 and 34 kg ha^{-1} yr^{-1} against a reassessed potential of 500, 200 and 100 kg ha^{-1} yr^{-1} from small, medium and large reservoirs respectively. Of late, the adoption of cage culture technology was proved to be a viable option to harness the potential of such resources. While the pangas catfish *Pangasianodon hypophthalmus* has been the species of choice for cage culture across the country due to its higher growth and production potential, other diversified species are being evaluated for a higher return. Yield levels of 2.5-3.0 tons of pangas are achieved in cages of 6 m x 4 m x 4 m in a 6-8 months culture period. ICAR-CIFRI has recommended the adoption of cage culture mainly in medium and large reservoirs accounting for about

1.67 million ha and thereby showing the availability of at least 1,500 ha of water area for installation cages by taking only 0.1% of the available water area. Surveys in Chhattisgarh, Maharashtra, Gujarat, Odisha and Jharkhand showed that an entrepreneur/fisherman could earn a net return of Rs. 60,000-1,50,000 cage^{-1} year^{-1}. The cage culture technology has been further refined and diversified with GI Model Cage for better adoption and profitability. At present, there are about 20,000 floating cages in place producing over 50,000 tons of fish and generating employment of 0.8 million man-days year^{-1}. The technology has paved new avenues for entrepreneurship development due to high production and profitability.

Wetlands or *beels* are among the most productive resources offering multiple ecosystem goods and services. The fish yield realized from floodplain wetlands was low, between 50-200 kg ha^{-1} yr^{-1} during 1990-2000, due to a lack of scientific management guidelines. With the intervention of ICAR-CIFRI, culture-based fisheries were adopted in various wetlands which resulted in increasing the fish yield to 200-400 kg ha^{-1} yr^{-1} in the Eastern and North-Eastern regions. The adoption of ecosystem-based integrated wetland fisheries management and the funding support from the National Fisheries Development Board (NFDB) has resulted in further improvement in fish production and an average fish yield of 400-800 kg ha^{-1} yr^{-1} was realized during 2010-20. Recently ICAR-CIFRI has also commercialized *CIFRI HDPE Pen* and developed policy guidelines for sustainable wetland fisheries management.

Table 2. Milestones in inland fisheries research

Year	Milestone
1950	Discovery of hilsa spawning grounds in Hooghly estuary Near Palta, West Bengal.
1957-61	Inventory of all the fishing villages along the Ganga (920 miles stretch), the Yamuna from Agra to Allahabad (500 miles) and the Tapti River (230 miles).
1960	Initiation of Database inventory on catch statistics and information of fish and fisheries of rivers, estuaries, reservoirs, lagoons and wetlands.
1978	Initiation of environmental pollution research-heavy metals and pesticides detection in rivers and estuaries.
1990-2010	Adoption of culture-based fisheries in reservoirs across the country by the State Governments with technical support of ICAR-CIFRI.
1993	Management guidelines of estuarine fisheries and sewage-fed estuarine wetlands.
2002	GIS mapping of inland water bodies.
2010-2020	Ecosystem-based integrated wetland fisheries management and commercial use of CIFRI HDPE Pen in Eastern and NE regions of the country.
2012-2021	Cage culture demonstration in reservoirs across the country for fish seed raising and table fish production and large-scale adoption of the technology.

2.1.3. Coldwater fisheries management

The water resources of high-altitude harbour rich Ichthyofaunal diversity, of which the majority are food fishes while others have potential ornamental and sports value. The commercially important indigenous species are mahseers and snow trout. The common exotic coldwater sport and food fishes include trouts (brown trout, *Salmo trutta fario*; rainbow trout, *Oncorhynchus mykiss*), and common carp. Research in coldwater fisheries in India began only in the 1960s. Fish production from the coldwaters falls short of expectations for a variety of reasons, *viz*., low productivity of upland waters, slow growth rate of fish species, and the low fecundity of fish species. ICAR-Directorate of Coldwater Fisheries Research (DCFR) has developed and standardized the breeding protocol of several indigenous food and ornamental fishes and disseminated the same to the farmers for employment generation through small-scale entrepreneurship. GIS-based resource mapping, the development of location-specific water conservation models for fish culture, genetic improvement programmes for commercially important species, and the development of thermal tolerance strains, etc. are a few areas being investigated to improve catches from coldwater fisheries. Sport fisheries being a vital activity in upland states, enhancing trout and mahseer population in hill streams and lakes through effective resource management and ranching programmes are of paramount importance.

2.1.4. Climate change and fisheries management strategies

Extensive studies have been conducted to assess the impact of climate change on marine fisheries and the development of management strategies, especially through the project on 'National Innovations in Climate Resilient Agriculture (NICRA)' operated by ICAR for the last one decade. Vulnerability maps have been prepared for coastal villages in eight districts in maritime states and developed Integrated District Level Adaptation and Mitigation (IDLAM) plans. The study following Life Cycle Analysis (LCA) showed that the carbon footprint for wild-caught marine fish in India is 17.5% lower than the global average. Using the climate change-fish biomass model the annual catch of Indian oil sardine was forecasted. These studies helped in developing management strategies and mapping of distributional shifts for 68 commercially important marine species based on the vulnerability assessment. Further, an adaptation framework based on the alternation in the distribution and abundance of 14 selected marine species due to changes in phenology, diet, and reproductive pattern impacted by increasing sea surface temperature (SST) was also developed. Citizen Science networks and climate clubs were created to generate climate-related information based on opportunities for awareness as well as data generation in sensitive ecosystems including marshy wetlands. The ecosystem of the Ganga River has experienced atmospheric temperature rising thus resulting in abnormalities of the heat budget of the riverine ecosystems. Natural recruitment of Indian major carps in the Ganga River System has been largely affected, resulting in a decline in fish spawning due to the impact of climate change. A considerable decline in fish seed availability has been noticed from 78.8% in the 1960s to 34.5% in 2004 (Vass et al. 2009). A digital elevation model generated for the coastal district of south 24 Parganas indicated the potential for 3-11% submergence of aquaculture areas in response to sea water incursions.

2.2. Developments in aquaculture

2.2.1. Freshwater aquaculture

Fish rearing was a traditional activity in India's freshwater impoundments, which were largely restricted in the eastern states. With the establishment of Fisheries Departments in certain states in the early twentieth century, attempts were made to initiate the fish culture practices. However, fish farming by then was based on the riverine seed collection and lacked basic scientific principles. Efforts to understand the reproductive physiology of major freshwater fishes yielded fruits only after independence. During the post-independence period, the research thrust was focused on fundamental studies aiming at artificial fish propagation, the introduction of exotic fast-growing species, and the popularization of fish production technology through widespread demonstrations of fish farming. The ICAR-CIFRI through its Pond Culture Division established at Cuttack in 1949, its subsequent up-gradation to the Freshwater Aquaculture Research and Training Centre (FARTC) at Kausalyaganga, Bhubaneswar in 1976 and further elevation of FARTC to an independent institute in 1987, the ICAR-Central Institute of Freshwater Aquaculture (CIFA), truly led the freshwater aquaculture research in the country.

Modern aquaculture research has been focused on three Indian major carps. The introduction of exotic species with faster growth rates, viz., grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*) and common carp (*Cyprinus carpio*) into the carp polyculture system was one of the first steps taken during post-independence to increase fish productivity in ponds. Several new species were brought into the culture system to increase productivity and farm income. Silver barb (*Puntius gonionotus*), African catfish (*Clarias gariepinus*), striped catfish (*Pangasianodon hypophthalmus*), Tilapia (*Oreochromis niloticus*) and red-bellied pacu (*Piaractus brachypomus*) are a few some of them, however, were illegally introduced. With required environmental impact assessment studies and formulation of guidelines, striped catfish was later approved for farming in different culture systems. Such species have gained widespread acceptance and contribute significantly to aquaculture production. In 2009 the Government of India permitted Rajiv Gandhi Centre for Aquaculture (RGCA), and three other Farmers' groups for seed production and farming of GIFT (Genetically Improved Farmed Tilapia) tilapia, and as per the suggestions of the National Committee on 'Introduction of Exotic Aquatic Species', guidelines were also developed for commercial farming of tilapia.

2.2.1.1. Breeding and hatchery development of finfishes and freshwater prawn

The collection of seed from the rivers was the only source of seed supply until the 1950s in the country. The technology of *Bundh* breeding in the 1960s, which become popular in West Bengal and Madhya Pradesh in particular was the first success towards controlled breeding in India. Though two types of *bundh* breeding techniques, viz., the perennial (wet bundh) and the seasonal or dry bundh were followed for fish seed production during the 1960s-1980s, they were largely dependent on the environmental conditions and were with limited success. With the development of induced breeding and larval rearing techniques for several commercially important fish and shellfish species subsequently, the seed requirement at present is completely met by hatchery-produced seed. The studies on inducing maturation of fishes covered a wide range of inducing agents *viz*., HCG, LHRH, LHRH-a and homologous and heterologous fish pituitary gland extracts. The first effective induced breeding of carp, however, was achieved in *Cirrhinus reba* on 10th July 1957. In just 15 days, all the three Indian major carps were then successfully induced bred (Chaudhuri and Alikunhi 1957). Induced breeding with the injection of carp pituitary gland (PG) extract created a novel seed production avenue (Chaudhuri 1960). The efficiency of the PG extract was reliant on the freshness, potency, and storage processes of the gland, which, however, made its use challenging due to potency inconsistencies. It also required two injections and too much handling of brooders resulting in post-spawning mortality. The technology of induced breeding became simple and user-friendly after the development of the synthetic hormone 'Ovaprim' by Syndel Laboratory in Canada. It was subsequently standardized for effective use in carps and later in other fishes in the country. Several other inducing agents are presently available for use. The breeding technique has been standardized for >40 commercially-important freshwater food fishes apart from many ornamental fishes (Raizada et al. 2019). ICAR-CIFA developed a protocol for multiple spawning, which involves breeding the same brooders four times within the same season (Gupta et al. 1995). The multiple spawning technique demonstrated 2-3 folds higher spawn recovery over conventional single breeding. Standardization of cryopreservation technique for carp milt in the 1990s lowered the requirement of male broodstock population in hatcheries overcoming the problem of inbreeding in many hatcheries. Manipulation of the environment for off-season carp breeding was also attempted with photothermal regulation in the 2000s resulting in an extension in the breeding season (Sarkar et al. 2010). Further, the development of a broodstock diet CIFABROOD™ ensured early broodstock maturation, the commercial availability of which is facilitating early breeding in carps. Along with the advancement of fish breeding research, significant advances were also made in the development of different hatchery systems, from the simple hatching pit to the current eco-hatchery. The eco-hatchery system is continued as the principal method of mass-scale carp seed production. Of late, the portable FRP hatchery system has been developed by ICAR-CIFA for decentralized seed production even in remote areas.

With increased focus on species diversification, technologies were also developed for breeding and seed production of several other important cultivable species over these years which include the minor carps and barbs (kalbasu *Labeo calbasu*, fringed-lipped carp *L. fimbriatus*, Kuria labeo *L. gonius*, bata *L. bata*, Olive barb *Systomus sarana sarana*, pengba *Osteobrama belangeri*, etc.), murrels (*Channa striata* and *C. marulius*), climbing perch (*Anabas testudineus*), and catfishes (magur *Clarias magur*, singhi *Heteropneustes fossilis*, pabda *Ompok pabda* & *O. bimaculatus*, yellow catfish *Horabagrus brachysoma*), etc. (Jena et al. 2020). With the increased popularity of farming of the striped catfish (*Pangasianodon hypophthalmus*) and to meet the seed demand, indigenous hatchery models were developed by the farmers of West Bengal.

The development of the seed production technology for freshwater prawns was another milestone in the freshwater sector. Following the successful closure of the life cycle of the giant freshwater prawn (*Macrobrachium rosenbergii*) in captivity, a successful hatchery model was developed at ICAR-CIFA. The seed requirement of *M. rosenbergii* was met by establishing commercial hatcheries in the coastal states. Following this success, a similar hatchery system was also developed by ICAR-CIFA for the two other prawn species viz., *M. malcolmsonii* (Indian River prawn) and *M. gangeticum* (Ganga River prawn). Considering the necessity of saline water of about 12% for seed production of *M. rosenbergii*, ICAR-Central Institute of Fisheries Education (CIFE) also developed the hatchery technology of the species with the use of artificial seawater, which was demonstrated in several land-locked states.

2.2.1.2. Seed rearing

Development of the seed rearing technique was the other concurrent progress that took place along with the induced breeding. With continued efforts towards the development and standardization of seed rearing technology, packages of practices were developed for two-tire seed rearing in carps i.e. (a) nursery phase, where the spawn of 6-7 mm size are reared at 5-10 million ha^{-1} to fry of 20-25 mm in 15-20 days, and (b) rearing phase, where the fry are reared at 0.2-0.3 million ha^{-1} to 6-10 cm fingerlings in 75-90 days. The packages of practices of the basic rearing technology involved pre-stocking pond preparation (eradication of unwanted fishes and aquatic insects, pH correction, manuring/fertilization), seed stocking (stocking density, species ratio, acclimatization), post-stocking pond management (maintenance of natural productivity through manuring/fertilization, supplementary feeding, health management), harvesting and seed transport (conditioning, packaging and transport condition). Effective management of the pond ecosystem including maintenance of water quality was given prime importance during the rearing period. Most of the basic technologies of carp seed production are credited to the efforts of the Pond Culture Division of CIFRI at Cuttack during the 1970s, and subsequently at FARTC and ICAR-CIFA, Kausalyaganga, Bhubaneswar (Ayyappan et al. 2015). Until the beginning of 21st century, earthen pond was the basic resource used for seed rearing of carps and it was often marred with poor seed survival and growth. The effectiveness of concrete tank systems for high-density seed rearing has been demonstrated not only in carps but also for other species. The better-controlled environment in the tank system has made it possible to achieve higher growth, survival and input use efficiency. With the increasing demand for larger seeds for grow-out stocking in recent years, the development of another tier of seed rearing is gaining increasing focus to raise stunted juveniles around the year.

Seed rearing techniques for species other than carps are mostly species-specific and are evolving over the years with regard to stocking density and the requirement of different inputs. Most of the catfish during early life stages show cannibalism and hence require periodic size segregation to improve seed survival. A similar technique is also being used for the rearing of murrel seed. The early larval stage of magur requires lower water depth (8-10 cm) in the tanks as the larva has to travel from the water column to the surface for obligatory air-breathing. Indoor rearing is done during the 1st phase of rearing @ 2000-3000 m^{-2} for 12-14 days in well-aerated tanks to reach 10-12 mm fry (30-40 mg) size. The 2nd phase of rearing for 30 days is carried out at 200-300 m^{-2} density in outdoor tanks provided with a 6-8 cm soil base to reach the fingerlings size of 3-4 cm (0.8-1.0 g). In the case of freshwater prawns, the post-larvae are reared at high stocking densities of 2000-5000 m^{-2} for 10-15 days.

2.2.1.3. Grow-out production technologies in fishes and freshwater prawn

The carp polyculture technology, frequently referred to as composite carp culture, was developed by the erstwhile Pond Culture Division of CIFRI in the 1960s and 1970s involving three Indian major carps, namely catla, rohu and mrigal only, and with a combination of three Indian major carps and three exotic carps, namely silver carp, common carp and grass carp (Alikunhi et al. 1971; Chaudhuri et al. 1974, 1975). It has been the most important grow-out culture technology practiced in the country, however, with several need-based modifications by the farmers in different regions. The development of this technology involved systematic trials with varied species combinations and densities which again depended on the information generated on biology, habitat preference, food and feeding habits, growth rate and compatibility of important species. This was a major contributing factor in the 'blue revolution' in the country. Much of the subsequent research and development on this subject was conducted through an All India Coordinated Research Project (AICRP) on 'Composite Culture of Indian and Exotic Fishes', initiated by the CIFRI in 1971 and renamed 'Composite Fish Culture and Fish Seed Production', which operated at 12 locations until 1984. During 1989-94, ICAR-CIFA undertook a major research programme on intensive carp culture and achieved higher fish production levels of 10-15 t ha^{-1} yr^{-1} with the use of balanced supplementary feed, biofertilization with *Azolla* and aeration (Tripathi et al. 2000). This was a landmark achievement in freshwater pond production. A large number of developmental projects starting from the 1960s helped towards effective dissemination of the technologies.

Even though the introduction of exotic silver carp: grass carp and common carp into the carp polyculture system could demonstrate achieving higher production, their incorporation into the commercial farming practice has remained low due to low consumer preference. However, common carp has been one of the important sought-after species, especially for seasonal water bodies. Production levels of 4-5 t ha^{-1} yr^{-1} with the adoption of technology of carp polyculture although is quite a common feature in most parts of the country, higher production levels of 8-12 t ha^{-1} yr^{-1} are being achieved by several farmers in Andhra Pradesh, Punjab and Haryana (Ayyappan and Jena 2005).

With the emphasis on species diversification, efforts have been made to introduce several minor carp species into the conventional major carp-based carp production system in several states. A new concept 'minor carp inter-cropping in carp polyculture' has demonstrated 20-25% higher yield and over 30% higher profit. With the extensive promotion of ICAR-CIFA, the Olive barb has now been well established in the culture system of eastern and north-eastern states. Such an effort has also helped in recovering the species from the IUCN status of 'Near threatened' to 'Least concerned' at present. Similarly, the promotion of pengba during the last decade has helped its spread from north-eastern states to Odisha and West Bengal. Olive barb, kalbasu and pengba are also being promoted by the National Freshwater Fish Brood Bank (NFFBB) established in Bhubaneswar by the National Fisheries Development Board (NFDB). Species like fringed lipped carp and kuria labeo have also been promoted in the culture sector in different states, but the adoption of the latter has not been so far impressive due to its slower growth. Whereas, the exotic silver barb has been widely adopted in many Indian states. Initial faster growth, wider feed acceptability, small head size, and good appearance, besides auto-breeding habit, have been the advantages for its growing adoption of farming along with major carps.

Research over the years has led to the development, refinement and standardization of a host of technologies with varying production levels depending on the input use. Specific low input-based farming involving aquatic macrophytes-based carp polyculture, and biogas slurry-fed fish culture could also demonstrate impressive production levels of 3-4 t ha^{-1} yr^{-1}. Multiple cropping, with two crops in a year, single stocking-multiple harvest, and multiple stocking-multiple harvests are some of the culture systems which proved to be advantageous over the year-long mono-cropping practice.

Striped catfish has become the second leading cultured species after the Indian major carp group in the pond culture system and is also a prime choice for cage culture in the open waters. Although the species had an illegal introduction during the 1990s, the higher growth potential, culture feasibility at high-density under monoculture, and most importantly the government nod that was given for its culture in 2005 after due environmental impact assessment study have helped its expanded farming. Andhra Pradesh has been at the forefront of striped catfish culture where the area coverage has steadily increased since the early 2000s to reach the maximum of 32,000 ha in 2010 with yield levels of 17-20 t ha^{-1} (Belton et al. 2017). Under an intensive culture setup, with the use of floating feed, higher yield levels of 40-50 t ha^{-1} are also often reported. Of late, increased adoption of the species in other states viz., Chhattisgarh, Bihar, Jharkhand, Uttar Pradesh, Punjab, etc. under both pond-based and cage culture systems, however, has led to reduced market price, leading to shrinkage of area coverage in Andhra Pradesh (Belton et al. 2017). Pacu is another important species widely adopted by the farmers despite its pending government approval. The increased popularity of the species has paved the way for its entry into the seed supply chain. With the start of its culture in the West Godavari district of Andhra Pradesh in 2004 (Ramakrishna et al. 2013), the farming area has increased substantially. In Andhra Pradesh alone, at present, pacu is cultured in almost 2600 ha, either in monoculture or polyculture with major carps and striped catfish (Seshagiri et al. 2022). The culture of pacu in recent years has spread to other states such as Maharashtra, Tamil Nadu, Karnataka, Kerala, Uttar Pradesh, Bihar, Odisha, and Northeastern states. There has been a growing interest in the culture of improved mono-sex tilapia and red tilapia, of course with certain governmental restrictions. The adoption of farming practices in the country, however, is highly diverse, and largely dependent on the input availability and investment capacity of the farmers.

With the implementation of the AICRP on Air-breathing Fish Culture,' the significance of catfish farming in the country was recognized. The preliminary culture techniques for magur, singhi, murrels and climbing perch were essentially borne out of this. In 5-6 months of monoculture in small and shallow ponds, production levels of 3-5 tons magur ha^{-1} were demonstrated. Furthermore, new research efforts on seed production and farming of climbing perch and murrels have demonstrated the possibility of monoculture of these species. In the Northeastern states, the monoculture of magur and pabda is becoming more popular.

The adoption of the technology of grow-out monoculture of giant freshwater prawn took momentum during 2000-05. The species also garnered increasing attention for its farming in polyculture with major carps. Co-culture of carps and prawns resulted in higher yields with production values of 300-500 kg prawns ha^{-1} and 2.0-3.0 tons carps ha^{-1}. Freshwater prawn production climbed gradually to 35,000 tons in 2005. However, with the white leg shrimp, *L. vannamei* attained popularity, the expansion of freshwater prawns showed a gradual decline. Prawn farming is found to resurge in the last few years in the coastal zone as a result of the rising problem of *L. vannamei* culture. In 2019-20, the production of freshwater prawns reached 9,500 tons. Although the culture of freshwater prawn faces tough competition from *L. vannamei* in coastal zones, strengthening the seed production and supply chain in the landlocked states, besides coastal zones would provide ample opportunity for culture promotion of the species.

The non-conventional culture practices viz., sewage-fed fish culture and integrated fish farming with cattle, pig, duck and poultry use carps as the principal component yield production levels of 3-5 t ha^{-1} yr^{-1} (Ayyappan and Jena 2003). Integration of high-valued horticulture crops on pond dyke has been accepted as a popular model. Integrated farming models have gained popularity in recent years due to their holistic approach to crop production with efficient nutrient recycling and resource utilization. This type of system has been proved to be useful for rural small household ponds. Fish production from the sewage-fed impoundments has been a practice that evolved since the 1930s and was largely practiced by the fish farmers of West Bengal. The Rahara Centre of ICAR-CIFA, which formerly was under ICAR-CIFRI before reorganization of institutes, has undertaken studies on the various kind of sewage, its utilization for fish farming and the after-effect on fish as well as in the food chain. Fish production levels of 3.0-5.0 t ha^{-1} yr^{-1} have been demonstrated under carp polyculture, and monoculture of *C. reba* and *L. bata* in sewage-fed ponds. Paddy-cum-fish culture, with customized models for different regions, has also shown its potential with the production of about 500 kg fish and 2.5-3.5 tons of deep-water paddy in one hectare. The practice is being successfully adopted in several parts of Odisha, Assam, and other Northeastern states.

Enclosure aquaculture (cage and pen culture) has been a promising intervention to increase the fish production potential of the large water bodies, as was demonstrated over these years by ICAR-CIFRI. The institute has demonstrated stock enhancement in selected wetlands of Assam through pen culture which had later been adopted in many *chaur* and *moan* resources of eastern Indian States including Bihar, Chhattisgarh, Jharkhand and flood plains of Assam and West Bengal. The Bangalore center of ICAR-CIFA has also worked towards developing cage farming technology in reservoirs during the 1980s and 1990s. Several schemes have been brought by NFDB with the technology partnership of ICAR-CIFRI and implemented through State Fisheries Departments to increase the cage farming activities in open waters. Such activities are implemented with an integrated approach as an alternative livelihood and income generation programme under the Blue Revolution Scheme of the Government of India. With the financial support of the RKVY scheme, Chhattisgarh was the pioneer state to start commercial cage farming in 2007-08 in reservoirs. High production levels of 3.0-4.0 tons of *P. hypophthalmus* per cage (6 m × 4 m × 4 m) were achieved in 6-8 months of rearing. Later, the cage farming technology has been adopted in the reservoir systems of many states especially in Jharkhand, Bihar, Odisha and Maharashtra.

2.2.1.4. Aquaculture in upland region

The fisheries development in the upland region till the last century was mostly concentrated on stocking the streams and lakes with fry and fingerlings of desired species. Several exotic trout species were imported to Kashmir in the first half of the twentieth century to enhance sport fishing. ICAR-DCFR has been working towards improving fish production potential through culture-based capture fisheries and developing cage farming technology for the utilization of Himalayan lakes. In the mid-2010s, the Institute imported two improved Hungarian common carp strains and demonstrated their superior growth in the upland areas. Native species like mahseers (*Tor putitora* and *Tor tor*), snow trouts (*Schizothoraichthys esocinus*, *S. progastus*, *Schizothorax richardsonii*, *S. niger*, and *S. curvifrons*) have been bred and promoted in the culture system. ICAR-DCFR has also developed induced breeding and seed rearing technologies for *Schizothoraichthys niger*, *S. esocinus*, *S. curvifrons*, *S. micropogon* and *Schizothorax richardsonii* through artificial fecundation in running water systems. The seed of golden and chocolate mahseers have been extensively ranched in upland streams, rivers, and lakes to increase their natural population. Apart from the trout, Deccan mahseer (*Tor khudree*) has received much attention during the last 40 years, mostly due to the commendable work of a privately owned hatchery of Tata Electric Company at Lonavla. The Lonavla hatchery has also developed induced breeding and hatching of *T. putitora*.

Table 3. Milestones in freshwater aquaculture research

Year	Milestone
1955	Induced breeding of *Esomus danricus* was achieved using catla pituitary gland extract.
1957	First success was achieved in induced breeding of *Cirrhinus reba,* followed by induced breeding of three Indian major carps.
1959	Grass carp and silver carp were introduced in India from Hong Kong.
1962	Successful breeding of Chinese carps (grass carp and silver carp).
1967	Development of packages of practices of sewage-fed fish culture.

Year	Milestone
1970	Development of packages of practices of paddy-cum-fish culture.
1970s	Standardization of composite fish culture through AICRP.
1971	Extraction, preservation and ampouling of fish pituitary hormones.
1980	Development of packages of practices of integrated fish farming.
1982	Large-scale breeding of magur (*Clarias magur*).
1994	Intensive carp culture technology with a production level of 15 t ha^{-1} yr^{-1} developed.
2000-2010	Technology development of breeding, seed production and grow-out farming of several freshwater fish species, viz. minor carps/barbs, murrels and important catfish species.

2.2.2. Brackishwater aquaculture

The brackishwater environment supports a diverse range of seafood species, including fish, shrimp, crab, seaweed, micro-algae and others. Brackishwater aquaculture has a long history of traditional practices from *bheries* of West Bengal to *pokkali* rice fields of Kerala. Brackishwater aquaculture at present is largely confined to a single commodity, the shrimp. The shrimp production in the country currently stands at more than 0.8 Mt (>90% is *L. vannamei*) from an area of 172,000 hectares, with average productivity of 4070 kg ha^{-1} crop^{-1} in 2020.

2.2.2.1. Breeding, seed production and grow-out farming of shrimps and crabs

In India, scientific shrimp farming was initiated in Kakdwip Experimental brackishwater fish farm of ICAR-CIFRI, West Bengal. Subsequently, the shrimp breeding and seed production technology was evolved in Narakkal, Kochi by the ICAR-CMFRI (Ponnaiah 2011). A simplified hatchery system was developed for *Penaeus indicus* in 1976 (Muthu and Laxminarayana 1977; Silas et al. 1985). In 1975, AICRP on Brackishwater Fish Farming started with centers in West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, and Goa. The yield was improved to 1000-1500 kg ha^{-1} with improvised farm-made feeds and health management. In the late 1980s, the MPEDA established two commercial hatcheries *viz*., TASPARC at Vishakhapatnam and OSPARC in Gopalpur, which paved the way for the establishment of several private hatcheries in subsequent years. A semi-intensive culture technology demonstrated in the early 1990s yielding 4-6 t ha^{-1} production through a pilot-scale project by MPEDA was a significant milestone. The 1990s witnessed significant growth in the adoption of commercial farming of black tiger shrimp. Subsequently, with the overall technical and logistical support from different organizations viz., ICAR-CIBA and MPEDA, India witnessed an extraordinary increase in the area under shrimp farming.

One of the major turning points in brackishwater shrimp farming was the introduction of Specific Pathogen Free (SPF) *L. vannamei* in 2009. The introduction of SPF *L. vannamei*, followed by strict quarantine at the country level and biosecurity at the farm/hatchery level, strict adherence to better management practices (BMPs) and zero tolerance for antibiotics usage have transformed the sector. The adoption of eco-based technologies for sustainable intensifications was actively mediated by ICAR-CIBA. With semi-closed intensive shrimp farming and BMPs productivity of 8-10 t ha^{-1} was achieved. Farming over the years has seen a gradual expansion in crop area not only in traditional states like Andhra Pradesh, Tamil Nadu, Odisha and West Bengal but also in Gujarat. The shrimp production increased by over 30-folds during the last 33 years, from 28,000 tons in 1988-89 to 8,43,360 tons in 2020-21. While *P. monodon* contributes less than 3% of shrimp production, the remaining have been by *L. vannamei.* Following the tremendous success of *L. vannamei* farming in the coastal region, ICAR-CIFE at its Regional centre of Rohtak, Haryana was instrumental in developing the packages of practices for its commercial farming in inland-saline areas. The extensive demonstration programme by the center has resulted in large-scale adoption of its farming in the states of Haryana, Punjab and inland saline areas of other land-locked states.

Penaeus indicus has shown to be a potential candidate species alternative to *P. monodon* or *L. vannamei*. Recent studies highlight its potential in zero-water-exchange systems and cultivation prospects in eco-based farming systems. ICAR-CIBA has standardized the culture practice of *P. indicus* in different agro-climatic zones. A nationwide culture demonstration showed a yield potential of 3-7 t ha^{-1} $crop^{-1}$ at a moderate stocking density of 25-40 nos m^{-2}. Recently, to diversify shrimp farming, selectively bred SPF fast-growing and disease-resistant variety of *P. monodon* was introduced in India. It is reported that the growth rate and WSSV resistance has been improved after each generation. ICAR-CIBA is facilitating the farming of SPF-Pm at low stocking density. It is expected that the BZEST (Bio-secured zero water exchange system technology) technology developed by ICAR-CIBA will ensure the successful culture and sustainability of this newly introduced species. The institute has also successfully standardized hatchery seed production and farming technologies for other penaeid species like banana shrimp (*P. merguiensis*); kuruma shrimp (*Marsupenaeus japonicas*); Pink shrimp (*Metapenaeus monoceros*) and kadal shrimp (*M. dobsoni*).

Mud crab, *Scylla serrata* is a high-value seafood most suitable for low intensive brackishwater farming. The hatchery technology for mud crab has been developed by RGCA, the research and development arm of MPEDA and also ICAR-CIBA, over a decade. The commercial seed production of the species, however, is principally limited to the hatchery facility of RGCA and a few small hatcheries in Tamil Nadu and Maharashtra. In grow-out culture, the long rearing period of 10-12 months (to raise from 1 g to >500 g), poor survival, and associated production loss are a dampener for the farmers. To avoid these, a three-tier modular farming system or zero stocking model was developed by ICAR-CIBA, which is getting popular in different states. It fetches Rs 1,000-1,400 kg^{-1} in export market.

2.2.2.2. Breeding, seed production and grow-out farming of brackishwater finfishes

Technology development aimed at species diversification has been a focus over the years. The lack of seed of important cultivable fish species for want of hatchery seed production technology remained a major bottleneck for a long period. ICAR-CIBA achieved a technological breakthrough for the year-round breeding of seabass (*Lates calcarifer*) under the captive condition in the year 1997, followed by a novel system of farming (Arasu et al. 2009). The institute made significant progress in developing a mature broodstock of seabass in captivity (Thirunavukkarasu et al., 2015). The technique of implantation of LHRHa in pellet form in fish was developed. LHRHa in conjunction with HCG was responsible for achieving maturation. Further, sustainable farming of seabass in open brackishwater cages in a three-tier model was also popularized as an alternate livelihood for coastal fishers. Induced breeding of milkfish (*Chanos chanos*) was achieved by ICAR-CIBA in 2015 as another significant milestone. Milkfish can be farmed in monoculture or polyculture with other species which grow to a marketable size of 500 g in six months. The institute has also successfully bred the grey mullet (*Mugil cephalus*), a high-valued brackishwater fish, with pond reared broodstock in 2016-17. Diverse culture systems such as monoculture, polyculture and IMTA are suitable for this species and yield 4.0 t ha^{-1} crop^{-1}. Similarly, the technologies for captive breeding of promising fish species such as Mangroves Red snapper (*Lutjanus argentimaculatus*), Nona tengra (*Mystus gulio*), pearl-spot (*Etroplus suratensis*) and Hilsa shad (*Tenualosa ilisha*) were standardized by the ICAR institutions, facilitating their large-scale culture.

Table 4. Milestones in brackishwater aquaculture research

Year	Milestone
1975	Standardization of induced maturation, breeding and larval rearing of penaeid shrimp.
1984	*In vitro* fertilization of egg and seed production of *P. indicus* achieved.
1987	Scientific shrimp farming - AICRP on Brackishwater Aquaculture; Production of 1-3 t ha^{-1} achieved.
1997	Hatchery technology for seabass breeding and seed production standardized.
2009	Import Risk Analysis and introduction of selectively bred SPF *L. vannamei.*
2015	Captive breeding seed production and farming technology of milkfish achieved.
2016	Biofloc-based nursery and grow-out shrimp farming technology developed.
2018	Improved breeding, larval rearing, and demonstration of the high-density culture of Indian white shrimp.
2020	Green-floc technology and CIBAFLOC consortium for biofloc development and bioremediation.
2021	Captive breeding and seed production of grey mullet and mangrove red snapper.

2.2.3. Mariculture

The pioneering attempt for mariculture development in the country was initiated by ICAR-CMFRI in the 1970s in its Mandapam and Tuticorin centres with seaweed and bivalve culture. Institutes such as ICAR-CIBA and the National Institute of Ocean Technology (NIOT), and agencies such as MPEDA played prominent roles in expanding research and development activities for mariculture. Subsequently, trials on open-sea cage farming were initiated by ICAR-CMFRI in the mid-2000s. Though India has a projected mariculture production potential of 4-8 Mt annually, the current mariculture production is <0.1 Mt.

2.2.3.1. Open-sea cage culture

Open-sea cage farming in India was initiated by ICAR-CMFRI with the implementation of a demonstration project at four locations viz., Diu, Ratnagiri, Mandapam and Visakhapatnam. The first successful open-sea cage culture harvest was achieved in 2007 at Visakhapatnam with seabass in HDPE cages of 15 m diameter. Since then, the institute has been able to make several innovations in the designing and fabrication of cages and mooring systems, and standardized guidelines and practices. The low-cost cage farming technology was very well accepted by the fishermen groups and entrepreneurs in various maritime states. Two different versions of indigenously fabricated 6 m dia cages (GI and HDPE) are presently being adopted by fishermen. A major scheme on sea cage farming was operational with the financial assistance of NFDB and technical support of ICAR-CMFRI in the states of Maharashtra, Tamil Nadu, Kerala and Karnataka under the Blue Revolution Scheme of the Union Government during 2017-20. At present, cobia, pompano and seabass are the major species used, which, however, are likely to diversify with other species like grouper, snapper and seabream. ICAR-CMFRI, based on Multi-Criteria Evaluation (MCE) parameters has identified an area of 46,823 hectares of suitable sites along the Indian coastline for sea cage farming. It is estimated that a total of 0.7 million cages can be installed in the identified sites which can yield over 2.0 Mt of fish. A planned programme to commercialize sea farming will go a long way in realizing the Blue Economy potential in India.

2.2.3.2. Culture of seaweeds and integrated multi-trophic aquaculture (IMTA)

Since the late 1970s, ICAR-CMFRI has been at the forefront of seaweed research. CMFRI's Mandapam Regional Station has devised a raft, coir-rope nets/spore system for commercial-scale culture of the agar yielding red algae *Gracilaria edulis* and *Gelidiella acerosa*. During the 1980s, the station created a cottage industry method for producing agar from *Gracilaria* spp. and alginic acid from *Sargassum* spp., and showed agar and algin production to several farmers and entrepreneurs. Many small-scale agar factories in Madurai, Tamil Nadu, have sprung up as a result of these demonstrations. Seaweed farming in India is currently centered on the exotic carrageenan-producing *Kappaphycus alvarezii*, grown along the coastal waters of Tamil Nadu and Gujarat. Its culture was initiated in the year 2000 with technical assistance from the Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavnagar. ICAR-CMFRI has identified a potential area of 23,970 hectares and 317 sites for seaweed farming all across the coast. This includes 10,316 ha area in Gujarat, 5,048 ha in Tamil Nadu, 2,724 ha in Maharashtra besides smaller stretches in other coastal states. It is estimated that the identified potential area can produce about 10.0 Mt of seaweeds (wet weight).

Integration of commercially relevant species at various trophic levels is developing as a new concept in aquaculture, in which the nutrient loads generated from fed species such as finfish or shrimp act as fertilizers or inputs for the non-fed extractive secondary species such as molluscs or seaweeds co-cultured. This technique is being used in cage aquaculture, where finfish/shrimp and shell/herbivorous fish are mixed with seaweed cultivation in appropriate proportions. This approach can help to alleviate the adverse effects on the environment of sea cage farming while also increasing seaweed yield. In this regard, the ICAR-CMFRI successfully demonstrated the technology of Integrated Multi-trophic Aquaculture (IMTA), combining seaweed *K. alvarezii* with cobia.

2.2.3.3. Culture of bivalve molluscs

Bivalves (oysters, mussels, clams and cockles) are widely distributed in the tropical and temperate waters. In India, they form a sustenance fishery for the coastal people in the west coast maritime states from time immemorial. The commercially important bivalve resources of India comprise the edible oyster (*Crassostrea* spp.), mussel (green mussel, *Perna viridis* and brown mussel, P. *indica*), pearl oyster (*Pinctada fucata* and *P. margaritifera*), and clams (*Villorita* spp., *Meretrix* spp., *Paphia malabarica* and *Marcia opima*). The annual bivalve production through wild harvest from the coastal waters and estuaries was estimated at 86,100 tons during 2012-19. ICAR-CMFRI developed the mussel culture technique in the late 1970s. However, its farming remained confined only to southwest India with a limited level of production. Further refinements in farming technology have also been made to reduce capital costs by using alternate core materials. Development of the hatchery technology for the production of bivalve seed including both green and brown mussels is another development. ICAR-CMFRI also developed oyster farming technology in the 1970s using the rack and ren, and rack and tray methods. The average annual farmed edible oyster production in India, however, is only around 3000 tons forming approximately 15% of farmed bivalves. Seed production techniques of the species have been standardized similar to mussels.

2.2.3.4. Breeding and seed production of marine fishes

To ensure a sustained seed supply of important species for cage culture, ICAR-CMFRI initiated breeding programmes of cobia and silver pompano in 2006. Induced breeding technologies of these species were successfully developed at its Mandapam Regional Centre in 2010 and 2011 respectively. Seed production technologies including nursery rearing protocols were standardized for commercial-level production. Sea cage farming technology was standardized through various farming trials and participatory demonstrations during 2011-13. Induced breeding and seed production of Orange-spotted grouper (*Epinephelus coioides*) was first achieved in 2013 and its large-scale seed production with higher survival rates during larval rearing was accomplished in 2017. Indian pompano (*Trachinotus mookalee*) is another potential candidate species for marine and brackishwater aquaculture which was induced bred in 2016 with high survival rates (>20%). The technologies have been transferred to the private entrepreneurs thereby facilitating round the year seed production of these four species of importance. Recently, the institute has also standardized breeding and seed production technologies of another three high-value species suitable for cage farming, viz. pink-ear sea bream, (*Lethrinus lentjan*), *Pomadasys furcatus* and John's snapper (*Lutjanus johnii*). The All-India Network Project on Mariculture is another major ongoing initiative to address technological constraints in mariculture and is being led by ICAR-CMFRI.

Table 5. Milestones in mariculture research

Year	Milestone
1964	Seaweed culture experiment was first initiated on the Gujarat coast.
1973	Development of pearl culture technology through the introduction of nuclear beads along with a secretory mantle tissue into a recipient oyster.
1974	Standardization of culture techniques of agar-yielding seaweeds *Gracilaria edulis* and *Gelidiella acerosa.*
1977	Culture techniques for green mussel and brown mussel and edible oyster standardized.
1980	Development of technology for seed production of edible oyster (*Crassostrea madra-sensis*).
2007	Sea cage farming started with seabass (*Lates calcarifer*).
2010-11	Induced breeding and seed production of cobia and silver pompano.
2012	Development and standardization of guidelines and practices including good sea-cage farming practices for different regions in the country.
2018	Standardized integrated multi-trophic aquaculture (IMTA) integrating seaweed farm-ing with cobia farming in cages.
2018-20	Breeding and seed production of important marine ornamental fish species and five cross-bred varieties of clownfish.
2020-21	Breeding and seed production of sea bream, John's snapper and Banded gunter.

2.2.4. Farming of non-food species

2.2.4.1. Farming of ornamental fishes

The rich ornamental fish resources of the country, both in terms of freshwater as well as marine species have not been tapped to their fullest potential yet. While the domestic trade of ornamental fish is dominated by exotic varieties, the export is largely confined to wild-caught freshwater indigenous fishes. With the research efforts in ICAR-CIFA, ICAR-CIFA, ICAR-NOFGR and other State Agricultural Universities breeding and rearing techniques of over two dozen indigenous species from NEH, Eastern and the Western Ghat regions have been standardized during the last three decades. This comprises barbs, danios, rasboras, catfish and chameleon fish. The development of 'shining barb' a new variety of rosy barb (*Pethia conchonius*), through the process is another significant contribution of ICAR-CIFA. The development of captive breeding technologies of brackishwater ornamental fishes, viz., Spotted scat (*Scatophagus argus*), Silver moony (*Monodactylus argenteus*) and orange chromide (*Etroplus maculatus*) by ICAR-CIBA have been some of the recent advancements. ICAR-CMFRI initiated the work on the development of captive breeding and seed production of marine ornamentals in the 1990s. These efforts culminated in the development of captive breeding technology for 23 marine ornamental species which include clownfishes (under genera *Amphiprion* and *Premnas*), damselfishes (under genera *Dascyllus*, *Pomacentrus*, *Chromis, Neopomacentrus* and *Chrysiptera*), Anthias (*Pseudanthias marcia*, *P. squamipinnis*), Firefish (*Nemeteleotris decora*), *Dotty back* (*Pseudochromis dialect*), and Camel shrimp, *Rhyncocinetes durbanensis*. Recently, breeding and seed production of five designer clownfishes (cross-bred) and two ornamental crustaceans-*Thor hainanensis* and *Acylocaris brevicarpalis* (peacock tail shrimp) were also achieved.

2.2.4.2. Marine and freshwater pearl culture

In India, the technology for pearl culture has been developed by ICAR-CMFRI for marine pearls and ICAR-CIFA for freshwater pearls (Alagarswami 1974, Janaki Ram, 1989). ICAR-CIFA developed the technology of freshwater pearl farming in the late 1980s using freshwater mussels, *viz*., *Lamellidens marginalis*, *L. corrianus* and *Parreysia corrugata*, the former being the most important species. To obtain shell-attached half-round or design pearls, as well as unattached and irregular to oval or round pearls, packages of practices for pre-operative conditioning, graft and nuclei implantation, post-operative care, and pond culture of implanted mussels were developed. ICAR-CMFRI initiated the pearl culture research at its Tuticorin centre in 1972 and succeeded in producing spherical pearls in 1973. Subsequently, the technology of Mabe/image pearls has also been developed. The production of fine-quality white and black pearls was with the use of the species *Pinctada fucata* and *P. margaritifera* respectively. The institute was also successful in artificially spawning *Pinctada fucata*, raising larvae, and producing year-round seed in the laboratory.

2.2.5. Modern farming practices: Biofloc-based aquaculture and farming in RAS and Raceways

Biofloc-based farming technology is based on management through heterotrophic microflora promoted and maintained through carbon-nitrogen (C-N) ratio manipulation, which can achieve higher productivity through the sustainable intensification concept. It is practiced in both freshwater and brackishwater systems with a wide range of species like shrimp (*L. vannamei, P. indicus* and *P. monodon*), tilapia, pangas, carps, and native air-breathing fishes. ICAR-CIBA has standardized the technology protocols for biofloc-based nursery and grow-out culture technology of penaeid shrimps. Production of 400-600 kg of tilapia/pangas or 50-60 kg of shrimp can be achieved from a 10 tone tank system.

Recirculatory Aquaculture System (RAS) is considered an environment-friendly aquaculture farming system. Though highly capital intensive, RAS system uses much less water and land facility compared to the flow-through system. Moreover, with well-developed filtration technology, greater control over disease outbreaks and water quality parameters, higher production is possible in this system. Research is also in progress for developing models for maturation and grow-out systems for marine finfish and shrimps. Intensive culture technology in the raceway system was also developed for high-value rainbow trout for the temperate hilly terrain of Jammu& Kashmir, Himachal Pradesh, Uttarakhand, etc. by ICAR-DCFR. Production levels of 500-700 kg raceway^{-1} in 10 months culture period have been obtained in raceways of 30-45 m^2 at a stocking density of 40-100 fingerlings m^{-2} and provision of formulated pellet feed.

2.2.6. Fish feed and nutrition

Fish nutrition research in India received increased attention only in the 1980s, focusing on understanding the dietary requirements of cultured species for the production of balanced supplementary feed. Besides the ICAR institutes, the Fisheries Colleges under the SAUs/CAUs and several other laboratories including at Delhi University, Aligarh Muslim University, etc. undertake fish nutrition studies in India. The research largely involved the use of different plant and animal protein sources. The studies also covered the aspects of non-conventional feed ingredients, additives, antinutritional factors, digestive enzymes, probiotics/gut microflora, etc. Several formulations have been developed for varied life stages of important finfishes of freshwater, brackishwater and marine origin and, freshwater prawns and shrimps. Fish feeds for carps, magur and freshwater prawn had been formulated and released by ICAR-CIFA in the 1990s. Recently ICAR-CIFRI has developed and commercialized a formulated feed known as *CIFRI CageGrow* for cage culture in inland waters. The broodfish diet CIFABROOD™ developed by ICAR-CIFA in 2009 and commercialized in 2013 showed its efficiency in advancing gonad growth and maturation, facilitating early spawning and increasing spawning response. In 2020, the institute has also developed carp feed fortified with nanoparticles for larvae and grow-out stages and released for commercial production. Floating, sinking and slow-sinking forms of commercial feeds in varied pellet sizes are now available in the market. Shrimp being a high-value species, at its initial stage of aquaculture development in the country, it necessitated the import of formulated feeds. Subsequently, several shrimp feed mills were established resulting in self-sufficiency. Highly cost-effective, indigenous shrimp feed technology was later developed and commercialized by ICAR-CIBA for both tiger shrimp and Pacific white shrimp. Vanami^{Plus}, a cost-effective shrimp feed, was developed by using indigenous ingredient resources. Other important feeds include extruded floating and slow-sinking feed for brood and grow-out culture of mullet, milkfish and seabass. Development of alternate protein sources for fish meal replacement using customized enzyme mixtures and solid-state fermentation technology, and functional feeds for various life stages are other achievements. The research at ICAR-CMFRI led to the development of nutritional solutions of both basic and applied nature for different marine fish species. R&D at ICAR-CMFRI, ICAR-CIBA and ICAR-CIFA has resulted in commercially scalable technologies including *Varsha* and *Varna* brand of ornamental fish feeds from ICAR-CMFRI and '*Kolorfishplus'* from ICAR-CIBA. However, feeds for ornamental fish and micro-feeds for nursery rearing of cage cultured fish are mostly imported. Commercial production of such feeds is yet to be taken up in the country as the volume of production demanded is below commercial viability.

2.2.7. Fish genetics & biotechnology

Genetic improvement of culture species was an important research area that attracted the attention of researchers even in the early years of aquaculture development. Over 40 interspecific and intergeneric hybrids were produced at the FARTC, but proved to have limited practical relevance, as none of them demonstrated to have significantly higher growth potential than their parents. With the studies conducted on the manipulation of chromosome sets, success was achieved in inducing ploidy, and the production of androgens and gynogens. The triploids and gynogens also could not be translated into field-level adoption. Later, emphasis was given to the trait-associated selective breeding of the cultured species which was a great success.

The genetic research during the initial years was largely confined to cytogenetic studies in fishes to characterize the species in terms of diploid chromosome numbers (2N), morphology/karyotype, staining of nucleolar organizer regions (NORs) of chromosomes, patterns of constitutive heterochromatic, and physical location of genes on chromosomes. The ICAR-NBFGR has undertaken cytogenetic studies on over 80 species including endemic and endangered species belonging to freshwater, marine and brackishwater ecosystems, ranging from plains and Himalayan foothills to the Western Ghats. Development of *Fluorescence* in situ hybridization (FISH) as a tool for physical mapping of repetitive DNA and study of the variation between and within species has also been undertaken in over 20 fish species.

Development of the first selective breeding programme in India was undertaken in rohu at ICAR-CIFA through an Indo-Norwegian project (AKVAFORSK, Norway) in the early1990s with growth as the trait of selection (Reddy et al. 1999). The impressive success achieved with an average of 17% higher growth response per generation after 11th generation of selection is a significant development. With 50-60% higher growth demonstrated in the farmers' pond across the country, the improved rohu, popularly known as *Jayanti* rohu, is a sought-after strain. Further, resistance to *Aeromonas* sp. has been included as another trait of selection (Sahoo et al. 2011). Similar selective breeding programmes for growth have been extended to improve catla and giant freshwater prawn. With >30% higher growth demonstrated in catla and freshwater prawn after 2nd and 10th generations respectively, these improved strains possess great potential for increasing productivity in freshwater aquaculture systems. A similar genetic improvement programme has been initiated in magur by ICAR-CIFE. RGCA has also developed 8th generation of Tilapia (GIFT) through pedigreed selective breeding with procurement of initial germplasm from WorldFish in 2008 which is expected to play a significant role in the expansion of tilapia farming in the country.

In 1991, the first triploid transgenic *Brachydanio rerio* was developed, followed by the first Indian transgenic zebrafish in 1995. Transgenic rohu and singhi grew four times faster in culture conditions than their non-transgenic counterparts and transformed food with much higher efficiency (Pandian 2003). Extensive research efforts in the last few years have led to whole-genome sequencing of six fish/shellfish species, *viz.,* rohu, catla, magur, hilsa, grey mullet and Indian white shrimp Transcriptome analysis and gene mining efforts in fish species have resulted in a greater understanding of abiotic stress tolerance mechanisms, which include hypoxia, ammonia and temperature and biological processes in magur; immune system, lipid metabolism in hilsa and growth in catla and hilsa. Sequencing, mapping and annotation of mitogenomes of more than 50 important fish species have been completed. The Network Project on Agricultural Bioinformatics and Computational Biology has established an online portal 'FisOmics' to support fish genomic data analysis. The portal also provides access to important genomic resource databases of Indian fishes and other aquatic life, like FBIS (COI barcodes), FishMicrosat (microsatellite information), FMiR (mito-genomes), Fish Karyome (chromosome information) and HRGFish (hypoxia-responsive genes).

2.2.8. Fish health management

With the intensification and diversification of aquaculture, and increased transboundary movement of fish seed, the disease incidence in fish farming has increased significantly over these years, necessitating greater emphasis on fish health research. Research on fish diseases received increased attention with the emergence of the epizootic ulcerative syndrome (EUS) in freshwater finfish in the late 1980s and white spot syndrome (WSSV) in shrimps in the late 1990s which caused havoc in the fisheries sector of India and neighbouring countries. ICAR Institutes have focused fish health research mainly on three aspects: identification of fish and shellfish diseases, development of diagnostics, and development of disease control measures.

During the 1980s & 1990s, EUS caused heavy loss across the country with heavy morbidity and mortality, especially in Eastern and North-eastern states of India. Extensive studies encompassing fungal, bacterial and viral pathogens were conducted, and it was established that the oomycete *Aphanomyces invadans* is the causative pathogen for the EUS. The development of a chemical formulation known as CIFAX™ in 1998 by ICAR-CIFA and its commercial availability was significant in preventing and controlling the EUS to a large extent. The development of both histological and molecular techniques has helped in the rapid diagnosis of EUS. CIFACURE was another formulation, developed for controlling common bacterial and fungal infections of freshwater ornamental fishes. Besides WSSV, which caused the worst economic losses in the brackishwater shrimp farming systems, a large number of viral pathogens such as infectious hypodermal and haematopoietic necrosis virus (IHHNV), monodon baculosvirus (MBV), yellow head disease, infectious myonecrosis virus (IMNV), hepatopancreatic parovirus (HPV), shrimp noda virus, etc. have been identified to cause substantial loss in shrimp and prawn in India. Pathologies of several bacterial diseases in diverse finfishes were studied. Viral diseases have been relatively less in finfishes in India, however, recently Tilapia Lake Virus (TiLV) has been found to cause a massive loss in tilapia farms. A vast array of parasites, from protozoa to metazoans, has been identified to cause infections in several teleost fish species and cause acute to chronic losses. The efficacy of doramectin and ivermectin was evaluated against *Argulus siamensis* infestation with a promising outcome. Ammonium chloride dip bath treatment as a quarantine measure to prevent the spread of *Lernaea cyprinacea* infection was quite promising. Recently, antiparasitic formulations such as CIFRI ARGCURE and CIBA-PARACIDE have been developed and field-tested. A biofilm-based immune stimulant was developed for controlling bacterial infections in shrimp leading to improved survival and growth. CIBA-LUMIPHAGE, a novel phage therapy, has been developed for the control of bacterial diseases in shrimp larvae. Recombinant RdRp protein of prawn Noda Virus (MrNV) as anti-viral & immunostimulant in *M. rosenbergii* is another major achievement. Recently, nano-particles are being tested for antimicrobial, immunomodulatory, growth-promoting and water remediating activities. An indigenous vaccine NodavacR has been developed for the control of viral nervous necrosis (VNN) in Asian seabass. Other major vaccines include *A. hydrophila* sub-unit vaccine against aeromoniasis and a recombinant DNA vaccine against *Edwardsiella tarda*. Studies also focused on the role of TRLs in innate immunity in divergent fish species to utilize in disease prevention.

The development of several diagnostic kits has helped in the early detection of causative pathogens and early warnings for combating the disease outbreaks. WSSV has been thoroughly characterized and PCR-based tests have been developed for the diagnosis of the disease. PCR-based diagnostic kits have also been developed for several other viruses viz., yellow head virus (YHV), KHV, TiLV, and taura syndrome virus. Reverse transcriptase-Loop mediated isothermal amplification (LAMP) for the detection of beta noda virus (VNN) was developed, besides molecular diagnostics for several OIE-listed pathogens. A colony multiplex PCR (cmPCR) was developed for rapid detection of *Bacillus* and *Pseudomonas* genera from diverse ecological niches. Rapid DNA-based diagnostic assays utilizing PCR have also been developed for *Gyrodactylus salaris, G. elegans, Dactylogyrus intermedius, Myxobolus cerebralis* and *M. clarii.* The latest in the list includes a nested PCR kit for rapid detection of *Enterocytozoon hepatopenaei* (EHP) in shrimp. Besides molecular techniques, microbiological, microscopic and immunological techniques have also been used for the diagnosis of pathogens.

A National Surveillance Programme for Aquatic Animal Diseases (NSPAAD), financially supported by the Department of Fisheries (DoF), Govt. of India is operational in 21 states and three union territories. The programme is implemented through 31 collaborating centers and is coordinated by ICAR-NBFGR. The major emphasis of NSPAAD has been to strengthen the passive surveillance system and undertake need-based active surveillance. Under the programme, eight new diseases have been reported for the first time in the country, including goldfish haematopoietic necrosis disease, koi sleepy disease, tilapia lake virus disease, and infection with red sea bream iridovirus. Referral Laboratories for Level-III diagnosis have been established to support an 'Emergency response system' in the aquaculture sector. The programme has been helping to provide scientific advice to farmers. In addition, the programme enables the DoF to report newly emerging diseases quickly and also provide alerts and advisories to the stakeholders. Recognizing the threat of antimicrobial resistance (AMR) to health and livelihoods, ICAR initiated a Network

Project for AMR surveillance covering the aspects of livestock and fisheries in the country in 2018 with the technical cooperation of FAO, named Indian Network for Fisheries and Animal Antimicrobial Resistance (INFAAR). The programme is generating baseline data on AMR in the fisheries sector across the country through eight fisheries research institutes of ICAR.

For regulating the import of aquatic animals, two documents, namely 'National Strategic Plan on Aquatic Exotics and Quarantine' and 'Aquatic Exotic and Quarantine Guidelines' have been prepared, which have been approved by the Ministry of Agriculture, Government of India. The National Strategic Plan provides a framework to regulate the introduction of exotic aquatic animals and translocation of species within the country to prevent the ecological and disease risks associated with the movement of live aquatic animals and their products. The 'Aquatic Exotics and Quarantine Guidelines' include the criteria and procedures for finalizing potential, details of prohibited aquatic animal species, evaluation of introduction proposals, management of exotics already present in the country, quarantine, surveillance, reporting and networking of diagnostic laboratories.

2.2.9. Aquaculture environment management

The research contributions on soil and water quality management in different aquaculture sectors by ICAR institutes over these years have been quite significant. Extensive studies on the water and soil quality parameters relating to fish production in freshwater fish ponds were undertaken as early as the 1960s (Banerjea 1967) suggesting optimal nitrogen, phosphorus and organic carbon requirement for higher productivity. Nutrient budgeting (C, N and P), productivity and water budgeting for diversified aquaculture practices has been assessed. The application of *Azolla* as a biofertilizer could replace chemical fertilizer. Studies deciphering the contribution of trace minerals Zn, Mg, Co towards fertilization boosting productivity by ICAR-CIFA and the role of Ca, Mg, K for shrimp and fish in low salinity by ICAR-CIBA are quite significant. Similarly, the role of alkalinity and hardness in breeding, hatching and production system has been established. ICAR institutes like CIFA, CIBA and CIFRI have substantially contributed to carbon footprint and carbon sequestration for fresh and brackishwater and wetland aquaculture systems to understand the impact of climate change and develop climate-resilient aquaculture practices. ICAR-CIBA has conducted many environmental monitoring programmes (EMP), and environmental impact assessment (EIA) studies to support sectoral growth. ICAR-CIBA had also generated a database on the use of chemicals, antibiotics and prepared guidelines for Effluent Treatment Ponds (ETP) for farming and hatcheries. A geographic information system-based multi-criteria decision support system was developed by ICAR-CIBA and ICAR-CIFRI to identify the suitable potential sites incorporating land, soil, and water resource characteristics with mandatory requirements specified under Coastal Aquaculture Authority or other Acts. CIBAMOX – a microbial product to reduce ammonia and nitrite problems in shrimp farms, soil probiotic CIBASOX for mitigation of toxic sulphur metabolites and CIBA OxyPlus for enhancing DO in water have been developed for use in shrimp farms.

Table 6. Milestones in fish nutrition, genetics and health management

Year	Milestone
1992	Selective breeding programme to improve the growth of rohu initiated.
1996	Release of '*Jayanti'* rohu developed by ICAR-CIFA through selective breeding.
1998	Development of 'CIFAX'- a chemical formulation to prevent and cure Epizootic Ulcerative Syndrome (EUS) disease of freshwater fishes.
2009	Development of carp broodfish diet CIFABROOD™.
2013	Initiation of National Surveillance Programme for Aquatic Animal Diseases (NSPAAD)
2018	Initiation of Indian Network for Fisheries and Animal Antimicrobial Resistance (INFAAR)
2018-21	Whole-genome sequencing of rohu, catla, magur, hilsa, grey mullet and Indian white shrimp.
2021	Commercialization of CIFRI *Argcure* for controlling the argulosis - a parasitic disease in fishes.

2.3. Genetic resource management

India is a world leader in institutionalized genetic resource management research, which encompasses aquatic genetic resources. Additionally, India accounts for nearly 8% of global biodiversity in terms of fish and shellfish species. ICAR-National Bureau of Fish Genetic Resources (NBFGR) was established in 1983 to address researchable issues related to the management and sustainable utilization of aquatic genetic resources as well as to provide technical assistance to various departments to meet the country's national and international obligations. The knowledge contributes to global information systems, such as the FAO's State of the World's Aquatic Genetic Resources for Food and Agriculture (SoWAqGR). The research programmes include population genetics, exploration and cataloguing of genetic resources, sperm cryopreservation, and *ex-situ* and *in-situ* conservation. Exploration of newer and unexplored geographical areas for assessment of fish diversity, evaluation of indigenous species for conservation and their mainstreaming, etc. are also priority areas.

Extensive surveys in various ecosystems have been conducted by ICAR-NBFGR for cataloging the aquatic genetic resources. The discoveries of over 300 new fish and shellfish species during the last seven decades, with ICAR-CMFRI and ICAR-NBFGR taking the lead, indicate that the fish agrobiodiversity can be still expanded through extensive explorations in the country. Reference DNA barcodes have been generated for more than 600 finfish and shellfish species in Indian waters. The technique was also effectively used for resolving taxonomic ambiguity and forensic applications. Research outputs also include the development of several markers, including protein and DNA markers for use in describing genetic diversity below the species level. Microsatellite DNA markers are commonly used for the description of patterns and distribution of genetic variation. To generate adequate knowledge on genetic diversity below the level of species ICAR-NBFGR in association with other ICAR institutes characterized genetic stocks of 32 fish and shellfish species of aquaculture and conservation value. Many of these species have distinct population structures, suggesting that stock-specific propagation-assisted restoration efforts are needed to replenish dwindling populations.

Ex-situ conservation and repositories are important aspects of fish genetic resource management. These are useful for conservation, utilization of material for future research, and claiming IPR stake. Sperm cryopreservation protocols have been developed for over 30 species. ICAR-NBFGR has taken up upscaling of sperm cryopreservation to customize the technique. During the last three years, field validation for commercial use and exchange of germplasm between hatcheries was carried out in 32 hatcheries in 10 states with the production of 10.0 million seeds of Indian major carps. The National Repository of Fish Cell lines (NRFC) established at ICAR-NBFGR in the early 2010s has over 70 fish cell lines at present and is the largest collection of the fish cell lines. The Aquatic Genetic Resource Information System is developed as a framework to obtain multiple types of information through a single source. At present, the system has fish diversity information comprising over 3150 species and linking to various genomic databases under "FisOmics" portal.

2.4. Post-harvest technology

2.4.1. Processing and value addition

Traditional methods of preservation of fish include drying, salting, pickling and smoking collectively called curing and these methods are of considerable importance for the utilization of seasonal bulk landings. Though these techniques had limitations concerning the standard operating procedures, recent advancements in drying techniques have facilitated good economic potential for cured fish products. ICAR-CIFT has developed different models and capacities of low-cost, energy-efficient and eco-friendly solar dryers as a viable and hygienic alternative to open sun drying of fish (Gopal 2011). This technology has been widely adopted by a large number of small and medium firms. CIFT-Hybrid model solar dryers have LPG, biomass, or electricity as alternate backup heating sources for continuous hygienic drying of fish. Eco-friendly model of community smoking kiln (Green kiln) popularly known as *COFISKI*, which ensures highly stable smoked fish products unlike traditional is another intervention.

The most widely used methods to preserve fish include chilling and freezing while heat treatments like thermal processing are also common. Traditionally, fish has been consumed fresh by adopting simple techniques like chilling using ice by which fish could be maintained fresh for a few days depending upon the species. Several standard protocols have been developed by ICAR-CIFT for the low-temperature preservation of seafoods. One recent advancement in this regard is the use of modified icing systems using plant-based extractives for improved quality and stability. Refrigerated Fish Vending Kiosk CIFTEQ™ Chill Fish is a low-cost energy efficient, hygienic mobile fish vending kiosk for small-scale fisher/retailers for the sale of fresh fish, which extends its shelf life for up to 5 days. Innovative technologies such as thermal processing, high-pressure processing (HPP), pulse light technology, e-beam radiation, radio frequency heating, etc. also present an additional layer of quality and safety for numerous seafood products. Thermal processing is a major area where ICAR-CIFT has made pioneer contributions in facilitating the standardization of a variety of ready-to-eat products. This high-impact technology employing retort processing has been adopted by over a dozen seafood companies in the country. HPP is an emerging technology for food preservation and has wide application potential in the seafood industry. Thorough studies have been undertaken by ICAR-CIFT for developing standardized protocols using HPP for enhanced quality and stability of various seafoods.

Improvements in packaging technology like vacuum packaging, modified atmosphere packaging, etc. also facilitate extended storage life of seafoods in addition to the adopted processing techniques (Biji et al. 2015). Studies carried out on innovative approaches of packaging like vacuum and MAP have given promising results for the extended stability of various seafoods. Another remarkable achievement in this field is the application of smart packaging for the development of a freshness indicator which is a simple dye-based paper disc to indicate the freshness of packed seafoods.

2.4.2. Nutraceuticals

The ICAR-CMFRI during the last decade has developed several nutraceutical products from mussels, seaweeds and other marine species, which contain small molecular weight bioactive compounds. These products have been used to treat a variety of life-threatening disorders, viz., combating arthritis (Cadalmin® GAe, Cadalmin® GMe), type-2 diabetes (Cadalmin® Ade), dyslipidemia (Cadalmin® Ace), hypothyroidism (Cadalmin® Ate), osteoporosis (Cadalmin® Aoe), low immunity (Cadalmin® Ibe), and hypertension (Cadalmin® Ahe). Cadalmin® MBc, a seaweed-based probiotic nutraceutical, and Cadalmin® Abe, an antibacterial ointment, are the most recent results in this area. ICAR-CIFT has developed various seaweed-based products with anti-inflammatory, anti-diabetic, anti-cancer, and immunological modulating effects attributable to their competence in post-harvest processing and value addition. Their product line now includes several ready-to-eat seaweed items, which are becoming increasingly popular (Gopalakrishnan et al. 2020). Fish oil (mainly omega-3 polyunsaturated fatty acids), algal oil, shark liver oil and squalene, chondroitin salts, collagen, gelatin, collagen peptide, chitin, chitosan as well as their monomers and oligomers, peptides and their derivatives, vitamins, seaweeds and their components, etc. are a few important products for both pharmaceutical and nutraceutical sectors. ICAR-CIFT-developed oyster peptide extract which is packed with antioxidants and anti-inflammatory properties. Several unique nutraceuticals, including dietary fibre extract from seaweeds, Nutridrink (grape juice fortified with seaweed extract), fish soup fortified with seaweed bioactive component, and seaweed-infused cookies are also developed and commercialized by the institute. Additionally, it has developed a nutrient formulation consisting of cereal mixtures and dried fruits enriched with various biomolecules such as high-profile fish protein, collagen peptides, and omega-3 oil in the form of crunchy granola.

2.4.3. Waste to wealth

Seafood processing generates nearly 50-60% of discards, and if not properly utilized it can lead to various environmental, social as well as economic issues. The recovery of biomolecules through the production of various products aids in the elimination of hazardous environmental aspects and improvement of quality in the fish processing business, as well as increasing profitability. The method developed by ICAR-CIFT for utilizing fish waste created a variety of key food and industrial goods including chitin, glucosamine hydrochloride, chitosan and carboxymethyl chitosan, hydroxyapatite, fish calcium from bones, bioactive melanin, astaxanthin from shrimp shell waste, absorbable surgical sutures from the fish gut, collagen peptide from fish scale and bones, etc. The process for the production of chitosan from prawn shell waste transferred to the industry during the 1980s has led to its large-scale production at present. The collagen-chitosan film developed from fish waste has a wide range of applications in wound dressing and dental surgery. The antioxidant chitosan derivative produced was beneficial in microencapsulating vitamins and ß carotene, resulting in a unique delivery mechanism. Technology has also been developed to overcome the threat of fisheries waste by effectively converting it into fish feed.

2.4.4. Quality & Safety

Important research developments in the area of quality and safety include standardization of protocols for detection of chemical contaminants, withdrawal period of antibiotics, microbiological interventions, challenge studies of different foodborne pathogens, different HACCP-based packages of practices, development of quality index schemes, etc. ICAR-CIFT has developed a chlorine level indicator paper called '*Cloritest*' in the 1980s for instant reading of the chlorine levels in process water. This easy-to-use concept and the technology since then is widely adopted in the industry, with many commercial companies producing similar kits, not only for the fish processing industry but also for many industrial and other non-commercial applications. Two simple and user-friendly kits namely '*CIFTest*' developed by ICAR-CIFT have been successful in determining the adulteration of ammonia and formaldehyde in fish which are also commercialized.

3. Knowledge gaps and way forward

One of the greatest concerns for India in the 21st century is food and nutrition security for a predicted population of over 1.6 billion by 2050 in the face of economic and financial uncertainty, climate change, and increasing competition for natural resources. The fishery production systems that could contribute significantly to future food production are increasingly under pressure due to rapid resource degradation as a result of anthropogenic activities including pollution from land-based sources, climate change, increase in hypoxic areas or dead zones, the spread of alien species, and ocean acidification. These challenges necessitate a coordinated response and a swift transition to a more sustainable, inclusive, and resource-efficient course for the future to build resilience in fisheries and sustainability in aquaculture. The Government of India's projections for 2024-25 includes the production of 22 million tons of fish at an average annual growth of about 9%, doubling export earnings from the present Rs. 46,663 crores (2019-20) to about Rs. 1,00,000 crores, enhancing national average aquaculture productivity from 3.5 tons to >5 t ha^{-1}, increasing the per capita domestic fish consumption from about 8 kg to about 12 kg, and reducing post-harvest losses from the reported 20-25% to about 10%. To achieve the potential of the sector, the following efforts are suggested:

The marine catches are plateauing and prompt action is necessary to resolve the underlying causes. Overcapacity in the fisheries sector is a severe issue. Overfishing and excessive juvenile catch are triggered by economic and social compulsions. The fishing effort needs to be optimized by (i) regulating fishing vessel design and construction, with more focus on energy-efficient fishing and strategies for making green vessels, (ii) regulating fishing gear concerning mesh size and gear dimension, (iii) regulating destructive fishing methods such as pair trawling/bull trawling and mini trawling, and (iv) strict implementation of spatial zoning regulations. The potential of artificial intelligence (AI) and big data is enormous, which can be utilized for effective monitoring, control, and surveillance (MCS). Tracking fishing vessels and strengthening the traceability of fish caught are important aspects. Regular stock assessment of major commercial fishes and adoption of Ecosystem Approach to Fisheries Management (EAFM) principles and application AI in marine fisheries data collection are necessary to monitor and devise strategic management of fish wealth. Likewise, measures to explore the potential of hitherto commercially unexploited species, including deep-sea resources need to be taken up. India's deep-sea harvestable potential (depths between 200 and 2000 meters) in both EEZs and Areas Beyond National Jurisdiction (ABNJ) is estimated to be over 3.3 Mt. This mainly includes the oceanic tuna, non-conventional deep-sea resources such as mesopelagic myctophids, giant purple-back squid, and other species in the Indian Ocean that can be harnessed through technological advancements and greater capital investments. Impact assessments and evaluations of climate change adaptation and mitigation policies must be founded on extensive assessments of risks and opportunities, benefits, and costs, as well as on modelling approaches that incorporate data from a variety of sources. Special emphasis should be placed on changes in the phenology of major fish species, temperature tolerance, the impact of algal blooms and their relationship to fisheries, the appearance and spread of invasive species, and the vulnerabilities of reef and other delicate marine and freshwater ecosystems. Climate change adaptation strategies must also be incorporated into the fisheries regulations, as well as capacity building and awareness campaigns, into action plans.

The large gap between potential and actual fish yields from culture-based fisheries resources like rivers, reservoirs, and wetlands provides plenty of room for fisheries improvement. Large-scale cage and pen culture in reservoirs for raising proper stocking material; wider reservoir coverage for stocking advanced fingerlings; and using Remote Sensing and GIS technologies to create appropriate databases required for the formulation of appropriate management norms and ensuring environmental flows for riverine systems are all necessary for the sustainability of inland fisheries and biodiversity conservation.

In the aquaculture sector, there is a need for the development of breeding and seed rearing protocols for new candidate species including the development of Broodstock Multiplication Centres (BMC) and Nuclear Multiplication Centres (NMC), sustainable intensification, nursery integration, development of suitable feeds for complete life cycle and cost-effective inputs, and surveillance and disease predictability. Modern high-input farming practices viz., RAS, biofloc, AI-based smart farming, etc. offer considerable scope to boost aquaculture production and therefore need special R&D focus. The programmes on selective breeding in important fish/shellfish species for traits such as growth and disease resistance need a special thrust. Development of cost-effective functional feeds using amino acid balancing and nutrigenomics, tailor-made cost-effective feeds, and live feeds are essential to utilize the production potential of the existing and new candidate species. Comprehensive disease control and health management programmes on existing and emerging diseases, surveillance, biosecurity, and packages for fish health management are essential to keep pace with the emerging needs of the aquaculture domain. The genetic and biotechnological interventions including genetic manipulation by CRISPR-Cas9 has immense potential in improving the commercial traits of ornamental and food fishes. Bioprospecting for the development of nutraceuticals and cosmetics from marine flora and fauna, bioremediation and bio-monitoring for ensuring sustainable production environments are other areas of importance. Recent research developments indicate the possibility of exploring *in vitro* techniques for fish meat production.

Intensification of mariculture is another promising option to meet the growing seafood demand. Research breakthroughs in the areas of captive breeding and mass production of some prioritized high-value marine fish species along with success in open sea cage farming in coastal waters have opened new vistas for enhancing marine fish production. However, it is important to identify and characterize suitable areas for mariculture, formulate suitable leasing policies for sea farming in large cages (>30 m dia), develop quality seed and feed production facilities, and strengthen value chains. Similarly, massive amounts of data accumulated during the aquaculture process could be digitized or appropriate ways devised to use them as inputs to decision-making processes. Mass culture of marine microalgae as a vegetarian source of PUFA for human consumption, and extraction of fish oil, valuable nutraceuticals and bioactive molecules have immense potential. Seaweed cultivation in India is being undertaken in near-shore waters, and to overcome inshore challenges its expansion to offshore areas is a suitable option. In the vegetative propagation of seaweed, a large amount of harvested material needs to be used during the seeding process. Large-scale use of the available technique of micropropagation (*in vitro* clonal propagation) can only meet the demand for seed material for the future expansion of seaweed farming.

Important priority areas in the post-harvest sector are: bringing out better designs of new-generation, fuel-efficient and multi-purpose green fishing vessels and gears; thrust on the deep-sea and distant water fishing with facilities of onboard handling, preservation, packaging and quality control; development of value-added products; addressing issues related to food safety; and value addition of discards.

4. Conclusion

The fishing and aquaculture sectors in India have shown steady growth in the past few decades which further aims to improve through continued R&D backing, local support networks for capture and aquaculture production, value chain development, and marketing. Motorization and mechanization of fishing boats as well as parallel advancements in craft and gear technology and navigation, considerably aided in the rise in productivity of marine capture fisheries. Marine fisheries production in the country has stagnated and many concerns demand rapid attention, the primary one being management efforts aiming at sustainability. Due to the saturation of conventional fishing grounds, any increase in marine output should come from offshore fisheries, which require improved technology, management, and infrastructure. Climate change research, their effect, and current mitigation strategies should be assessed, and appropriate technologies/interventions based on forecasts should be deployed and changed as needed. There is enormous potential for expanding fish output from reservoirs, and both traditional and contemporary farming methods such as cage culture might be used to do so. GIS-based inland water resource mapping is crucial for identifying and planning the optimal locations for culture or other fisheries-related activities.

In the aquaculture sector, the achievements in induced breeding, seed production, and culture procedures aided to production basket enormously. Greater thrust on diversification aimed at bringing high-value new candidate species and production systems with greater water and energy use efficiency is expected to boost the farming in all three sectors *i.e.*, in freshwater, brackishwater and marine waters. Frontier research fields such as selective breeding, genomic section, genetic engineering, cryopreservation, surrogate fish development, and bioprospecting have sparked a considerable interest to increase production output. With changing climatic circumstances, it is necessary to produce strains with high thermal tolerance that can survive in a broad range of water temperatures. The development of breeding methods for native ornamental fishes has enormous promise. Effective disease diagnosis and control measures are becoming more critical in culture operations, because of increased stocking numbers and changing climatic conditions. Priority should be given to developing vaccines to prevent disease, as well as treatments and chemicals that have the least adverse effects on the environment. More emphasis is needed on post-harvest value addition to create high-value products, besides effective utilization of low-value species or fish waste. Though numerous technologies have been developed across diverse domains, for greater adoption at the ground level, better integration of technologies as well as collaboration with other organizations and departments are essential. Finally, fish is becoming important as a health food, and therefore, ensuring quality and safe fish production is of foremost priority.

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Milk Fish

Cage Mariculture at Karwar

Organic Shrimp Farm

Deep Sea Shrimp

9
Chapter

Achievements in Crop Protection in Independent India

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Summary

In the post green revolution, the pest scenario of crops has undergone drastic change. The pest problems in terms of number of species, frequency of outbreaks and entry of invasive species have intensified. Various efforts on pest management have achieved varying extent of impact leading to food security to the nation. The pest management which was chemical centric initially moved towards ecofriendly integrated pest management with an optimum substitute of chemicals by blend of non-chemical measures. Location specific IPM strategies for field, commercial, vegetable and fruit crops were developed, validated and disseminated with proven economic and ecological benefits. Implementation of ICT-based e-pest surveillance and digital dissemination of advisories across different states facilitated adoption of scientific pest management by the farming community. The R&D set up and plant protection industries, have all paraphernalia needed for an effective preparedness and management of pest. While past has been glorious with some pathbreaking achievements, the future challenges are rather formidable in view of changes in cropping systems and climate change, which have escalated the dynamism in pest' infestation with higher risks. It requires a converged functioning of plant protection stakeholders. The quarantine and pest surveillance needs networking, international cooperation, artificial intelligence, diagnosis and data analytics. The biocontrol agents are the potential tool for pest management for which the entrepreneurial capacity in farm women, rural youth and agri-graduates needs to be developed for their mass production. The major development in plant protection has been described in this chapter.

1. Introduction

Crop pests include weeds, insects, rodents, nematodes, and pathogens - fungal, oomycete, bacterial, viral, and mycoplasmas. The use of the pesticides has been one of the major strategies to reduce the damages caused by these pests. In India, the insecticides use is 44% followed by herbicides (22%). Despite the extensive worldwide use of pesticides, there are massive losses to pests (Oerke 2006). A recent global level study on crop losses in the main food security hotspots (including the Indo-Gangetic plains) for five major crops showed significant losses by pests (weeds excluded) that ranged from 10.1-28.1% for wheat, 24.6-40.4% for rice, 19.5-41.1% for maize, 8.1-21% for potato, and 11-32.4% for soybean (Savary et al. 2019). Losses could be due to either warmer climate and or lack of access to more effective pesticides. It is projected that losses to insect pests and pathogens will increase with global warming (Deutsch et al. 2018; Velasquez et al. 2018). The ‘arms race’ between the pests and the hosts is real; this should be clear to everyone after the Covid-19 pandemic. Pests can be dealt with either by pesticides or by genetic means by mobilizing resistance-conferring genes from the landraces or the wild relatives of the crop by crossing and in case of more distantly related species by genetic engineering technologies. During the last 75 years, many milestones, have been achieved in managing the pests and diseases in crop plants and sustaining the food and nutritional security of the country.

2. Plant pathology

2.1. Enriching collection and conservation of plant pathogen cultures/disease specimen

Herbarium Cryptogamae India Orientalis (HCIO) is a national herbarium established by Sir. Edwin John Butler at Pusa, Bihar in 1905, which was shifted to Indian Agricultural Research Institute in 1934. Nearly 50000 fungal diseased specimens of different groups of fungi preserved in HCIO (2000 genera and more than 3000 “Type specimens”). So far, 570 new species and 19 genera were described to the science from HCIO. Indian Type Culture Collection (ITCC) was established in 1936 in the then Division of Mycology and Plant Pathology, Indian agricultural Research Institute, New Delhi, with a view to furnish a knowledge on living fungi. About 4000 fungal and 600 bacterial cultures are maintained at ITCC which includes plant pathogens, biocontrol agents, fungi for medical and industrial use including mushrooms and yeasts. ITCC is an affiliate member of the World Federation for Culture Collections (WFCC) and is registered with the World Data Centre for Microorganisms (WDCM, registration number 430). Central Insecticide Board, Directorate of Plant Protection, Quarantine & Storage, Ministry of Agriculture, Government of India had made it mandatory to deposit the bio-agents at ITCC before they are released.

Four designated microbial repositories (under Biodiversity Act, 2002) that are established in India under DARE are National Agriculturally Important Microbial Culture Collection (NAIMCC) at ICAR-NBAIM, Mau; Indian Type Culture Collection (ITCC) at ICAR-IARI, New Delhi; Centre for Conservation and Utilization of Blue Green Algae (CCUBGA) at ICAR-IARI, New Delhi and National Centre for Veterinary Type Cultures (NCVTC) at ICAR-NRC Equines, Hisar. Microbial Culture Collection at National Centre for Cell Science, Pune; NAIMCC at ICAR-NBAIM, Mau and the Microbial Type Culture Collection and Gene Bank (MTCC) at the Institute of Microbial Technology (IMTECH), Chandigarh have been recognized by the World Intellectual Property Organization (WIPO), Geneva and acquired the status of International Depositary Authority (IDA) for the purposes of patent procedure under the Budapest Treaty.

2.2. Diagnostics for major pathogens

Highly reliable and sensitive PCR based diagnostics have been developed for several major fungal, bacterial, viral and phytoplasma disease causing agents. DNA barcodes have been developed for several plant pathogens including multiplex PCR and qPCR assay for diagnosis of pathogens infecting pulse crops to facilitate safe exchange and healthy conservation of germplasm. Diagnostics were also developed for several viral diseases of national importance using coat protein for simultaneous detection of several viruses as *Cucumber mosaic virus, Papaya ring spot virus* and *Groundnut bud necrosis virus*. One step lateral flow assay has been developed for on-farm detection and identification for four viruses *viz.,* large cardamom chirke virus, Cardamom bushy dwarf virus, *Potato virus Y* and *Papaya ring spot virus.* Multiplex PCR was standardized for detection of six RNA viruses infecting potato namely PVX, PVY, PVS, PVM, PLRV and PVA. Multiplex PCR was also standardized for the detection of Poty, Carla and Alexi viruses in Garlic. A microarray has been developed for detection of plant viruses and viroids for which sequences were available. Several viruses and viroids were detected using this chip from different crops such as grapevine, chilli, tomato and sugarcane.

2.3. Epidemiology of major plant diseases

On the basis of a series of epidemiological investigations by wheat researchers, the stem rust rules were formulated using climatic data which explained the nature and recurrence of *Puccinia graminis tritici* and *P. triticina*. These rules suggested that the urediniospores originating from the Nilgiris spread to Central India under the influence of tropical cyclone that occurs in the Bay of Bengal during November. Based on this a disease management strategy was formulated and implemented to contain crop losses. On a similar basis, the nature and recurrence of the leaf rust (*P. triticina*) and the stripe rust (*P. striiformis*) over the Indo-Gangetic Plains. Gene matching techniques developed helped in postulating the resistance genes in the variety before its official release.

The work on late blight forecasting in India started in 1950's when Chaudhuri and Pal (1959) utilized the rainfall data and dates of appearance of late blight in Darjeeling hills for 12 years. A computerized forecasting model 'JHULSACAST' for western Uttar Pradesh which has 3 important components: late blight prediction model, a computer programme for forecasting and an interface to utilize weather data from an automatic weather station. Recently, JHULSACAST model was implemented in western Uttar Pradesh using Wireless Sensor Networks (WSN) to forecast late blight and the model could forecast the disease well in advance in comparison to other forecasting models tested. Indo-Blightcast, a web-based pan India model has been developed for forecasting potato late blight across the country (Singh et al. 2016). The advantages of Indo-Blight cast model are that it predicts late blight appearance using daily mean temperature and RH data available with meteorological stations and is an improvement over JHULSACAST. The model is being used to forecast appearance of late blight across agro-ecologies and accordingly agro-advisories are being issued to respective regions using electronic and print media thereby containing the losses caused by late blight by forewarning the farmers and reducing fungicide load by applying fungicides judiciously. Computer based forecasting system has also been developed for rice blast, grape downy mildew, Karnal bunt of wheat, apple scab, Marssonina blotch and many important plant diseases in India.

2.4. Biological control

Biological control has become an alternative strategy for the control of diseases, insect-pests and weeds to reduce the excessive use of agrochemicals and its health hazards. The list of biocontrol agents included in Central Insecticides Board (CIB) for registration are *Bacillus subtilis*, *Pseudomonas fluorescens, Gliocladium spp., Trichoderma spp., Beauvaria bassiana, Metarrhizium anisopliae, Verticillum lecanii, granulosis viruses, nuclear polyhedrosis viruses (NPV), Nomurea rileyi, Hirsutella species, Verticillium chlamydosporium, Streptomyces griseoviridis, Streptomyces lydicus, Ampelomyces quisqualis, Candida oleophila, Fusarium oxysporum* (non-pathogenic), *Burkholderia cepacia, Coniotyrium minitans, Agrobactarium radiobacter strain 84, Agrobactarium tumefaciens, Pythium oligandrum, Erwinia amylovora* (harpin protein), *Phlebia gigantean, Paecilomyces lilacinus, Penicilliuim islanidicum* (for groundnut)*, Alcaligenes spp., Chaetomium globosum, Aspergillus niger* – strain AN27, VAM fungi, *Myrothecium verrucaria, Photorhabdus luminescences akhurustii* strain K-1, *Serratia marcescens* GPS 5 and *Piriformospora indica* etc. However, the market share of the microorganisms is very -low and currently biopesticides occupy about 4% of the total pesticide market share in India. For increasing the use of biocontrol agents by farmers, the identified bottlenecks related to quality needs to be overcome them. *Trichoderma harzianum* based bio-formulation Pusa 5 SD and C*haetomium globosum* based bioformulated product have been developed and proved effective against several plant pathogens.

2.5. Biopesticides, PGPRs and novel molecules

Biopesticide formulation based on bacteria, fungi, viruses, nematodes, protozoa etc. are microbial pesticides used for biological control of plant diseases. Nine microbes, namely *Bacillus subtilis*, *Gliocladium* spp., *Trichoderma* spp., *Pseudomonas fluorescens*, *Beauvaria bassiana*, *Metarrhizium anisopliae*, *Verticillium lecanii*, granulosis viruses and nuclear polyhedral viruses (NPV) have been included in a schedule vide as an amendment in Insecticides Act, 1968 for the commercial production of biopesticide and published in the Gazette of India dated 26th March 1999. To date, 26 more microbes have been included in the schedule to the Insecticide Act 1968 for production of microbial biopesticides. ICAR has documented information of 31 biopesticides developed by its institutions and are at various stages of registration and commercialization (Saxena et al. 2021). Many PGPRs *viz*., *Azotobacter*, *Azospirillum*, *Alcaligenes*, *Arthrobacter*, *Bacillus*, *Enterobacter*, *Burkholderia, Klebsiella*, *Pseudomonas* and *Serratia* have been reported to control several diseases and enhance plant growth. *Pseudomonas* and *Bacillus* are the two bacterial genera that are well documented for their antagonistic as well as ISR activity against several plant pathogens. A nanocopper based formulation developed as an alternative, cost-effective management option for major bacterial diseases of crop plants.

2.6. Deciphered molecular basis of pathogenesis in different host-pathogen systems

Type 3 Secretion System (T3SS) effectors are required by the pathogenic bacteria for their growth, virulence and colonization in host plant. The function of T3SS effectors during bacterial blight development in rice and pomegranate by *Xanthomonas oryzae* pv. *oryzae* (Xoo) and *Xanthomonas axonopodis* pv. *punicae* (Xap) respectively, has been demonstrated (Mondal et al. 2020). The role of the effectors on disease development was verified in several host pathogen system including Xap and pomegranate (Kumar et al. 2016). A new rice blast (*Magnaporthe oryzae*) resistance gene Pi-kh (Pi54) from a unique source was identified, mapped, which provides resistance to major isolates of *M. oryzae*. This gene activates complex defense mechanism as demonstrated by using microarray analysis. New alleles Pi54rh and Pi54of were mined from wild rice species which are resistant to the blast fungus. Robust DNA makers tightly linked to Pi54 gene were developed which are being used extensively in India to improve rice varieties. A novel QTL qSBR11-1 for sheath blight resistance in rice, which has been transferred to Basmati type varieties by the rice breeders. During 2021, a new leaf rust resistance gene *Lr80* was identified and closely linked markers were developed for its successful pyramiding with other marker-tagged genes to achieve durable control of leaf rust.

2.7. Genome of the plant pathogens unravelled

Plants immune system seems to be evolved from simpler to more complex system keeping in pace with the evolution in the pathogens. Pathogen equally has modified in such a way to break the barriers of plant immune system. This necessitates to understand the genomic features of major plant pathogens. In this context, genomic database of several important plant pathogens have been unravelled like *Puccinia graminis* f sp. *trtici*, *P. striiformis* f sp. *tritici*, *P. triticina*, *Tilletia indica*, *Magnaporthe grisea* and *X. oryzae* pv. *oryzae*. These data base would help in understanding the pathogen more appropriately and thereby would lead to novel management options. The big challenge now is to make effective utilization of the enormous sequence data that is available.

3. Insect pest

Insects are economically productive as well as destructive depending upon their behavior-beneficial or damaging to agricultural/horticultural crops and threats to food production causing food security, nutrition and livelihood support concerns of mankind. These also work as potential vectors for transmitting of disease-causing pathogens to humans and animals. Despite the annual investment of US$ 40 billion for the application of 3 of pesticides, and various biological and other non-chemical control worldwide, global crop losses remain a matter of concern (Pimentel and Peshin 2014). The attractive option to boost the food and nonfood crop production include, among others, growing of improved crop cultivars and better crop and pest management. The perils of insect pests to crop production and the strategies of their management adopted post-independence are briefly discussed herewith.

3.1. Insect collection and conservation

The National Insect Museum of ICAR-National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru, a facility created under the aegis of the Indian Council of Agricultural Research, was inaugurated on March 10, 2019. This museum is recognized as the designated national repository by the Ministry of Environment, Forest & Climate Change in 2012 for preservation of insects, spiders and mites. The specimens in the museum are systematically collected, preserved and catalogued for over 30 years and these represent the historical journey of insect species richness and diversity aided by timely taxonomic identification and documentation leading to advanced biological studies. Presently there are only three repositories in the country recognized by MOEF & CC for insect preservation. They are National Insect Museum (NIM) at ICAR-NBAIR, Bengaluru, Karnataka recognized as a designated repository for preservation of insects, spiders and mites. Zoological Survey of India, Kolkata, West Bengal became a designated repository for fauna (which included insects and related arthropods). Tropical Forest Research Institute, Jabalpur, Madya Pradesh (under the Indian Council of Forestry Research and Education, Dehradun) is designated as a repository for termites, butterflies and moths. Other important Indian insect collections are National Pusa Collection (NPC), ICAR-Indian Agricultural Research Institute, New Delhi, TNAU insect museum, Coimbatore and Forest Research Institute, Dehradun.

3.2. Detection of transboundary insect pests and their suppression

Transboundary insect pests including exotic/invasive species are a serious threat to food security and the environment, a condition exacerbated by the globalized movement of people and commodities. Many insects that invaded India got established as regular pests include cassava mealybug (2020), fall armyworm (2018), South American tomato moth (2014), papaya mealy bug (2007), cotton mealybug (2005), eucalyptus gall wasp (2000), silver leaf whitefly or 'B' biotype of *Bemisia. tabaci* (1999), coconut eriopyhid mite (1998), spiralling whitefly (1993), coffee berry borer (1990) and psyllid vector of citrus greening disease during 1960s. Besides, many exotic pests that entered the country during earlier decades are causing significant damage to various crops. Desert locust (*Schistocerca gregaria* Forskål) caused significant loss to crops in North West and Central India between April to June 2019. India witnessed an upsurge of the locust in 2020 also with the swarms attaining epidemic proportions alongside of COVID- 19 pandemic. Several efforts have been made to contain invasive species through biological control. Under classical biological control, examples of pest suppression with imported natural enemies include predator, *Rodolia cardinalis* against cottony cushion scale, *Icerya purchase* (1951); predator, *Curinus coeruleus against s*ubabul psyllid, *Heteropsylla cubana* (1990); parasitoids, *Prorops nasuta* & *Cephalonomia stephanoderis* against coffee berry borer, *Hypothenemus hampei* using (1990); parasitoid, *Encarsia Guadeloupe* against spiralling white fly, *Aleurodicus* *disperses* (1995); predators, *Amblyseius largoensis & Neoseiulus mumai* against coconut eriophid mite, *Aceria gurreronis* (1998); predator *Tetraphleps raoi* against, pine woolly aphid, *Pineus pini* (2007); parasiotoid, *Aenasius arizonensis against* cotton mealy bug, *Phenococcus solenopsis* (2007); parasitoid, *Acerophagous papayae* against papaya mealy bug, *Paracoccus marginatus* (2010); parasitoid, *Quadrastichus mendeli* against eucalyptus gall wasp, *Leptocybe invasa* (2018); parasitoid, *Encarsia guadeloupae* against coconut rugose spiraling whitefly, *Aleurodicus rugioperculatus* (2019). The latest introduction has been the parasitoid *Anagyrus lopezi* from Benin for the control of cassava mealy bug in Tamil Nadu and Kerala during 2021 (Sampathkumar et al. 2021).

3.3. Development of surveillance and forewarning techniques

3.3.1. Pest surveillance

Regular real-time monitoring of crop pest enables assessment of risks and in turn adopt timely need-based measures for their effective management. Information and communication technology (ICT) is very effective in assimilation of data on pests over time and space, and its quick processing to facilitate a decision on pest management. The ongoing programmes *viz.,* crop pest surveillance and advisory project (CROPSAP) and horticulture pest surveillance and advisory project (HortSAP) in Maharashtra (Vennila et al. 2016) and e-pest surveillance in vegetables in Haryana are few successful examples for digital surveillance and delivery of the pest management advisories to farmers that resulted in prevention of pest outbreaks. Hyper spectral remote sensing has been used to develop spectral signatures for rice BPH to discriminating damaged crop from undamaged crop (Prasannakumar et al. 2013).

3.3.2. Pest forewarning

The weather based 'pest alerts' offer better preparedness for pest management. Weather based early warning systems are in place for desert locust, potato and grape pests. Rule-based robust tools for location specific forewarning of rice insect pests, *Spodoptera litura* for groundnut and early blight of tomato (*Pest predict*-RBS) and empirical models (*Pest predict*-EMS) for rice, pigeon pea, groundnut and tomato insects and diseases are available as mobile Apps. Climatic variability in terms of monsoon rainfall influence rice BPH population and more than 30 rainy days during June to September months resulted in the pest outbreaks with >75% probability (Chander and Husain 2018). Likewise, pest-weather models in combination with historical weather and with the help of GIS have been used for delineation of pest hotspots for rice BPH through agro-ecological pest zoning, thereby facilitating strategic pest management planning (Yadav et al. 2010). InfoCrop, a generic crop growth simulation model for tropical environments has been developed and coupled with different pest damage mechanisms. The mechanistic pest population simulation models based on thermal constant concept, and biotic and abiotic mortality factors were developed for rice pests (Reji and Chander 2008). Further, these models were coupled to the InfoCrop model and the coupled model could be used to analyse impact of climate change on pest dynamics as well as crop-pest interactions (Selvaraj and Chander 2015).

3.4. Development of pest management techniques

3.4.1. Host plant resistance

One of the fundamental pillars of pest management is host plant resistance (HPR). The germplasm has been screened and exploited for development of varieties and hybrids in different crops. Commercialization of *Bt* transgenic hybrids since 2002 followed by Bollgard-II double gene technology in 2006 has been a standalone HPR attempt against bollworms of cotton and it brought down insecticide usage by 69%. Some of the important resistant cultivars include, CoSe 01421 (Imarti) of sugarcane in North Central Zone against red rot, shoot borer, top borer and stalk borer; JS 93-05 of soybean tolerant to insect pests and drought in Madhya Pradesh, Maharashtra, Rajasthan, and Karnataka, and cashew variety, Bhaskara, less prone to the attack of tea mosquito bug in coastal Karnataka.

3.4.2. Cultural and mechanical tactics

Companion crops-based management of insects-pests has been a time-tested practice in India. Tomato intercropped with cabbage against diamondback moth, African marigold intercropped with tomato against fruit borer *Helicoverpa armigera,* and Napier grass and Napier millet as trap crops against stem borer *Chilo partellus* in maize and sorghum are some outstanding examples. Advanced insect light trap technology *viz.* 'Light trap safer to beneficial insects' for mass trapping of selective phototrophic macro-lepidopteran insect pests has been developed that facilitates escape of beneficial insects and non-targeted insect fauna through a porous filter chamber (Singh 2015). This technology in being used by different organizations in various states of the country.

3.4.3. Semio chemicals

Sex pheromones are routinely used for monitoring and mass trapping for species of insects *viz., Helicoverpa armigera, Spodoptera litura, Pectinophora gossypiella, Tuta absoluta, Aproaerema modicella and S. frugiperda*. Similarly, species specific pheromones for rice yellow stem borer, borers of sugarcane, diamond back moth of cabbage, white grubs of sugar cane, rhinoceros beetle and red palm weevil of coconut are deployed in various cropping systems. Pheromones are also used for mating disruption with delivery mechanism such as traps or ropes or specialized pheromone and lure application technology (SPLAT) formulation against *P. gossyiella* in *Bt* cotton ecosystem.

3.4.4. Biological pest suppression

Besides several outstanding successes in respect of suppression of invasive species with imported natural enemies as discussed earlier in this section, many obnoxious insect pests have been managed with indigenous natural enemies. *Epiricania melanoleuca*, a parasitoid of *Pyrilla perpusilla* introduced into Gujarat in 1982 from Maharashtra and Haryana on sugarcane has been suppressing the pest since then with 72% parasitism. Likewise, the ichneumonid, *Isotima javensis* a parasitoid of sugarcane top borer, *Scirpophaga excerptalis* in northern India, has been successfully colonized in South India. Recently, several native hymenopteran parasitoids and pentatomid bug predators *viz*., *Eocanthecona furcellata* and *Andrallus spinidens* in maize ecosystem exhibited scope of natural bio control of fall armyworm (FAW). Mass production protocols have been developed for predators, parasitoids and pathogens. Multiple insecticide and high temperature tolerant strains of the egg parasitoid, *Trichogramma chilonis*, pesticide tolerant strain of predatory *Chrysoperla zastrowi sillemi*, formulations of entomopathogenic nematode *Heterorhabditis indica* for the biological control of white grubs and other soil insects and indigenous *Bacillus thuringiensis* liquid formulations against many lepidopteran crop pests have been the technologies promoted for agribusiness in biocontrol. Since discovery of antifeedant activity of neem seed kernel extract against desert locust, significant progress has been made in research and development of azadirachtin based biopesticides.

3.4.5. Chemical pesticides

The chemical control has seen many generations of insecticides. While first generation pesticides were inorganics, second generation included DDT and BHC, and organophosphates and carbamates, on which the crop protection relied heavily 1950 onwards with other management interventions almost subdued. Presently, in India safer organophosphates and pyrethroids have been registered and they are being used by the farmers. The overuse of pesticides resulted in problem of resistance development in insects, first reported in the country in singhara beetle, *Galerucella birmanica* in 1963 (Pradhan et al. 1963). The non-lethal methods such as attractants, repellants, antifeedants, chemosterilants, pheromones, and insect hormones constituted the third-generation pesticides, while mid 1970s witnessed the introduction of synthetic pyrethroids as fourth generation pesticides. These were followed by new molecules with novel mode of action such as neonicotinoids, spinosad (spinosyn A and spinosyn B) and avermectins, the latter two often referred as bio rational insecticides.

A total of 299 pesticides have been registered in India as on July, 2021. Methyl bromide as fumigant has been used for more than six decades to disinfect imported commodities and in storage (DPPQ&S 2017). Following the Montreal protocol phase out schedule, India has worked on aluminum phosphide as an alternative to methyl bromide. As pesticides have not been registered against pests on all crops, farmers often use off-label products that have implications on food safety and export. Grouping of crops and commodities (554 numbers) in line with the codex classification and guidelines for label expansion with respect to maximum residue limits (MRL) has been a step forward by the government. Draft notification of 2020 on ban of 27 pesticides including 12 insecticides is still under review by DAC&FW. The Pesticide Management Bill 2020 emphasizes on adopting systematic standard operating procedures with transparency with optimization of benefits between the industries and growers mediated by the Government.

3.5. Evolution of integrated pest management

Pest control during subsistence phase prior to green revolution was through natural factors and insecticide use was rare. Prophylactic treatments and indiscriminate use of synthetic insecticides during exploitation phase (1960-70) led to the development of resistance in pests and secondary pest outbreaks that created a crisis situation for pest control during 1980s. Disaster phase coincided with collapse of management programmes especially in cotton and despite increased insecticide usage and rising the cost of production, there were crop failures trapping farmers in debt. The concept of integrated control in India was propounded by Dr. S. Pradhan in 1969. Pest management at field level in India was initiated in 1975 with introduction of Operational Research Programme (ORP) on cotton and rice. India became member of FAO-country programme in 1980s and adopted IPM as a national policy in 1985. The FAO–Inter country programme was started in rice during 1993 simultaneously with IPM programme in cotton by CABI. Bio–intensive IPM (BIPM) is being promoted for a sustainable insect pest management since1985. Location specific successful strategies of IPM for various field, commercial, vegetable and fruit crops have been developed, validated and disseminated with proven economic and ecological benefits in the country. The milestones in insect pest management as listed in Table 1.

Table 1. Milestones in the area of insect pest management

Year	Milestone
1914	The Destructive Insect Pest Act was introduced.
1951	Classical biological control of cottony cushion scale, *Icerya purchasi* through predatory *Rodolia cardinalis.*
1962	Discovery of antifeedant properties of neem against desert locust.
1963	Detection of first case of insecticide resistance development against DDT in Singhara beetle.
1968	The Insecticides Act No. 46 was introduced to regulate the import, manufacture, sale, transport, distribution and use of insecticides with a view to prevent risk to human beings or animals, and for matters connected therewith.
1969	The concept of 'Integrated Control' in India propounded by Dr. S. Pradhan.
1970	Introduction of synthetic pyrethroids.
1971	Insecticide Rules (GSR 1650, DT. 9-10-1971): In exercise of the powers conferred by section 36 of the Insecticides Act, 1968 (46 of 1968), the Central Government, after consultation with the Central Insecticides Board, made the rules.
1975	Pest management at field level initiated in India with implementation of operational research programme (ORP) in cotton and rice.
1980	India became member of FAO-country programme.
1982	Introduction of *Epiricania melanoleuca*, a parasitoid of *Pyrilla perpusilla* into Gujarat from Maharashtra and Haryana on sugarcane.
1985	Adoption of 'Integrated Pest Management' (IPM) as national policy for crop protection.
1993	FAO–Inter country programme started in rice during 1993, simultaneously with IPM programme in cotton by CABI.

Year	Milestone
2002	Commercialization of *Bt* transgenics in cotton.
2006	Commercialization of Bollgard-II double gene technology in cotton transgenics.
2006	Development of InfoCrop, a generic crop simulation model for tropical environments.
2007	Introduction of parasiotoid, *Aenasius arizonensis* against cotton mealy bug, *Phenococcus solenopsis.*
2008	Development of mechanistic pest population dynamics simulation model.
2010	Suppression of papaya mealy bug, *Paracoccus marginatus* through *Acerophagous papaya.*
2010	Initiated application of geo-spatial techniques GIS and remote sensing in pest management.
2014	Detection of invasive South American tomato pinworm.
2015	Development of coupled InfoCrop-Pest model.
2015	Designing of light traps safer to beneficial insects.
2016	Implementation of ICT-based pest surveillance and advisory project CROPSAP & HORTSAP in Maharashtra.
2017	Application of specialized pheromone & lure application technology (SPLAT) for mating disruption of cotton pink bollworm (PBW).
2018	Detection of invasive fall armyworm (FAW), *Spodoptera frugiperda.*
2019	Invasion of desert locust, *Schistocerca gregaria* North West and Central India.
2019	Suppression of coconut rugose spiraling whitefly, *Aleurodicus rugioperculatus* through parasitoid, *Encarsia guadeloupae.*
2020	Invasion of cassava mealybug.
2020	Introduction of Pesticide Management Bill.
2021	Introduction of parasitoid *Anagyrus lopezi* for control of cassava mealy bug.

During last one-decade sincere efforts made by ICAR-National Research Centre for Integrated Pest Management (NCIPM), New Delhi on validation and promotion of integrated pest management (IPM) have resulted in successful implementation of IPM in basmati rice in Gautam Budh Nagar (UP) in 1275 ha with participation of 715 farmers; Panipat, Jind and Kaithal in (Haryana) in 6904 ha involving 1748 farmers and Fatehgarh Sahib (Punjab) in 1270 ha with involvement of 117 farmers. The study indicated higher average yield and benefit-cost ratio (3.3-4.0) in IPM as compared to farmers' practice with 58.3% enhancement in net return. Chemical pesticide application was reduced to 75.3 g *a.i.* ha^{-1} in IPM against 892.9 g *a.i.* ha^{-1} in farmers' practice.

3.6. Alien invasive insect pests intercepted and classical biological control with international cooperation

The spread of alien species is one of the greatest threats to the ecosystem in the country. Classical biological control appears to be an important approach in the management of these invasive species. International collaboration for the management of invasive species is of utmost importance as exchange of resources can help in timely control of the pest. In the recent years several invasive insects are managed through Classical biological control by introduction of natural enemies from home range. The quarantine facility at NBAIR set up in the year 2009 as a fully equipped quarantine block as per the international standards, since then several natural enemies have been imported, such as *Acerophagus papayae* for the management of papaya mealybug, *Quadrastichus mendeli* for the management of eucalyptus gall wasp, recently the encyrtid wasp, *Anagyrus lopezi* was imported from Benin for the management of the cassava meal bug.

4. Nematology

Nematodes are one amongst the various biotic factors that cause stress to plants. Approximately 40% of food crops are lost to agricultural pests, including plant nematodes (FAO 2019). Damage caused by plant parasitic nematodes (PPNs) has been estimated between US$ 80 billion (Nicol et al. 2011) to US$ 157 billion per year (Abad et al. 2008). However, the extent of nematode damage is expected to be far more as most of the farmers, predominantly in developing countries, are oblivious of the presence of PPNs (Jones et al. 2013).

Nematology as a scientific discipline was possibly the last of the plant protection disciplines to get recognition only in mid to late 19th century, although nematological investigations date back to the days of Aristotle (Chitwood and Chitwood 1950; Chen et al. 2004). Scientific attention eluded PPNs because of (i) their microscopic size; (ii) below ground habitat (in soil/roots); (iii) non-specific symptoms (except in few cases like root-knots or ear cockle of wheat); (iv) techniques of extraction were not known till early twentieth century; (v) difficulty in proving their pathogenicity as they are obligate parasites and cannot be cultured on artificial media; (vi) lack of trained human resource and (vii) unawareness among the farmers.

The earliest mention to nematodes (Krimi or Krmin) can be traced to Rig, Yajur and Atharva Vedas written in 6000-4000 BC. Charak is supposed to have recognized 20 different organsims as krimis in his Samhita, which included nematodes besides arthropods and leeches. The first allusion to a PPN is, however, preserved in the famous writ, "Sowed cockle, reap'd no corn," a line by William Shakespeare penned in 1594 in, "Love's Labour's Lost", Act IV, Scene 3, most certainly has reference to blighted wheat caused by the plant parasite, *Anguina tritici* (Thorne 1961).

Needham (1743) cracked the "riddle of cockle" when he crushed one of the diseased wheat grains and observed the earcockle nematode, *Anguina tritici*. In the following years till early 1900s, the descriptive reportage of nematodes and their taxonomy is mostly documented. Contributions of N A Cobb in America laid the foundation of the discipline Nematology. In pre-Independent India the first report of plant parasitic nematode was by Barber of the root-knot nematode on tea from Devala estate, Tamil Nadu in 1901. Later same nematode was reported on black pepper in 1906 by Butler from Kerala. These two reports indicate the trade interests of the colonial power. The first report of Indians documenting economic importance of the root-knot nematodes in south India is by Ayyar in the year 1926. Dastur in 1936 reported occurrence of the white tip disease of rice by *Aphelenchoides besseyi*. The major handicap in this time period was non-availability of trained human resource in nematology.

4.1. Assessment and management of nematodes

In order to generate location specific nematode management technologies or practices for different agro-climatic conditions. Plant Nematode Pests and their Control" was initiated in 1977 by the Department of Science and Technology, Govt. of India. The critical analysis of data generated through AICRP on Nematodes over the years revealed 21.3% crop losses amounting to Rs. 102039 million annually in India due to plant parasitic nematodes which included Rs. 50224 million in 19 horticultural crops and Rs. 51814 million in 11 field crops. Rice root knot nematode, *Meloidogyne graminicola* was found the potent upcoming nematode problem of rice with economic loss of about Rs. 23272.32 million. Citrus (Rs. 9828 million), banana (Rs. 9710 million) among fruit crops; and tomato (Rs. 6035 million), brinjal (Rs. 3499 million) and okra (Rs. 2480 million) among the vegetable crops suffered comparatively more losses (Walia et al. 2018). Region-specific 'Package of Practices' for nematode management in cereal, vegetable, horticultural, fibre, oilseed, pulses, spices and plantation crops have been released under AICRP on Nematodes (Walia and Chakrabarty 2018).

4.2. Nematode management by biopesticides

ICAR-Indian Institute of Horticultural Research, Bengaluru has become the lead centre of ICAR for developing eco-friendly technologies for sustainable management of nematode problems in horticultural crops *viz.,* tomato, capsicum, cabbage, cauliflower, gerbera, carnation, tuberose, chillies, banana and papaya. IIHR developed six biopesticide technologies *viz., Paecilomyces lilacinus* 1% W. P.**,** *Trichoderma harzianum* – 1% W.P, *Pseudomonas fluorescens* – 1% W.P., *Trichoderma viride* – 1.5% W.P, *Verticillium chlamydosporium* (*Pochonia chlamydosporia*) – 1% W.P, Arka – Organic plant growth enhancer and yield promoter. IIHR has been granted seven international patents and one Indian patent on bio-pesticide technologies. ICAR-National Bureau of Agricultural Insect Resources, Bengaluru has also produced a silicate-based formulation of a natural biocontrol agent, *Pochonia chlamydosporia* (NBAII PC55), a fungus species (Nagesh et al. 2019a). It is now widely accepted for managing the root-knot and cyst nematodes.

4.3. Insect management by entomopathogenic nematodes

Entomopathogenic Nematodes (EPN) offer a sustainable management option for insects. Pusa NemaGel, a bio-pesticidal formulation based on heat tolerant indigenous insect-parasitic nematode species *Steinernema abbasi* with improved viability and shelf life of the nematode for the management of soil arthropods has also been developed. Novel insecticidal WP formulations of *Heterorhabditis indica* for the biological control of white grubs and other soil insect pests have also been developed by ICAR-National Bureau of Agricultural Insect Resources, Bengaluru (Nagesh et al 2019b). ICAR- sugarcane Breeding Institute, Coimbatore, Tamil Nadu have developed EPN formulations containing *Heterorhabditis indica* and *Steinernema glaseri* with considerable product shelf life. ICAR-IARI has also developed an apparatus for *in vivo* mass production of entomopathogenic nematode and an Indian patent has already been granted to it. Small entrepreneurs can use these technologies to establish EPN production units and earn profit.

4.4. Basic research in nematology

Division of Nematology at the ICAR-IARI is one of the best centres of Nematology research and teaching. The National Nematode Collection of India is also housed in the Division. There are 2595 type slides; 611 type species; 3302 wet collections and 2285 identified slides. Apart from EPN technologies the Division is identified for international level of basic research in nematology. It has identified RNAi target genes relating to parasitism, neuro muscular system, structural component and reproductive system genes etc. of PPNs. A US patent has been granted for a host delivered double-stranded RNA (ds RNA) mediated gene silencing of root knot nematodes for the control of nematodes in plants. Patents for nematode induced promoter sequences expressing (i) only in roots and the (ii) other in only root-knot nematicide induced galls have also been filed.

4.5. Eradication of earcockle disease of wheat

Anguina tritici, the first plant parasitic nematode described in 1743 causes the earcockle disease in wheat. Wrinkled and twisted leaves of young plants, reduced and irregular heads (ears) having the typical cockles (light to dark brown, round galls instead of healthy grains) are the main symptoms of the disease. The earcockle and *tundu* disease (causal organisms *A. tritici* + *Corynebacter tritici*) have been eradicated completely from Punjab, Haryana and Western Uttar Pradesh and from most parts of Rajasthan, Eastern UP, Madhya Pradesh and Bihar.

4.6. Policy decisions impacting nematology

The discovery of Golden Nematode (*Globodera rostochiensis*) of potato in the Nilgiri hills of Tamil Nadu in 1961 ushered in the era of applied Nematology in India. It was traced that this dreaded nematode had been introduced into India along with seed potatoes imported from Europe. Immediately after its detection in India and going by the European experience, a policy decision to enforce domestic Quarantine against this nematode was taken in 1971 to check its further spread within the country. However, the nematode was intercepted from northern hilly areas of Himachal Pradesh, Uttarakhand and Jammu & Kashmir in recent years. The provision of domestic quarantine was further extended to these states in 2018. This notification will restrict any further spread of this nematode in the potato cultivation area of the northern plains.

In consideration of the economic losses attributed to the plant parasitic nematodes in agricultural crops, the Ministry of Agriculture, Govt. of India accorded priority registration to two new chemical molecules, Fluopyram and Fluensulfone in 2018 as exclusive nematicides. These are considered relatively safe to the environment and will replace the currently used highly toxic carbamate and organophosphatic nematicides. For the first time, a fungal bioagent, *Paecilomyces lilacinus* has also been granted regular registration in 2018.

5. Weed research

Among various biotic factors that limit production, weeds cause highest yield loss of 33% (DWR 2015). In India, total economic losses due to weeds in 10 major field crops in 18 states are ~US$ 11 billion annually (Gharde et al. 2018). Very high economic losses were estimated in rice (US$ 4420 million), wheat (US$ 3376 million) and soybean (US$ 1559 million). Weeds compete with crops for inputs/resources, decrease quantity and quality of produce and cause health hazards for humans and animals. Hence, managing weeds is pre-requisite for attaining higher crop productivity, profitability and improved resources/input use efficiency. Amongst the various methods of weed management, herbicide is proven easier to apply, most efficient and cost-effective tool. The milestones and impacts in weed research and management technologies during the last 75 years of Independence of India are presented in following section.

5.1. Weed survey and ecology research

Research on weed survey/distribution across crops/cropping systems and biology and ecology have been recurrent one that continues over times. There were focusses on ecology and life cycle of predominant weeds to determine the weakest phase in the life cycle when weeds could be easily controlled. Estimation of yield losses due to weeds; determining critical period of weed competition in major crops as early as 1964-1969, a PL 480 research project with USAID was undertaken on the ecology of ten common noxious weeds that included *Chenopodium album*, *Cyperus rotundus*, *Eichhornia crassipes*, *Anagallis arvensis*, *Spirodela polyrrhiza*, *Portulaca oleracea*, *Cassia tora*, *Eleusine indica*, *Amaranthus spinosus* and *Eleocharis palustris*.

During 1990s, studies also embraced upon physiology/ biology and ecology of some important perennial/ annual weeds, namely, *Eupatorium adenophorum/ riparium/ odoratum, Cyperus rotundus, Oxalis latifolia, Echinochloa colona/ glabrescens* and weed seed bank dynamics in rice-wheat cropping system and comparative eco-physiology of *Phalaris minor* and *Avena ludoviciana* Dur. and wheat. The ecology of problematic weeds, *Parthenium hysterophorus* was assessed and its chemical and biological control measures was developed. Parthenium Awareness Week (PAW) was initiated in 2005 and is being organized every year thereafter. A Weed Atlas for major weeds in major crops in 435 districts spread across 19 states of the country was published (Dixit et al. 2008). 826 weed species were reported to cause yield losses in India of which 80 and 198 were considered very serious and serious weeds, respectively. Economic threshold level (ETL) of *Trianthema portulacastrum* L. (Hazra et al. 2011) and *Cyperus rotundus* L. (Das et al. 2014) in soybean, and *Chenopodium album* L. (Dodamani and Das 2013), *Phalaris minor* Retz. (Raj et al. 2020) and *Avena sterilis* ssp *ludoviciana* (Dur.) in wheat were determined through models. Other significant achievements included impact of climate change on weeds, biology and control measures of *Orobanche,* weedy rice problem and management, understanding crop weed-fertilizer-water interactions and their implications for weed management in agricultural systems for doubling farmers' income (Rao et al. 2020).

5.2. Herbicide recommendations

Generally, phenoxyalkanoic acids in 1940s; carbamates (thiocarbamates) in 1950s (1954 onwards); phenylureas in 1950s (1951 onwards); dinitroanilines in 1950s (1955 onwards); acetamides in 1950s (1956 onwards); triazines (symmetrical triazines) in 1950s (1956 onwards); uracils in 1960s (1962 onwards); aryloxyphenoxypropionates (APPs) in 1970s (mainly in the late 1970s and early 1980s); imidazolinones in the 1970-80s; sulfonylureas in 1980s were developed/reported in the world. Candidate herbicides of these respective groups were commercially used contemporarily to these years or later. Initially non-selective inorganic herbicides like sodium chlorate ($NaClO_3$) were used in the world and to a limited scale in India for weed control in bunds, roadsides, and non-crop situations. Then came several selective herbicides for weed control in cropped situations. These herbicides were used in higher doses, usually in kg/ha like triazines (atrazine, simazine, propazine, cynazine, ametryn, prometryn, etc.), dinitroanilines (pendimethalin, fluchloralin, trifluralin etc.), phenylureas (diuron, linuron, isoproturon, chlortoluron etc.), phenoxyalkanoic acids (2,4-D, MCPA, etc.). Recently, there has been a tremendous shift in herbicide molecules, called novel herbicides, having specific mode of action. They include imidazolinones (imazamethabenz, imazapyr, imazaquin, imazethapyr, imazamox), sulfonylureas (halosulfuron-methyl, pyrazosulfuron-ethyl, nicosulfuron, flazasulfuron, sulfosulfuron, chlorimuron-ethyl, bensulfuron-methyl, primisulfuron-methyl, sulfometuron-methyl, chlorsulfuron, metsulfuron-methyl, triasulfuron, tribenuron-methyl), pyrimidinylthiobenzoates (pyrithiobac-Na, bispyribac-Na, pyriminobac-methyl), triazolopyrimidines (penoxsulam, pyroxsulam, flumetsulam, cloransulam-methyl, diclosulam, metosulam), which are recommended at lower doses, have high potency and lower residual toxicity.

5.3. Integrated weed management

Cultural and mechanical practices were evaluated and included into the packages of integrated weed management programmes (Das et al. 2012). The utilization of weeds such as *Lantana camara, Eupatorium odoratum, Parthenium hysterophorus, Eichhornia crassipes* for compost/green manure/soil mulch in several crops and cropping systems was explored. Integrated weed management practices were also developed for several crops across regions. Soil solarization using black/transparent polyethene (25-100 µ thickness) for weed management was developed (Das and Yaduraju 2008), and was recommended for reducing soil seed bank. Soil solarization combined with herbicides (metolachlor, glyphosate, imazethapyr (as applicable) were recommended for crops and cropping systems for better weed control including *Cyperus rotundus* (Kumar et al. 2012). Recently, many machine-operated weeders are available for use by farmers in India. Brown manuring technology with *Sesbania aculeata* or mixture of *Sesbania aculeata* and *Crotalaria juncea* was developed for direct-seeded rice and maize crops (Das et al. 2019). Additionally, several innovative practices like band application, stale seed-bed, and novel combinations of dormancy breakers like KNO_3 or GA_3 and herbicides were developed (Das and Das 2018). Integrated weed management schedules for major crops and cropping systems, including the management of deadly weed *Parthenium hysterophorus*; noxious weed *Cyperus rotundus* and resistant/cross-resistant *Phalaris minor* were also developed.

5.4. Management of *Phalaris minor* resistance

Continuous use of isoproturon for 10-15 years in wheat under rice-wheat system led to evolution of resistant *Phalaris minor* populations/biotypes. The resistance against isoproturon was established in 1992 (Malik and Singh 1995). It posed severe threat to wheat production in India and required 8-11 times more dose of Isoproturon than that required for susceptible biotypes to achieve 50% growth reduction (GR_{50}) in resistant populations of this weed. It is considered as the most serious case of herbicide resistance in the world. The resistance spread in more than 1.0 million ha of rice-wheat cropping system. Based on a joint recommendation of ICAR-IARI and SAUs-PAU and CCSHAU the Government of India gave provisional registration to clodinafop-propargyl, sulfosulfuron, and fenoxaprop-p-ethyl in 1997-98 for use as alternative herbicides to control isoproturon-resistant *Phalaris minor*. ICAR -IARI, CCSHAU and PAU and manufacturing companies and several Farmers Groups jointly created awareness about the resistance and its management which proved successful. Integrated weed management (IWM) modules involving alternative herbicides, cultural and other agronomic practices for controlling *P. minor* was suggested.

In recent years, use of bio-technology tools for understanding molecular diversity of *Phalaris minor* populations in wheat and mechanism of resistance of *Phalaris minor* to isoproturon were initiated. After continuous use of clodinafop-propargyl, fenoxaprop-p-ethyl, diclofop-methyl and sulfosulfuron for 6-7 years, evolution of cross-resistance in *P. minor* against these herbicides was reported during early 2000s. *P. minor* developed multiple resistance to many herbicides in recent years (Das et al. 2014). Pinoxaden, mesosulfuron+ iodosulfuron (Ready-mix) and sulfosulfuron + metsulfuron (Ready-mix) were recommended for the control of resistant *P. minor* populations in wheat (Chhokar and Sharma 2008).

Continuous refinement of weed management technologies is essential to cut down production costs, and also in the light of ever-changing socio-economic conditions of the farmers and international trade policies. Herbicides are going to become increasingly popular in the coming years but the residue hazards and other environmental issues are also required to be suitably addressed. Development of suitable technologies to tackle the probable scenario that may emerge in the area of crop-weed competition due to increasing atmospheric CO_2 concentration and subsequent global warming are some of the major future challenges. Herbicide-tolerant crops may be a possibility in Indian agriculture as an important component of integrated weed management in near future.

6. Plant quarantine for plant genetic resources

International exchange of plants/planting material carries an inadvertent risk of introduction of exotic pests or their new virulent races/strains into new areas. History has witnessed several examples of dangerous pests introduced along with plants/planting material/ plant products that have led to serious socio-economic consequences. Plant quarantine is a mandatory requirement to regulate the entry of seed/planting material, plant products, living organisms and soil etc. so as to prevent unintended entry of pests across nations. International exchange of plant genetic resources (PGR) is important to broaden the genetic base of crops in order to develop improved crop varieties. In India, there are two routes for entry of plants or their parts. First is the bulk import for commercial use and consumption is being monitored by Directorate of Plant Protection Quarantine and Storage (DPPQS), Faridabad and the second route is for small seed samples for research purposes, though larger in number which are being imported through ICAR-National Bureau of Plant Genetic Resources (NBPGR) at New Delhi since its establishment in 1976. The Government of India has legislated the Plant Quarantine (Regulation of Import into India) Order in 2003 to regulate the import of plant material. Under this Order, ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR) has been delegated powers to issue Import Permit and to carry out quarantine processing of imported PGR including transgenics and for issue of Phytosanitary Certificate for PGR meant for export. The Division of Plant Quarantine at ICAR-NBPGR, New Delhi has developed an efficient and systematic protocol for quarantine processing for pest diagnostics, salvaging and containment to ensure biosecurity during exchange of PGR and to be transparent during exchange internationally. Stringent quarantine examination of 49,97,795 samples of PGR during 1976–2021 of which 1,78,507 samples were found infested/ infected by insects (1,08,615); pathogens (42,123); Nematodes (23,952) and weeds (3,817). A total of 78 exotic pests including insects/ mites (26), fungi (6), viruses (19), nematodes (9) and weeds (18) that are not yet reported from India were intercepted. A systematic step-wise strategy is being followed for testing of each of the samples imported for presence of any unwanted pests.

All the samples found infested/infected with pests viz., were salvaged using suitable methods and if they could not be salvaged, they were rejected and destroyed by appropriate means. Had any of these exotic pests not been intercepted and had escaped, they could have entered and established in the country and subsequently caused devastation to our agriculture. Presently, exchange of PGR has become more difficult under the Convention on Biological Diversity, hence, all attempts were made to salvage the germplasm and over 99 % of samples were salvaged and less than 1% samples were rejected. Efforts are needed in the national plant quarantine system to develop and use the latest detection and eco-friendly disinfestation/ disinfection techniques to minimalize the risk of pest escape in quarantine.

The 78 pests of quarantine significance for India mentioned previously, if not quarantined had the potential to cause serious economic losses to the country as these do in the host countries. Favourable environmental conditions do exist in India for all the 78 pests. A simple calculation, assuming just eight pests of four major crops, viz., wheat, soybean, cotton and maize causing 1.0% economic loss, would amount to more than Rs. 300 crore annually to farmers. These losses in fact would be much higher in real life situation and a just 10% loss will amount to Rs 3000 crores per annum based on minimum support price 2019-2020 and yield of 2018-2019. These pests once established cannot be eliminated, hence would cause recurring losses.

7. Conclusion

The present compilation on the technologies of plant protection in independent India depicted a holistic picture of the major researches and development of useful techniques that helped the farmers/stakeholders to protect the crops from avoidable losses. Pest and disease management is an evolving system approach that accommodates all need-based innovations, concepts and policies in regard to various management practices. The innovations in bio- and- nano-technologies and ICT have taken advantage for improving effectives of IPM programmes and their dissemination. The judicious use of pesticides needs to be ascertained to produce safe and quality food, prevent environmental contamination, promote exports and reduce cost of production thereby increasing farmer income. Increasing - concern for safer chemicals led to priority registration and use of safer new generation chemicals. Likewise, conservation and enhancement of natural bioagents for pest suppression should be an essential approach. In order to augment such natural management strategy, large-scale production of biocontrol agents through entrepreneurship development is urgently required. The responsibility of plant protection has been increased many folds under natural farming. Management of pests and diseases without using pesticides for sustainable agriculture is a major challenge.

On the other hand, discoveries in molecular biology and nanotechnology (as carrier molecule) have resulted in formation of product (Bioclay) which can be used for topical application of dsRNA on crop plants. The concept of biomolecule-nanomaterial complexes could be the next generation agrochemicals for pest management as they would be pest specific, and will have minimal ecological and environmental impacts.

Reorientation in functioning of plant protection stakeholders for effective coordination and collaborations through convergence is needed. Pre-import and post-entry quarantine require need based international cooperation and collaboration. Preparedness for exotic pests is major challenge needs to be address properly. Field surveillance aided by geo-reference based mobile and artificial intelligence for diagnosis and data analytics need emphasis. Development of entrepreneurial capacity in farm women, rural youth and agri-graduates for mass production of parasitoids, predators, biopesticides and insect traps at cottage level would be helpful in promoting cause of pest management as well as generating employment. Faster registration of biological control agents with quality checks will pave the way for their commercialization and field use. Nonetheless, the developments that has taken place during the past years, particularly with reference to biopesticides or natural way of containing the major diseases, insect-pests, weeds are significant and provide the base data for further insight into those leads towards managing the plant health in a way under natural farming ecosystems.

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Achievements in Animal Health Management in Independent India

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Summary

Livestock and poultry diseases continue to adversely affect the productivity and production of animals. Keeping in view the importance of animal husbandry sector, several animal health and species-specific institutes were established under the umbrella of ICAR to improve the animal health management system in the country. Technological interventions for over seven decades have led to the eradication of three diseases, namely; rinderpest (2006), contagious bovine pleuropneumonia (2007) and African horse sickness (2014). It has been estimated that rinderpest eradication has resulted in increase of milk production by 4.66 % with a net present value of Rs.3,463 crores (34.63 billion) and a cost benefit ratio of 10:43. Foot-and-mouth disease (FMD) and *Peste des Petits Ruminants* (PPR) control programs undertaken using indigenous technologies during last two decades also contributed to enhanced production. In spite of the growing human population in the country, the per capita milk availability has increased from 130 g in 1950 to 406 g in 2019-20. Similarly, the per capita per annum egg availability has increased from 5 eggs in 1950 to 86 eggs in 2019-20. Intensification of animal production system to meet increased demand for foods of animal origin, faster international trade and travel, and globalization have led to higher risks of new emerging infections including zoonotic and transboundary diseases. Incursions of avian influenza, porcine reproductive and respiratory syndrome (PRRS), lumpy skin disease (LSD), and African swine fever (ASF) in the last two decades, are the examples. ICAR institutes have developed more than 25 vaccines and 40 diagnostic test/surveillance kits and several molecular methods for the diagnosis and control of livestock and poultry diseases in the country. Also, these institutes keep a strict vigil over 30 emerging, re-emerging, and exotic diseases by systematic surveillance using indigenously developed diagnostic methods and help implementation of national animal disease control programmes.

1. Introduction

Livestock and poultry farming sustain rural livelihoods and contributes 25.6% to the agricultural GDP and 4.1% to the overall GDP of India (Bharadwaj et al. 2020). The growing demand for quality livestock products in human diet has promoted commercialization efforts, which in turn, has necessitated technological interventions for controlling animal diseases and efficient service delivery in the sector (Ahuja et al. 2008). Given the size and distribution of India's livestock population, improvement of the livestock health and production presents a significant opportunity to enhance rural income and accelerate the pace of poverty alleviation. Animal diseases like FMD, LSD, haemorrhagic septicaemia (HS), brucellosis in cattle/buffalo, PPR, goatpox, sheeppox, contagious caprine pleuropneumonia (CCPP) in goat/sheep, classical swine fever (CSF), and African swine fever (ASF) in pig, Avian influenza (AI), Newcastle disease (ND) and other infectious diseases in poultry birds (Yadav et al. 2016) continue to inflict economic losses on livestock and poultry producers with trade implications.

Owing to the technological interventions of ICAR institutes, the livestock and poultry production and productivity have increased considerably. However, despite improved housing facilities, balanced nutrition, and disease control programmes including strict bio-security protocols, India is witnessing repeated occurrences of emerging, re-emerging, and transboundary diseases. The Indian poultry industry is facing major challenges due to many diseases, including complex chronic respiratory disease (CRD), Marek's disease (MD), AI, ND, etc. CRD, caused by *Mycoplasma gallisepticum* and further complicated by avian pathogenic *Escherichia coli* (APEC) is a serious impediment to potential broiler production in the country. Post-mortem based diagnosis and treatment is often not accurate and effective since mixed infections are becoming dominant and posing difficulty for differential diagnosis. The porous international border across some of the North eastern states present opportunities for spread of many infectious diseases from neighboring China, Bangladesh, Bhutan, and Myanmar. This necessitates immediate attention through systematic surveillance, development of vaccines, and diagnostics for onsite use along with strict border control.

2. Initiatives to strengthen livestock and poultry health management in India

The ICAR-Indian Veterinary Research Institute (ICAR-IVRI) was initially established as the Imperial Bacteriological Laboratory in 1889 at Pune for conducting research for the protection of Indian livestock wealth from the dreaded diseases. The laboratory was shifted to Mukteswar in 1893, and later in 1913 it was expanded to Izatnagar, Bareilly to start large scale production of veterinary biologicals. In view of the main focus on production of veterinary biologics, the institute was renamed as Imperial Serum Institute in 1930, but as the institute expanded to conduct research on all contemporary disciplines of veterinary and animal sciences, it was renamed again as Imperial Veterinary Research Institute (IVRI) in 1936. Post-independence, this institute was finally renamed as Indian Veterinary Research

Institute (IVRI). The most significant contributions of the institute in the field of vaccine development and production are depicted in Fig. 1.

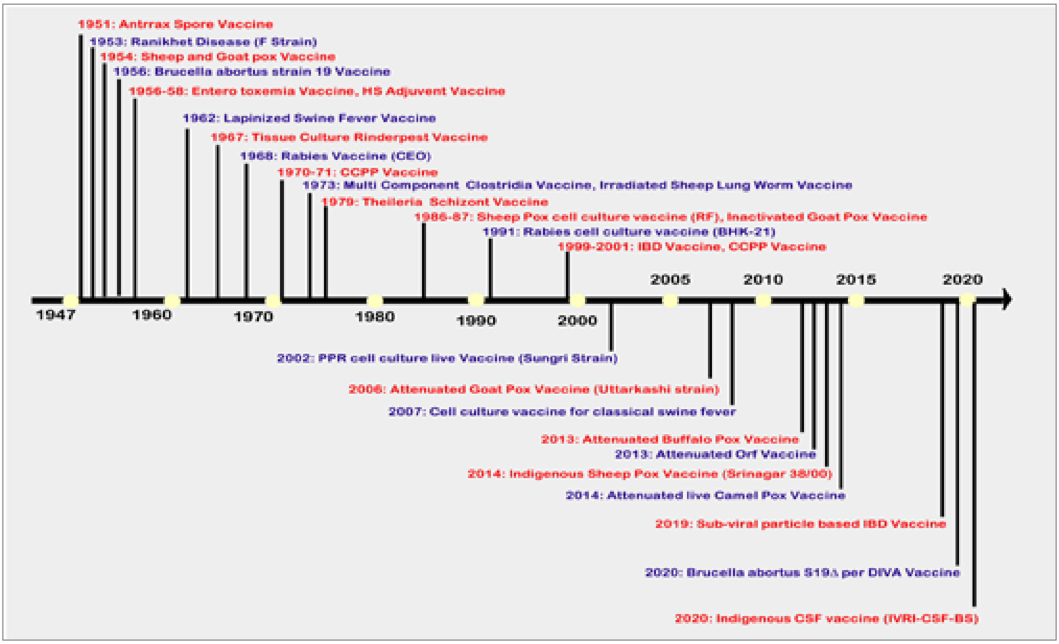

Fig. 1. Important veterinary vaccines developed in the post-independence era

Over a period of time, two animal health institutes, namely ICAR- Directorate of FMD (DFMD) and ICAR-National Institute of High Security Animal Diseases (NIHSAD) were established from IVRI. Both these institutes are now reference centers for FMD and Avian Influenza as recognized by FAO and OIE, respectively. Research need for FMD was realized at the 11th International Veterinary Congress in 1930 and later in 1943 ICAR initiated an ad-hoc scheme entitled "Vaccination of Indian cattle against foot-and-mouth disease" at IVRI, Mukteswar. An "All India Co-ordinated Research Project (AICRP) for FMD virus serotyping" was initiated in 1968 with a central FMD laboratory at Mukteswar and three Regional Centers located at Hisar, Hyderabad, and Calcutta. During the year 2001, AICRP on FMD was upgraded to Project Directorate on FMD (PDFMD) with a network of 23 laboratories located all over the country. In the year 2015, PDFMD was renamed DFMD with 27 regional and collaborating centers. ICAR-DFMD is a member of the Global FAO/OIE network of FMD reference laboratories. The institute also functions as the FAO-FMD Reference Center and SAARC Regional Leading Diagnostic Laboratory for FMD. It is a member of GFRA (Global FMD Research Alliance). The state-of-the-art FMD research centre (ICFMD) with high containment laboratory facility established by ICAR at Bhubaneswar meets the major requirement of FMDCP as stipulated by OIE/FAO. High Security Animal Diseases Laboratory (HSADL), a regional center under IVRI, Izatnagar was upgraded to an independent national institute and was named ICAR-NIHSAD, Bhopal in 2014 with the main objective to deal with emerging exotic animal diseases and bio-risk management. The institute has Biosafety Level 3+ (BSL-3+) bio-containment facility available for research on exotic and high-risk pathogens of livestock and poultry in India. As a national referral laboratory, ICAR-NIHSAD is networking with all the 6 Regional Disease Diagnostic Laboratories (RDDLs) and provides diagnostic services for 30 exotic and emerging diseases. As an OIE reference laboratory for avian influenza, ICAR-NIHSAD provides diagnostic services to SAARC countries also.

Realizing the significance of disease epidemiology and informatics in disease control and eradication, ICAR upgraded the AICRP on ADMAS to PD-ADMAS in 2000 and subsequently to ICAR-National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI) in 2013. Among the three phases of rinderpest (RP) eradication, the phase of disease surveillance and monitoring was spearheaded by ICAR-NIVEDI by providing nationwide RP surveillance and monitoring plan, implementation strategies, and screening of serum samples. ICAR-NIVEDI is coordinating with other institutes and developed the national disease surveillance and monitoring plan for FMD, brucellosis, PPR, and CSF. The diagnostic kits developed by the institute are being used for sero-monitoring under brucellosis and CSF control programs.

Considering the importance of equine species, ICAR established National Research Centre on Equines (NRCE) in 1985 at Hisar and its regional station in 1989 at Bikaner. ICAR-NRCE has developed diagnostics against various equine diseases, including equine herpesvirus 1 (EHV1) infection, equine infectious anaemia (EIA), *Theileria equi,* glanders and inactivated vaccines for EHV1 and equine influenza. ICAR-NRCE has contributed towards declaration of disease-free status for African horse sickness (AHS) by OIE, and control of EIA and equine influenza. The National Centre for Veterinary Type Cultures (NCVTC), established in 2005 at NRCE, Hisar is working through 18 network units spread throughout the country and is maintaining a total of 3403 accessioned microbes.

Animal health institutes of ICAR monitor the quality of veterinary biologics produced by the industry through a stringent testing policy and certify for further use in the field. ICAR institutes have a key role in national animal disease control programs of Govt. of India by providing nationwide sampling plans, diagnostic kits, and epidemiological inputs to ensure success of animal health programs implemented by State and Central governments. Presently, technologies developed by ICAR institutes are being used for the diagnosis and control of four diseases *viz.* FMD, brucellosis, PPR, and CSF. R&D activities in the field of stem cell biology and their application in regenerative medicine has opened new avenues for treating non-communicable animal diseases. These interventions for improving the livestock health will ensure livelihood and nutritional security of the country (details given in Chapter 7).

3. Success stories of disease eradication

3.1. Eradication of rinderpest and its impact

Rinderpest, also known as "Cattle Plague" was one of the most devastating diseases of cattle and buffalo during the 18th and 19th century. The disease was caused by rinderpest virus (RPV) belonging to the Morbillivirus group. RPV also affected sheep, goat, and pig populations. Owing to the symptoms and death pattern, rinderpest in India was called "*Ponkani*", "*MaanRog*" or "*Pashu Mahamari*". The first Indian report on rinderpest was documented in 1752 by "Hallen Commission". Clinically the diseased animals had shooting diarrhoea due to inflammation in the digestive tract. Nasal and ocular discharges were common in diseased animals. The death and infection rates in newly exposed populations were very high and sometimes up to 95-100 % leading to huge economic losses. Before the 1950s, a large number of bovine deaths were reported every year due to rinderpest in the country. The incidence of disease decreased to some extent (100-150 thousand) after 1935, when Goat Tissue Vaccine (GTV) developed at IVRI Mukteswar in the year 1927 (Edwards, 1927) was applied in livestock population. Subsequently during the 1st plan period (1954), a mass vaccination campaign against the cattle plague in the name of National Rinderpest Eradication Programme (NREP) using GTV vaccine was launched. The cattle and buffalo above 6 months of age were vaccinated using GTV vaccine. Subsequently, a safer vaccine developed by Plowright and Ferris (1962) namely Tissue Culture Rinderpest (TCRP) vaccine was introduced in India during 1970s (Yadav et al. 2016).

The TCRP vaccine was safe for pregnant and lactating animals, and conferred life-long immunity. Calf hood vaccination was done at 6-12 months of age and it was also efficacious in cross breed cattle, sheep, goats and pigs. Therefore, this vaccine was widely adopted. Between 1956-1989, a total of 1300 million doses of vaccination against rinderpest were carried out. These interventions led to reduction in disease outbreaks in India; however, extensive surveillance was required to prove absence of disease as per OIE pathway of rinderpest eradication. The overall sero-conversion rates/herd immunity of more than 70% were achieved at the completion of the national vaccination campaign in 2000. This effort totally stopped the transmission cycle of rinderpest virus. The mAb-based rinderpest competitive ELISA kit developed by ICAR-IVRI, validated by FAO and recommended by OIE, was used during the final stage of rinderpest eradication. The sero-surveillance using indigenously developed competitive ELISA kit (Singh et al. 2000) was continued till the year 2004 in order to prove that no virus is circulating in the population. The effect of vaccination on rinderpest related disease incidence & mortality is shown in Table 1.

Table 1. Plan-wise incidence and mortality of rinderpest in India

Plan	Period	Outbreaks	Mortality	Mortality per million bovines
First	Prior to 1955	8000	200000	980
Second	1956-61	4368	31915	157
Third	1961-66	791	8348	27
Annual	1966-69	774	6146	22
Fourth	1969-74	237	2638	12
Fifth	1974-79	124	1200	5
Annual	1979-80	120	1296	5

Plan	Period	Outbreaks	Mortality	Mortality per million bovines
Sixth	1980-85	142	1596	6
Seventh	1985-90	173	1649	6
Annual	1990-92	52	247	1
Eighth	1992-97	47	148	0.5
Ninth	1997-2000	0	0	0

Following OIE pathway for rinderpest eradication, India became free from rinderpest in the year 2004. OIE recognized the country free from rinderpest infection in the year 2006 and finally, global eradication of rinderpest was declared by FAO in the year 2011. To mark this stupendous achievement which ushered an era of agricultural revolution in the country, ICAR-IVRI installed a commemoration pillar at its Mukteswar campus on 2nd June, 2012. The pillar depicts important landmark achievements made possible through contributions of all national and international organizations (Fig. 2).

Fig. 2. Memorial at IVRI Mukteswar to commemorate rinderpest eradication

The successful implementation of rinderpest eradication programme has yielded major economic benefits which enhanced food and nutrition security. It was observed that investment made in NREP launched in 1954 yielded net benefit and significant increase in growth rates in milk production. National Programme on Rinderpest Eradication (NPRE) was launched in 1991-92, to eradicate rinderpest following the pathway prescribed by World Organization of Animal Health/ OIE. The benefits of NPRE can be appreciated from the increased access of India's bovine meat and milk in the international market (Rich et al. 2012). Indeed, Indian exports of bovine milk picked up substantially around 1992-94 and simultaneously India's dependence on milk imports also reduced drastically at the same time (Bardhan 2007). These developments ultimately contributed enormously to White Revolution and enhanced per capita availability of milk in the country. The growth rate and economic benefits during rinderpest control and eradication is depicted in Table 2. As against the huge economic benefits accrued from rinderpest eradication in India, the expenditure on rinderpest vaccine research and production was estimated to be Rs. 47,856 million (1063.46 million US$) over a period of 92 years from 1913 to 2005 (Yadav 2011). The FAO estimated that India gained additional food production valuing 289 billion US dollars between 1965-1998 (Yadav et al. 2016).

Table 2. Growth rate and economic benefits during rinderpest control and eradication

Parameters	Growth rate/benefits
1.a. Growth rates in milk production (1961 to 1983)	3.11% per annum
1.b. Growth rates in milk production (1983 to 2016)	4.66% per annum
2a. Net benefit during NREP (1956/57)	Rs. 1576 million
2b. Net benefit during NPRE (1994/95)	Rs. 6933 million
3. Net benefits accrued to the nation during 1992/93 to 2015/16	Rs. 4619 million per annum
4. Net Present Value of rinderpest eradication	Rs. 34.63 billion
5. Benefit Cost Ratio of NPRE (BCR)	4.37

There have also been several indirect benefits of rinderpest eradication, which include capacity building in terms of human resource development, development of disease surveillance and diagnostic infrastructure, acquisition of vehicles and equipment, establishment of epidemiology units, creation of a wide network of veterinary departments and research institutes. Lessons learnt from rinderpest eradication are invaluable for achieving the goal of PPR control and eradication. The important milestones on the road to eradication of rinderpest and contagious bovine pleuropneumonia are given in Table 3.

Table 3. Milestone achievements of rinderpest and CBPP eradication post-independence

Year	Milestones
1954	National Rinderpest Eradication Programme (NREP) launched.
1967	Large scale production of tissue culture rinderpest vaccine.
1983	National task force on rinderpest constituted.
1987	Establishment of AICRP on ADMAS at Bengaluru for rinderpest sero-surveillance.
1992	National Project on Rinderpest Eradication (NPRE) launched.
2000	Development of FAO/OIE validated rinderpest competitive ELISA kit.
2003	Provisional freedom from CBPP.
2006	OIE recognized India free from rinderpest infection.
2007	India declared CBPP free by the OIE.
2011	FAO Gold Medal for outstanding contribution to global rinderpest eradication program.
2011	Global freedom from rinderpest.
2012	Global Rinderpest Eradication Memorial installed at IVRI, Mukteswar.

3.2. Eradication of contagious bovine pleuro-pneumonia

Contagious bovine pleuropneumonia (CBPP) was an insidious pneumonic disease of cattle and water buffalo referred to as lung sickness. It was caused by *Mycoplasma mycoides* subsp. *mycoides* (*M. mycoides*). Clinically, CBPP was manifested by anorexia, fever, and respiratory symptoms such as dyspnoea, cough, and nasal discharges. Eradication of CBPP was linked with the NPRE activities. The objective of the scheme was to strengthen the veterinary services to eradicate rinderpest and CBPP and to obtain freedom from rinderpest and CBPP following the pathway prescribed by OIE, Paris. The country was provisionally free from CBPP in October 2003. The eradication programme for CBPP was initiated in 8 districts of Assam and the dossier for CBPP eradication was submitted to OIE. India was declared CBPP free by the OIE in 2007. Now, it is important that the country's freedom status against CBPP is maintained as per OIE requirements. The states and union territory governments are required to carry out physical surveillance up to the village level to maintain the freedom status of CBPP and to undertake surveillance of other animal diseases in the country on a routine basis.

3.3. Eradication of African horse sickness

African horse sickness (AHS) is a serious fatal disease of horses, mules, and donkeys. It is caused by a virus of the Genus *Orbivirus* belonging to the family *Reoviridae*. The virus is spread by infected insects (biting midges) and causes fever, cardiac and respiratory (breathing) problems with sudden death in affected animals. In India, the first case was reported in Cavalry of Army in April 1960. From 1960 to 1963, 22,977 horses got affected and 20,822 died (90.6% mortality). Initially, AHS7 virus strain vaccine was used to control the disease; however, this failed to provide sufficient protection. Later, indigenous mouse adopted strain 9 monovalent vaccine followed by AHS-9 chick embryo origin vaccine was developed to control the disease. The last report of AHS was in 1963 (Kumar 1976). In the 82nd General Session of OIE, India was declared free from AHS. Thus, IVRI played a lead role in eradication of AHS by contributing towards virus isolation, characterization, and development of vaccines and diagnostics.

4. Control of cattle and buffalo diseases

In addition to the eradicated diseases, several other livestock diseases are being monitored and controlled through different interventions.

4.1. Control of foot and mouth disease and its impact

Foot and mouth disease is caused by an Aphthovirus of the family *Picornaviridae*. Seven serotypes (O, A, Asia-1, C, SAT1, SAT2 & SAT3) are present globally. Out of the known serotypes, four serotypes viz., O, A, C, and Asia 1 were reported in India, before 1995. Now 3 serotypes (O, A, and Asia1) of the FMD virus are circulating in livestock in the country. Serotype C has not been recorded in India from 1995 onwards. The FMD affected large ruminants exhibit high fever, excessive frothy salivation, vesicles in the mouth especially on the tongue, teats, and inter-digital space, and decrease in milk yield due to reduced feed intake. Effective vaccines with short lived immunity are available; however, vaccines with long term immunity are needed. Indigenously developed state-of-the-art diagnostics are available for laboratory and field applications. Being a transboundary animal disease, technical know-how for FMD needs to be extended to SAARC member countries, which requires strong linkages with FAO and OIE.

The research on FMD vaccine started at IVRI, Mukteswar in 1943 with an ICAR sponsored Ad-hoc scheme "Vaccination of Indian cattle against FMD". Crystal violet vaccine was prepared in the initial stages (1946-52), followed by goat kidney primary tissue culture methodology in 1964-65 and BHK-21 monolayer during 1972-77 at Mukteswar. With the increasing need for FMD vaccines, the Bengaluru campus of IVRI was established in 1972 for large-scale vaccine production using suspension cell culture. From 1971 to 1990, techniques for FMD virus typing, micro-complement fixation test, and microneutralization tests for subtyping were developed. ICAR driven FMD research and infrastructure development contributed immensely to FMD control efforts (Table 4).

Table 4. Milestones in foot and mouth disease control

Year	Milestones
1946-52	FMD crystal violet tongue vaccine developed and updated.
1968	All India Co-ordinated Research Project (AICRP) for FMD virus typing launched.
1971	AICRP for Epidemiological studies on foot-and-mouth disease initiated.
1972	Bengaluru campus of IVRI established for large scale FMD vaccine production.
1976	Large-scale production of FMD vaccine started at Bengaluru campus ICAR-IVRI.
1995	Virus serotyping ELISA developed for FMD.
2000	AICRP on FMD upgraded to Project Directorate on FMD (PD-FMD).
2003	Liquid Phase Blocking ELISA (LPBE) for FMD developed.
2003	Uniform vaccine strain support to industry started.
2004	Multiplex PCR (mPCR) for FMD virus detection developed.
2007	PD-FMD became constituent laboratory of OIE/FAO FMD reference laboratories network.
2008	PD-FMD recognized as "FAO reference centre for FMD for south asia".
2009	PD-FMD became Member Laboratory of Global FMD Research Alliance (GFRA).
2009	Recombinant non-structural protein (3AB3) based ELISA test developed for differentiation of FMD infected from vaccinated animals (DIVA).
2009	Foundation stone laid for International Centre for FMD (ICFMD), Bhubaneswar.
2010	PD-FMD became SAARC regional leading diagnostic laboratory of FAO.
2013	FMD lateral flow test and ELISA using recombinant antigen developed.
2015	PD-FMD upgraded to ICAR-Directorate of FMD (ICAR-DFMD)
2016	Solid Phase Competitive ELISA (SPCE) developed by ICAR-DFMD.
2017	Inauguration of International Centre for FMD, Bhubaneswar.
2021	ICAR-DFMD recognized as "FAO Reference Centre for FMD".

The FMD Control programme (FMDCP) was launched in 2003-04 in selected districts of India and expanded progressively to cover the entire country in 2017. A large number of FMD outbreaks were encountered prior to FMDCP. The number of FMD outbreaks/

incidences came down by almost 60% (781 from 1911), in 2006/07 and in 2008/09 the number of incidences came down to 245, further ~70% drop in the incidences of the disease. The progressive drop in the incidences of FMD is attributed to the herd immunity. A trend of reduction in FMD outbreaks since implementation of FMDCP in 2003-04 is shown in Fig. 3. Through the application of the indigenous diagnostic kits India saved revenue worth Rs. 531 crores during last one decade.

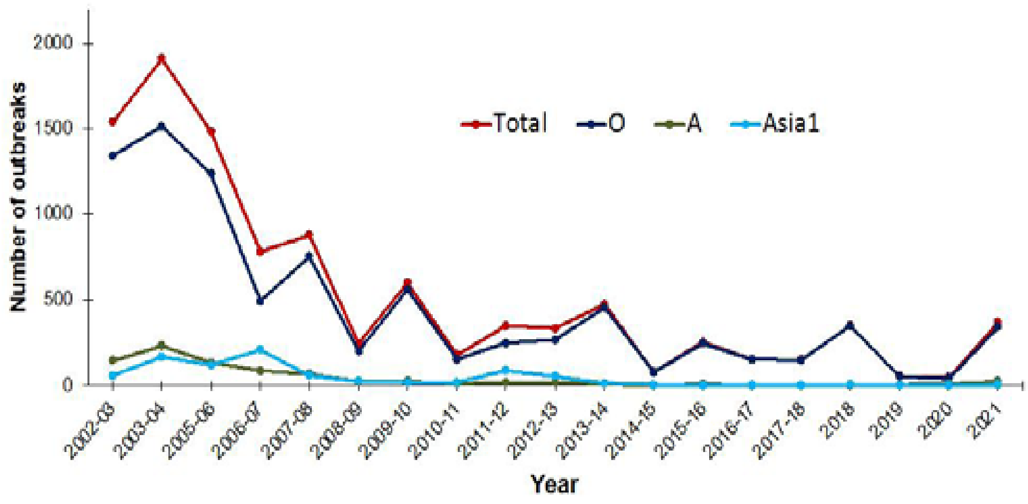

Fig. 3. Reducing trend of FMD outbreaks in India after implementation of control programme

4.1.1. Socio-economic impact of FMD vaccines and diagnostic research

To evaluate the benefits of control measures on the production of affected animals, it is necessary to determine the variable effects of FMD including mortality rate (usually very low), reduction in milk production (usually significant), infertility, abortion, delays in attainment of slaughter weight, reduced food conversion efficiency in animals and lameness in bovine draught animals. It was projected that the state of Andhra Pradesh would stand to lose Rs. 1147 crore only on account of direct impacts, if there were no vaccination programme against FMD. The country would incur a total direct loss of Rs. 15575 crore. According to one study, the annual total economic loss due to FMD in India ranges from 12,000 crore to 14,000 crore (Singh et al. 2013). Another study in India estimated the benefit-cost ratio (BCR) to be between 5:1 and 8:1 (James and Ellis, 1978). Overall, existing evidence on BCR analysis of FMD vaccination in India and other endemic countries with comparable socio-economic status as that of India, strongly favours implementation of vaccination-based control of FMD for the benefit of livestock owners. There has been increase in milk yield and meat production in India over a period of time. Decline in incidences of FMD might have contributed to increase in milk yield and meat production in the country.

4.2. Control of brucellosis and its impact

Brucellosis is a bacterial disease caused by various *Brucella* species, which mainly infect cattle, swine, goats, sheep and dogs. Humans generally acquire the disease through direct contact with infected animals, by eating or drinking contaminated animal products. The seroprevalence of brucellosis in humans varies from place to place and also depends on the type of test method applied in the study. In a study conducted in and around Ludhiana, it was found to 26.6% using Standard Tube Agglutination Test (STAT) with a titre range between 80 and 1,280 IU/ml (Gamechu and Gill, 2011). For effective control of brucellosis, calf hood vaccination programme has been initiated under National Animal Disease Control Programme (NADCP). Reliable and verifiable diagnostics to support these efforts are available. This requires very strong linkages and awareness among stakeholders. IVRI provided diagnostic reagents for brucellosis at national level through production and supply of RBPT antigen, Milk Ring Test (MRT) antigen and SAT antigen. Recently, two indirect ELISA diagnostic kits have been developed one each at NIVEDI and IVRI. These diagnostic kits and the marker vaccine developed at IVRI (*Brucella abortus* S19Δ per vaccine) promise effective sero-monitoring and disease control.

The annual economic losses due to brucellosis in different livestock species in India were estimated on the basis of secondary seroprevalence data collected from published peer-reviewed literature and government reports. Meta-analysis was carried out to arrive at the pooled prevalence of bovine brucellosis. Various components of losses included in the study were reproductive losses (due to abortions and increased infertility), production losses, mortality losses in aborted animals and draught power losses. Simple mathematical models were developed to estimate the component-wise losses, which arrived at Rs. 9212 crores (Bardhan et al. 2020b). On account of the possibility of variation and uncertainty in various epidemiological and economic parameters, a sensitivity analysis was also carried out by considering worst-case and best-case scenarios. The benefit-cost ratio of brucellosis control through vaccination, under different scenarios, implied economic feasibility of vaccination.

4.3. Control of haemorrhagic septicemia and its impact

Haemorrhagic septicemia (HS) is an acute and often fatal disease of cattle and buffaloes, caused by *Pasteurella multocida* serotype B:2. The disease is characterized by high fever with concurrent shivering followed by profuse salivation, lachrymation, nasal discharge, and a sharp drop in milk yield. *Pasteurella multocida*, the cause of HS was first discovered by Perroncito in 1878 and the organism was isolated by Louis Pasteur in 1880. The work in India for control of HS was started at IVRI, as early as 1895 with the production of anti-HS serum. Due to the high cost involved in the production of serum and short-lived immunity, serum production was discontinued after the development of improved HS vaccines. Due to the devastating effect of the disease on livestock, the ICAR initiated the All India Network Programme on HS in the year 2000 to develop and improve vaccines against HS. A low volume saponified vaccine was developed to alleviate the problem of syringibility and swelling at the injection site in animals.

The economic loss due to HS in bovines was worked out as the sum of mortality loss, direct milk yield loss, losses due to increased abortions, drought power loss, cost of treatment, and extra labour costs (sample size 10,839 dairy animals). Simple mathematical models were developed for computing component-wise losses due to the disease. The economic loss per animal due to HS in India was estimated to be Rs.11,904; Rs.13,044 and Rs.20,296 in the case of indigenous and crossbred cattle and buffaloes, respectively. The share of buffaloes in the total economic loss was highest (55%), followed by indigenous (28%) and crossbred (16.5%) cattle. In view of the uncertainties associated with the epidemiological and economic parameters, stochastic modeling was used to estimate the economic impact of HS. The estimated annual economic loss due to HS in India was about Rs. 12758 crores (Bardhan et al. 2020a).

4.4. Control of infectious bovine rhinotracheitis (IBR)

IBR is a highly contagious disease caused by bovine herpesvirus 1 (BHV1). Apart from respiratory disease, which may lead to bovine respiratory disease complex or shipping fever after secondary bacterial infection, other clinical syndromes are infectious pustular vulvovaginitis (IPV) or infectious pustular balanoposthitis (IPB), abortion, conjunctivitis, infertility, arthritis, mastitis, and enteritis. During the past two decades, various types of vaccines developed include inactivated, live modified, subunit, DNA vaccines, and gene deleted marker vaccines. The gD-based subunit vaccine is considered most efficacious in reducing the clinical disease after they are combined with effective adjuvants like chitosan and CpG oligonucleotides. However, none of the presently available vaccines can prevent the establishment of latency of wild-type virus infection. Because of this, countries with vaccination programmes aiming at eradication were unsuccessful while the countries with programs of culling seropositive animals could achieve disease free status. The milestones for other cattle and buffalo disease control are given in Table 5.

Table 5. Achievement milestones in other diseases of cattle and buffalo for health improvement

Year	Milestone
1951	Anthrax spore vaccine developed.
1956	*Brucella abortus* strain19 vaccine developed.
1956-58	Haemorrhagic septicaemia adjuvant vaccine developed.
1979	Bovine *Theileria* schizont vaccine developed.
2001	ELISA diagnostic kit for IBR and bovine brucellosis developed.
2005	NADRES was developed through "Weather based animal disease forecast (WB_ADF)" and "Animal health information system through disease monitoring and surveillance (AHIS_DMS)" projects.
2008	AB ELISA for detection of IBR virus antibodies developed.
2013	Buffalo pox vaccine developed.
2020	*Brucella abortus* S19Δ per vaccine developed.

5. Small ruminant health management and their impact

Small ruminant health management, related technology development and knowledge generation has been a priority activity of ICAR institutes. The important milestones in small ruminant health are shown below in Table 6.

Table 6. Achievement milestones in goat and sheep health improvement

Year	Milestone
1956-58	Enterotoxaemia adjuvant vaccine developed.
1973	Irradiated sheep lung worm and multi-component clostridia vaccines developed.
1986-87	Sheeppox cell culture vaccine (RF strain) developed.
2000	PPR cell culture live vaccine developed.
2001	Monoclonal antibody-based PPR Competitive & Sandwich-ELISA kit developed.
2006	Live attenuated Goatpox vaccine developed.
2012	Indirect ELISA for sero-screening of brucellosis in sheep and goat developed.
2013	Cell culture attenuated live Orf vaccine developed.
2015	Indigenous Sheep pox vaccine (SRIN-38/00 strain) developed.
2021	ICAR-NIVEDI, PPR OIE Reference Laboratories Network (South Region).
2021	ICAR-IVRI Mukteswar, PPR OIE Reference Laboratories Network (North Region).
2022	Recombinant antigen based PPR competitive ELISA kit developed.
2022	Recombinant antigen polyclonal based PPR antigen capture ELISA kit developed.

5.1. Control of *Peste des Petits Ruminants* and its impact

Peste des petits ruminants (PPR), popularly known as "goat plague" is a contagious viral disease of small ruminants caused by a morbillivirus. The disease is found in several countries in Asia, the Middle East, and Africa. The control of disease is important from the point of view of livelihood security for millions of families involved in small ruminant husbandry. The important symptoms of PPR include fever, discharge from eyes and nostrils, conjunctivitis, gastroenteritis, and pneumonia. It was first described in Ivory Coast by Gargadennec and Lalanne in 1942, and in India from Tamil Nadu in the year 1987. The disease causes high economic losses in the country, as the infection rate in goat and sheep may reach up to 80-90%. The range of expected economic losses due to PPR was estimated to be between Rs. 4571 and Rs. 4683 crore/annum (Bardhan et al. 2017). By the years 2001 and 2002, the technologies with proven efficacy for vaccine and mAb-based diagnostic kits for antigen and antibody detection were developed.

The PPRV/Sungri/96 strain (Sreenivasa et al. 2000) is a vaccine virus strain used in India under mass PPR vaccination campaigns. This vaccine virus has been characterized extensively at antigenic and genomic levels (Singh and Bandyopadhayay 2015). The long-term immunity study indicated that the vaccine induces and maintains optimum virus-neutralizing antibodies for a long duration. Therefore, a single dose is sufficient for the protection of small ruminants. Large scale application of this vaccine to control the disease in India has been largely possible due to the Government of India's supported PPR control programme and transfer of technology by ICAR to commercial manufacturers in the public and private sectors. The monoclonal antibody-based diagnostic kits namely sandwich-ELISA and competitive-ELISA have been used for diagnosis within the country for the last 20 years. The country is now self-sufficient in requirement of PPR vaccine and conventional/molecular diagnostics technologies including the recombinant antigen-based competitive ELISA kit (Balamurugan et al. 2021a), which may help during disease eradication programme. The trend of disease outbreak reduction during the last 15 years since the vaccines and diagnostics became available is shown in the maps below (Balamurugan et al. 2021b):

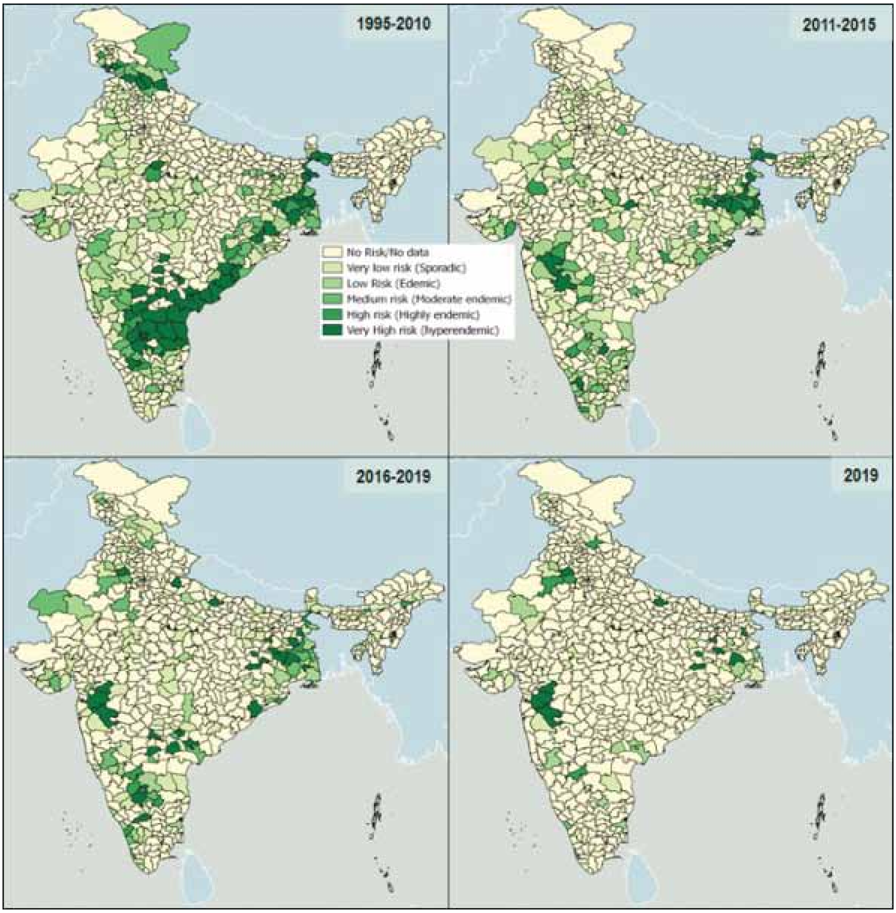

Fig. 4. District-wise outbreaks of Peste des Petits Ruminants over the years

District-wise cumulative outbreaks of PPR are considered one of the most important health constraints in rearing small ruminants. Various components of losses due to PPR in sheep and goats are mortality losses, reproductive failure, increased abortions, body weight loss, and treatment costs (Govindaraj et al. 2016). In addition, wool loss, increased inter-lambing period in case of sheep and milk loss and increased inter-kidding period in case of goats are other important losses (Bardhan et al. 2017). The benefit-cost of 'Mass Vaccination Campaign' in Chhattisgarh state reported benefit: cost ratio, net present value, and internal rate of return of 4.9:1, Rs. 342 crores and 146.6% under low incidence scenario; 12.4:1, Rs. 998 crores and 430.4% under medium incidence scenario and 13.5:1, Rs. 1096 crore and 430.4% under high incidence scenario respectively (Govindaraj et al. 2019). The change in total economic surplus due to vaccination, research, and delivery cost were projected from 1997 (the year of the start of the research project) to 2030 (by which 100% of the small ruminant population is to be vaccinated, as per OIE/ FAO specifications for disease eradication) after adjusting to the above adoption pattern. The benefits to society (economic surplus) and costs of the control programme were deflated using a suitable consumer price index to 2016 level. Using a long-run discount rate of 7.5%, the benefits were compared to research and delivery cost, and the net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (BCR) were calculated. Using the economic surplus model, the change in total surplus as a result of mass vaccination of sheep and goats against PPR in India was found to be Rs.8,253 crore per annum with BCR and NPV of 123:1 and Rs. 480 crores, respectively (Bardhan et al. 2017). It is estimated that indigenous PPR diagnostics may have saved Rs.6.22 crore worth foreign exchange through import substitution (Singh et al. 2009), which may have increased several folds by now.

5.2. Sheeppox and goatpox

Sheeppox and goatpox diseases are caused by capripox viruses, all of which can infect sheep and goats. Modeling studies from the data collected in Maharashtra suggested that it would take about 6 years for a flock or herd to recover from an outbreak, with 30-43% average annual losses in income, depending on flock type and the owner's actions (Garner et al. 2000). An inactivated goatpox vaccine was developed at IVRI (Yadav et al. 1986) for field use till the development of a vero-cell culture-based attenuated vaccine for goatpox at ICAR-IVRI, Mukteswar during the year 2006. The lyophilized cell culture vaccine provided immunity for about 40 months (lifelong). This vaccine has also been used for the control of LSD in cattle as a strategy for emergency vaccination. For sheeppox, the RF strain of sheeppox vaccine, based on LT-32/Vero-9 cell culture was developed in 1986-87. It induces protective antibodies for at least one year. The vaccine is safe for pregnant animals and young ones. Another Vero cell adapted sheeppox vaccine was also developed from an indigenous virus strain (SRIN-38/00) by ICAR-IVRI, in 2014. The scalability of the vaccine and downstream processing is simple and easy. The vaccine confers protection for up to 4 years.

6. Pig health management and their impact

Classical swine fever (CSF), is a contagious viral disease of domestic and wild pigs. It is caused by a virus of the genus Pestivirus of the family *Flaviviridae*. Animals with the acute disease die within 1-2 weeks. With low virulence strains, the only expression may be poor reproductive performance and the birth of piglets with neurologic defects such as congenital tremors. ICAR-NIVEDI has developed two diagnostic kits *viz.* (i) Indirect ELISA using recombinant antigen for detection of antibodies against CSFV in pigs (ii) CSFV Ag Check Kit for detection of antigen in clinical specimens. Vaccination can prevent the spread of the disease. A lapinized vaccine virus (Weybridge strain), was adapted to grow in cell line at ICAR-IVRI, Izatnagar. The cell culture vaccine is safe and potent. Each dose contains at least 100 PD_{50} and provides immunity for a year. Similarly, another vaccine strain (IVRI-CSF-BS) using an Indian isolate of CSFV has been developed and the technology transferred to industry.

7. Equine health management and their impact

7.1. Glanders

Glanders is a fatal infectious and notifiable zoonotic disease of equids caused by *Burkholderia mallei*. The long duration of therapy and unavailability of vaccine makes this pathogen formidable to control. The existing control policy dictates the identification and elimination of seropositive equines. The complement fixation test (CFT) is the OIE-prescribed serodiagnostic method for glanders; however, it produces false-positive or doubtful results with donkey and mule sera. ICAR-NRCE developed three recombinant protein-based ELISAs in 2012-13, which were validated in OIE reference laboratory on glanders, Germany during 2015-2017 and *Hcp1* ELISA showed superior performance with 95.28% sensitivity and 99.56% specificity (Elschner et al. 2019). This ELISA has been extensively used for surveillance of glanders by State Disease Diagnostic Laboratories (SRDDLS) and Regional Disease Diagnostic Laboratories (RDDLs) of Govt. of India. More than 150,000 equines were tested by the Hcp1 ELISA (Singha et al. 2020). The ELISA has proved to be safe, rapid, inexpensive, accurate, and user friendly to adopt in a diagnostic laboratory with limited resources. The test has proved to be very useful in state-wide surveillance and control programmes of glanders and has been commercialized.

7.2. Equine influenza

Equine influenza (EI) is an OIE listed respiratory disease of horses, mules, ponies, donkeys, and zebra, caused by two strains of Influenza A virus *viz.* H7N7 and H3N8. Since 1980, no outbreak has been reported due to H7N7. Outbreaks due to H3N8 have been regularly reported from different parts of the world. The disease is highly contagious and spreads very fast through the aerosol route, and is characterized by fever, dry hacking cough, and watery nasal discharge, which later become mucopurulent. In India first report of influenza-like symptoms was from erstwhile Bombay in the Bombay Turf Club in 1964, where around 400 horses had an outbreak of coughing. Subsequently, two major epizootics have been reported. The first one was in 1987 when around 83,000 horses were infected mostly in northern Indian states (Uppal et al. 1989). The second epizootic occurred during 2008-09 in Katra (J&K) from where it spread to 14 States affecting thousands of animals and leading to huge economic losses to the stakeholders (Virmani et al. 2010). Phylogenetic analysis indicated clade 2 of the Florida sub-lineage of the H3N8 virus. ICAR-NRCE developed an inactivated low-cost vaccine using a virus from the outbreak of 1987. Subsequently, an updated inactivated equine influenza vaccine was developed during 2008-09, which was followed by a recombinant vaccine candidate through reverse genetic engineering. ICAR-NRCE has also developed several diagnostics including haemagglutination-inhibition (HI) assay for serological diagnosis, RT-PCR, qRT-PCR, monoclonal antibody-based sandwich ELISA, RT-PCR for subtyping of EI virus, and immunohistochemical diagnosis.

7.3. Equine herpesvirus infections

Equine herpesviruses (EHV1 and EHV4) are the most important pathogens that infect 80 to 90% of horses by two years of age, resulting in respiratory infection, characterized by fever, anorexia, nasal and ocular discharge. EHV1 causes upper respiratory tract infection in young horses at the time of weaning, abortion in pregnant mares, neonatal foal mortality, and neurological disorders. Abortion is economically most crippling outcome of EHV1 infection with 95% of EHV1 associated abortions occurring in the last four months of pregnancy. Abortions in pregnant mares range from 4-8% in organized horse breeding farms in India, which is the major cause of economic losses in equine industry. For timely diagnosis of EHV1, NRCE has developed various diagnostic assays including HERP kit in 2003, monoclonal antibody-based blocking ELISA kit in 2008 and recombinant protein-based ELISA for differentiation of EHV1 and EHV4 infection (NRCE Annual report 2016-17 and 2017-18). These diagnostics have contributed towards timely diagnosis and control of disease in equine population. In addition, an effective inactivated vaccine 'Equiperabort' for control of abortions in pregnant mares has been developed (Singh et al. 2009a). This vaccine has been extensively tested in field trials and is now being used in organized equine farms, including Equine Breeding Studs of Indian Army.

7.4. Equine infectious anemia

Equine infectious anaemia (EIA) is a persistent viral infection of equids, caused by Lentivirus of *Retroviridae* family. The EIAV is mechanically transmitted from infected to susceptible equids by biting horse flies, deer flies and stable fly. Once a horse is infected with EIAV, it remains infected for rest of the life and a potential source of infection to other horses. There is neither effective vaccine nor treatment for this disease. It is one of the notifiable equine diseases, which entails implementation of strict control policy including elimination of the sero-positive equids. ICAR-NRCE has been regularly monitoring EIAV infection in the country. In India, first case of EIA was detected in race horses in Karnataka in 1987 (Uppal and Yadav 1989). Later, maximum number of EIA cases (n=186) were detected during 1987-1990 but thereafter, it was rarely reported. As there are no specific pathognomonic clinical signs in EIA, demonstration of EIAV specific antibody in the serum is required for confirmation of the infection. Agar gel immunodiffusion (AGID) test (Coggins test) is the OIE recommended test; however, it lacks sensitivity and may give false negative results. The test is also time-consuming & requires 48 to 72 hours. Therefore, ICAR-NRCE developed a recombinant p26 protein based indirect ELISA for EIA diagnosis (Singha et al. 2013) and the diagnostic technology has been commercialized.

7.5. Trypanosomiasis (Surra)

Trypanosomiasis, caused by *Trypanosoma evansi*, is an important disease of equines resulting in high morbidity and mortality. Clinical symptoms mainly are fever, anaemia, reduced milk yield, weight loss, lower work output, abortion, infertility, and in many cases, a deteriorating condition, that results in death. Total annual economic loss associated with surra in equines has been estimated to be Rs. 146.87 million (Rs. 61.45 to 293.92 million at a 95% confidence interval). ICAR-NRCE is currently monitoring the prevalence of *T. evansi* in equines in India, using antibody ELISA developed by the institute (Kumar et al. 2013a). A total of 20,609 equine serum samples from different states were tested up to March, 2021 and 1077 (5.22%) equids were detected positive. It has helped in risk assessment of trypanosomiasis in endemic areas. Diagnostic service has helped the animal owners in timely initiation of treatment and saving their precious animals as well as check further spread to in-contact healthy animals.

7.6. Equine piroplasmosis

Equine piroplasmosis, a tick-transmitted haemoprotozoan disease caused by intraerythrocytic protozoa *Theileria equi* and/or *Babesia caballi* is an economically important disease of equids. Equine babesiosis is transmitted by Ixodid tick species of genera, *Hyalomma*, *Dermacentor,* and *Rhipicephalus*. Diagnosis of most acute haemoparasitic infections is routinely done by microscopic examination of thick and thin smears. However, serodiagnosis following clinical or sub-clinical disease is a powerful tool in detecting and defining the prevalence of protozoan diseases. NRCE developed recombinant antigen-based ELISA kit in 2008 for the diagnosis of *T. equi* antibodies and testing of one sample costs Rs. 55 only, which is quite economical as compared to a commercial kit by VMRD, USA costing Rs. 610/- per sample (Kumar et al. 2013b and Kumar et al. 2015). Milestones registered in equine, porcine, canine, and camel health improvement are given in Table 7.

Table 7. Milestones in equine, porcine, canine and camel health improvement

Year	Milestone
1962	Lapinized swine fever vaccine developed.
1982	Anti-Rabies BPL inactivated vaccine developed.
1991	Rabies cell culture vaccine (BHK-21) developed.
1996	Inactivated low cost vaccine for equine influenza developed.
2003	HERP kit for Equine herpesvirus infections developed.
2007	Development of cell culture vaccine for classical swine fever.
2008	Monoclonal antibody-based blocking ELISA kit against EHV1 developed.
2008	Recombinant antigen-based ELISA kit for diagnosis of *T. equi* antibodies developed.
2008	Recombinant protein-based ELISA for differentiation of EHV1 and EHV4 infection developed.
2008	Inactivated vaccine Equiperabort' against EHV1 developed.

Year	Milestone
2014	India declared free from African Horse Sickness by OIE.
2014	Vero cell culture attenuated live camelpox vaccine developed.
2015	Updated inactivated equine influenza vaccine developed.
2019	Glanders ELISA kit developed.
2019	Recombinant p26 protein based indirect ELISA for equine infectious anaemia developed.
2020	Live attenuated Classical Swine Fever cell culture vaccine using indigenous strain developed
2021	*Trypanosoma evansi* diagnostic kit developed.
2021	Inactivated Japanese encephalitis vaccine for pigs developed.
2021	Canine distemper indigenous vaccine developed.

8. Poultry health management and their impact

Indian poultry is facing a major challenge in the control of diseases. Despite strict bio-security protocols, enhanced housing facilities, and caring nutrition, India is witnessing repeated occurrences of emerging and re-emerging diseases, especially in the organized sector. Now the most alarming concern is that the post-mortem based diagnosis and treatment is often confusing since mixed infections are becoming dominant and pose difficulty for differential diagnosis. Even vaccine strains are sometimes causing the disease in birds after vaccination. The north-eastern part of India shares a porous border with China, Bangladesh, Bhutan, and Myanmar adding high burden of infectious diseases to Indian poultry flocks. Pathogenic and emerging diseases namely avian influenza often causes heavy loss both in the domestic market and international trade. Respiratory disease complex and complicated chronic respiratory disease in poultry are other major challenging issues posed to the Indian poultry industry.

8.1. Avian influenza

Except for avian influenza, all poultry disease outbreaks are going almost unnoticed, hence remain underreported. Highly pathogenic avian influenza (HPAI) caused by the H5 subtype of Type A influenza virus has emerged as an economically most important disease with a significant impact on marginal and rural backyard poultry farmers (DAHD 2015). The outbreaks have occurred as epidemic waves during 2008-09 and thereafter established as sporadic occurrences. Frequent detection of H5N1 infections in north eastern and eastern regions (sharing borders with Nepal, Bangladesh, Bhutan, and Myanmar) indicates a regional cross-border problem with porous borders and illegal movement of poultry and poultry products contributing to the threat of potential endemic circulation within the region (Dhingra et al. 2014). Unlike other countries, India is continuously experiencing a frequent outbreak of the HPAI H5N1 strain (DAHD 2015). A survey report on poultry economics in West Bengal (Otte et al. 2008) indicated that economic impact through losses largely exceeds the monetary support provided by Govt. and therefore, there is little incentive for farmers to report infection, which compromises the efficiency of passive surveillance. It has been observed that the initial introduction of HPAI to a country is usually associated with long-distance transmission from infected areas through migratory birds (Newman et al. 2012). The massive border migration involvement in northeastern and eastern regions must be controlled with stringent border security measures. An amount of Rs. 26.44 crore has been paid from february 2006 to 23rd march 2020 as compensation to poultry farmers on account of culling due to avian influenza based on each outbreak. Series of outbreaks till 2009 cost the poultry industry a loss of Rs.30 crore. To date, 32 outbreaks occurred with two H5 serotypes that resulted in the death and culling of 4.36 and 87.24 lakh birds, respectively. Nevertheless, no such scientific and organized study has been conducted in India regarding the economic loss incurred due to the avian influenza outbreaks in poultry concerning each outbreak that happened between February 2006 to March 2020. India adopted stamping out protocol as the main strategy for the control of AI. ICAR-NIHSAD, Bhopal has made a tremendous effort in timely and accurate diagnosis of high and low pathogenic avian influenza in India, since the occurrence of the first outbreak in 2006 in the country. Some of the notable diagnostic achievements include development of avian influenza antibody detection ELISA kit, multiplex real-time RT-PCR kit for avian influenza A virus typing, and H5 and H9 subtyping and Lateral Flow Test for rapid detection of H5 avian influenza virus antigen in poultry. Important milestones in AI and other poultry diseases are mentioned in Table 8.

Table 8. Milestones in poultry health improvement

Year	Milestone
1945	Ranikhet disease vaccine (R2B Mukteswar strain) developed.
1946-47	Fowlpox vaccine developed.
1953	Ranikhet disease vaccine (F strain) developed.
1959-60	Fowlpox vaccine (Egg adapted) developed.
1999-2001	Development of IBD vaccine.
2000	Preparedness for avian influenza diagnosis initiated.
2001	ICAR-NIHSAD recognized as national referral facility for avian influenza by DAHD, Govt. of India.
2009	ICAR-NIHSAD recognized as international avian influenza reference laboratory by OIE.
2010	Diagnostic services for avian influenza for Bhutan.
2013	Diagnostic services for avian influenza for Nepal.
2016	Development of reverse genetics based rgH5N2 DIVA marker vaccine for HPAI.
2019	Sub-viral particle based infectious bursal disease (IBD) vaccine.
2021	Inactivated vaccine for H9N2 virus developed.

8.2. Newcastle disease

Newcastle disease virus (NDV) is prevalent worldwide and often spreads rapidly during epizootics in poultry, causing severe economic loss due to disease and, for countries that export poultry or poultry products due to trade embargoes. It spread rapidly in Asia and became panzootic within four decades (Alexander et al. 2012). ND has existed in India for the past 85 years and is also known as Ranikhet disease (RD) where the disease was first noticed and described. In India, almost every farmer carries out ND vaccination (Vegad 2014). The seroprevalence of ND may be as high as 83% in the country. It is the single greatest constraint limiting productivity and development throughout the developing world. Heterogeneity within strains of NDV may play a very important role in the maintenance and development of infection in village poultry populations. R_2B (Mukteswar), a mesogenic vaccine strain of ND, is the popular vaccine strain used in the Indian subcontinent, especially in older birds (6–8 weeks old) with long-lasting immunity, but has proven to be pathogenic for young chicks. This vaccine strain had its origin by passaging one of the three Indian field isolates at IVRI, Mukteswar in 1945 and has been used as a vaccine candidate for booster immunization since then (Iyer and Hashmi 1945). This technology has been adopted by the biggest poultry vaccine manufacturers viz., Indovax Private Limited, Haryana; Hester Biosciences, Gujarat; Venkys Private Limited, Maharashtra, and billions of doses have been produced. A recombinant antigen-based ELISA kit has also been developed for active and passive sero-surveillance for Newcastle disease in commercial and backyard chickens.

8.3. Infectious bursal disease

Infectious bursal disease (IBD) seen in young domestic chickens is caused by infectious bursal disease virus (IBDV). Symptoms of the disease can include depression, watery diarrhoea, ruffled feathers, and dehydration. Morbidity is high, and mortality is usually low, but some very virulent strains are capable of causing 60% or higher mortality. Macroscopic and microscopic lesions in the cloacal bursa and molecular identification of the viral genome are used for the diagnosis of the disease. Very virulent pathotypes of IBDV emerged in 1992, resulting in huge economic losses to the poultry industry. Currently, IBDV is endemic and a serious problem for the poultry industry in India. Virulent, very virulent (vv), and classical forms of the disease are present in India with no reports on variant form of IBDV. Sequence alignment of these viruses with reported viruses of other countries revealed Indian IBDV field isolates to be 100% similar to very virulent Japanese (OKYM), European (UK661), and Bangladesh (BD3/99) IBD viruses at the amino acid level. Whereas they had 0.2-0.9% divergence at the nucleotide level. Vaccination to induce maternal immunity in young chicks is initially used to control the disease. Vectored and live-attenuated vaccines can be used to induce active immunity in chicks as the maternal antibodies wane. At ICAR–IVRI, recombinant antigen-based sero-diagnostic assay for IBD has also been developed.

9. Other achievements on animal health management

9.1. Diagnostic pathology

Pathomorphological diagnosis has come a long way and plays an important role in the prognosis and diagnosis of various livestock and poultry diseases. At ICAR-IVRI, the fluorescent antibody test for diagnosis of Johne's disease (JD) and the biological mouse inoculation test for rabies were applied for the first time. A modified Periodic Acid-Schiff reagent for routine staining and turpentine oil as a clearing agent were developed. For diagnosis of poultry diseases, the chicken embryo susceptibility test for avian encephalomyelitis in 1975, micro HI for ND and EDS-76, and MATSA test for Marek's disease in 1984 were standardized. In 1986, Reovirus and vvIBDV were detected for the first time in the country. Inactivated, oil-based tissue culture and/or embryo origin vaccines against ND, IBD, Reo, EDS-76, IBH and DVH (Duck Viral Hepatitis), and combined inactivated vaccines like ND, EDS-76 and IBD were developed. In 1986, the COFAL kit for monitoring ALSV infection was developed. Avian leukosis virus subgroup "A" was recovered in 1991 for the first time in the country. Other diseases/conditions documented were: avian spirochetosis, avian aspergillosis, avian tuberculosis, mucormycosis, coccidioidomycosis (sheep and goats), protozoan/parasitic diseases, urea poisoning, HCN and nitrate/ nitrite poisoning and aflatoxicosis in poultry and cattle, and various tumors in animals and wildlife.

The reliability of PPD tuberculin/Johnin skin test was studied by examining pathological lesions at post-mortem. Experimental studies were conducted in goats to elucidate the pathogenesis of goiter and molybdenum-induced secondary hypocuprosis. From 1990 to 2010, extensive research was carried out on JD to develop and adapt various diagnostic methods such as bacterial culture, AGID, ELISA, PCR, RE analysis, and DNA probes. The experimental models (sheep, goat, rabbit, and mouse) for JD, entry of *Mycobacterium avium* sub sp. parartuberculosis (MAP) organisms via M cells and enterocytes and cytokine profile in sheep with pauci- and multibacillary pathology were established. On molecular typing, majority of Indian MAP isolates were found to be "bison" type and PFGE type 25. Pathogens associated with neonatal calf enteritis, viz., *E. coli*, rotavirus and coronavirus were also studied. The prevalence of Enzootic Bovine Haematuria (EBH) in Uttarakhand, levels of ptaquiloside and quercetin toxins in different ferns, and its pathology was studied. The cutaneous and teat warts and rumen/reticulum/urinary bladder mucosal growths showed involvement of bovine papillomavirus (BPV)-1 and -2 in cattle/ buffaloes and yaks, BPV-1 and -2 in equine sarcoids, BPV-1, -2, -5 and -10 and their combinations in cattle and buffaloes in EBH associated urinary bladder tumors.

Extensive research was carried out on classical swine fever (CSF) in pigs. Probe based RT-PCR assays were developed for detection and quantification of virus load in pigs with different clinical forms of CSF. The pathogenesis of CSF was studied using tissue based nucleic acid probes (DNA and RNA) and Indian isolates of CSFV were genotyped as 1.1 and 2.2. Swine influenza in pigs was confirmed for the first time in 2009, and the virus was shown to share close homology to the human H1N1 pandemic virus. Post-weaning multiple wasting syndrome (PMWS) caused by porcine circovirus-2 (PCV2) was reported for the first time in the country in 2005. PCV2 was genetically characterized as PCV2a and PCV2b and its recombinants. Other pig pathogens detected were porcine parvovirus, rotavirus, enterovirus, sapelovirus, Japanese encephalitis virus, *Bordetella bronchiseptica* and *Streptococcus sui*s.

9.2. Parasitic diseases

The development of vaccines against lungworms of sheep and bovine tropical theileriosis were useful for control of these diseases. For lungworm control, a gamma radiation-attenuated *D. filaria* vaccine (Difil) was developed by IVRI in 1971. The vaccine constituted infective stage, L3 filarial larvae, radiation attenuated at 50 krad. The 'Difil' vaccination significantly reduced the incidence of lungworm infection in sheep in the temperate Himalayan region. A series of ectoparasitic management practices and an anti-tick vaccine were developed at IVRI for tick management. The advent of immunological and molecular techniques helped parasitologists initiate work on characterization of parasite antigens and their use in diagnosis of parasitic diseases. Serodiagnostic tests viz., IFAT, ELISA, dot-ELISA, s-ELISA, EITB, and LAT were developed and standardized for accurate diagnosis and studying seroepidemiology of trypanosomosis, babesiosis, theileriosis, toxoplasmosis, hydatidosis, cysticercosis, toxocariasis, ancylostomiasis, prepatent fasciolosis, and haemonchosis.

9.3. Surgical interventions

Veterinary surgery is one of the dynamic and enterprising areas of veterinary science research and practice. Different surgical techniques like castration, dehorning, hoof trimming, caesarean section, etc. have been part of the animal husbandry and management system. However, veterinary surgery has undergone a sea change in the past 2-3 decades with many advancements taking place in the areas of anesthesia and pain management, minimally invasive surgical techniques, and diagnostic imaging. At ICAR–IVRI, these techniques include – treatment of posterior paresis using stem cell therapy, treatment of a hernia using acellular biomaterial, tube cystostomy in goat and bullock, Epoxy-pin fixation for treatment of open fracture in calf, treatment of compound fracture in horse using circular fixator, interlocking nailing of tibia in cow, etc.

9.4. Stem cell biology

Stem cell biology is currently one of the most potential areas of biomedical research, which can revolutionize both medical and veterinary sciences. ICAR-IVRI has conducted research on stem cells for therapeutic application in livestock and pets. Emphasis on basic research is required before stem-cell-based therapies are widely used in veterinary sector. Embryonic/induced pluripotent stem cells could be used as a reference model to understand important molecular signaling pathways which control cell fate decisions and organ differentiation.

The clinical use of stem cells in veterinary sciences is clearly in its early stages and various approaches are still being investigated. To preserve the germplasm of threatened/wildlife species, stem cell-based approaches could provide an opportunistic basis in the form of xenografting of testis tissue obtained quickly after the death of pre-pubertal animals.

10. Challenges and way forward

Development of improved vaccines (thermo tolerant vaccines, marker vaccines, etc.) and point of care diagnostics should be the thrust areas of research and development. For FMD, serotype-specific monoclonal antibody-based ELISA needs to be developed to replace polyclonal antibody-based ELISAs. There is also an urgent need for a cost-effective vaccine with long-term immunity for FMD control. Traditional methods for quality control of veterinary vaccines and drugs can be time taking and expensive, therefore there is an urgent need to develop alternate models that obviate the use of animals. Ethical use of experimental animals is also the compelling reason to develop alternate systems for quality control of veterinary vaccines and therapeutics. The emergence of Lumpy skin disease (LSD) in cattle and its rapid spread is a significant threat to cattle farming in India. Control of LSD mainly relies on early diagnosis along with restriction on movement of cattle in the affected areas, effective vector control measures, proper vaccination, and awareness of livestock farmers. ICAR institutes (IVRI and NRCE) are working on development of a candidate vaccine for LSD in cattle. Important diseases like brucellosis can be controlled to some extent by calf hood vaccinations, but, R & D for developing therapeutic strategy of the livestock is required. Similarly, some strategy for the control of Bovine tuberculosis is also need of the hour. Even with the proven animal health technologies, the major challenge lies with the implementation of disease control program in a diverse country like India, as the execution part rests with the state animal husbandry departments. CSF control in pigs is very important and a cell culture vaccine developed by IVRI is expected to contribute immensely to its control. But new diseases such as PRRS in 2013 and ASF in 2020 have entered the Indian pig population. These diseases cause heavy mortality and morbidity in swine. The complex nature of the PRRS and its genetic and antigenic variations pose a great challenge in the diagnosis and control of the disease. The management of farms and related biosecurity, diagnosis and surveillance, lack of public awareness, and concerns from across the border are the major challenges to control of PRRS and ASF in India. Avian influenza continues to be a serious concern because of its destabilizing effect on the poultry sector and public health risk. Country wide surveillance, early diagnosis of avian influenza along with subtype identification will help implementation of rapid and effective control measures to check further spread.

In the past two decades, a large number of new viral infections with severe life-threatening and economic consequences have emerged. Severe acute respiratory syndrome (SARS), Middle East Respiratory Syndrome (MERS), and SARS-CoV-2 (COVID19) corona viruses emerged from bats. Crimean Congo haemorrhagic fever (CCHF) and Ebola are currently the most important threats. After the first report of CCHF from Gujarat in 2011, it has been reported sporadically from Gujarat, Rajasthan and Uttar Pradesh. With current threats of

CCHF, Ebola, Nipah, and other zoonotic viruses, ICAR-NIHSAD has an important role to play in conducting surveillance of these diseases in animals or vector hosts of these viruses, including wildlife. Since many of these emerging diseases have originated from animals, it is expected that more will follow unless a close watch is kept at the interface of animal human interaction. Anthropogenic factors are also responsible for facilitating the species jump of pathogens from wild animals to humans. The impact of any such pandemic, such as the COVID-19 in recent time, is tremendous and such episodes can perhaps be avoided through the One Health approach that the scientific world is now advocating. The animal health institutes of ICAR contributed to the fight against COVID-19 pandemic and are continuing it through the One Health approach to combat zoonotic disease threats to public health.

11. Conclusion

ICAR's path-breaking innovative and cutting-edge technologies have helped the livestock and poultry industry to flourish and contribute extensively to raising the income of livestock owners. Animal Health Institutes of ICAR have developed more than 25 vaccines and about 80 diagnostics including nucleic acid-based tests, which have played a significant role in the control of economically important diseases and eradication of some of them from the country. In the current era of intellectual property rights, the adoption of new technologies from other sources requires various protocols. Hence, it is very important to develop indigenous technologies as has been emphasized by the Government of India through slogans 'Vocal for Local' and '*Atmanirbhar Bharat*'. Besides prevention and control of endemic diseases, the emergence of new diseases requires a robust disease forecasting mechanism, preparedness, and rapid emergency response to prevent the incursion of new transboundary diseases/ exotic diseases. Therefore, advanced preparedness to handle any such eventuality through prior risk assessment and rapid emergency response becomes very important to combat such incursions. Recent experiences with COVID-19 pandemic emphasize the need for robust epidemiological data and availability of indigenous and cost-effective diagnostics/ vaccine platforms for dealing with such outbreaks and pandemics. There is an urgent need for greater regional collaboration and cooperation with organizations like BIMSTEC, ASEAN, SAARC, etc., for sharing of information and technical know-how including microbial resources for monitoring and control of animal diseases.

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Tharparkar herd at ICAR-IVRI, Izatnagar

Achievements in Natural Resource Management in Independent India

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Summary

India accounts for 2.4% of global land mass and 4% of water resources indicating a tremendous pressure for providing livelihood support to about 18% of the global population and to a growing economy. The finite land and water resources are vital for agricultural production for securing food for all kinds of life. However, competing demands of the various land uses have put more pressure on these precious natural resources that caused their depletion and deterioration. In India, 37% of total geographical area is degraded due to various natural and anthropogenic factors. Also, unplanned development and management of water resources have led to negative environmental consequences such as waterlogging and salinity in many canal command areas, decline in groundwater level and its quality, seawater intrusion in coastal areas, drying up of wetlands and low-flows in streams, etc. To address the twin challenges of degradation of land resources and declining productivity, development of efficient and eco-friendly resource management technologies is necessary to maintain the soil health, manage water efficiently and to achieve sustained crop productivity. Indian Council of Agricultural Research (ICAR) through its 15 institutes under Natural Resource Management (NRM) division is mandated for research on conservation and management of natural resources in different agro-ecologies of arid, semi-arid, coastal, hill and irrigated areas so as to sustain the production systems. With this backdrop, the important achievements include concept of targeted yield based fertilizer requirement to address the issue of excessive use of fertilizer in agriculture. In order to correct imbalance use of fertilizers, *Mridaparikshak*, a portable soil test kit/mini lab has been developed. It is capable of analysing all the 12 soil parameters included in the Soil Health Card Scheme of the Government. For better management of soils multiple thematic maps for red soils, acid soils, wastelands and degraded land were prepared at country level. The agro-ecological mapping of the country facilitated delineation of 20 Agro-ecological Regions (AERs) and 60 Agro-ecological sub-regions (AESRs) for efficient management and planning of natural resources. The bio-engineering measures, sand dune stabilization and shelterbelt technologies have been able to control erosion. The participatory watershed management for integrated management of land, water and vegetation resources were successfully demonstrated in different agro-ecological regions. In order to achieve food and nutritional security at household level, 64 prototype Integrated Farming System (IFS) models with potential to enhance the income by 3 to 5 times over the existing systems/

practices of farmers in a period of 3 to 4 years have been developed. For promoting organic farming in niche areas, 68 organic packages have been developed and integrated in central sector schemes of *Paramparaghata Krishi Vikas Yojna* (PKVY) and Mission on Organic Value Chain Development (MOVCD) for NEH Region. Climate resilient technologies under network project on National Innovations on Climate Resilient Agriculture (NICRA) have also been developed for different agro-ecologies of the country.

1. Introduction

The land and water are the basic natural resources for agricultural growth and development of a country. When population was low, a single crop in a year was adequate to feed the masses. As the population grew, the demand for food grains and other agricultural commodities increased leading to intensification in agriculture and, therefore, the natural resources were put under intensive usage in some of the most productive geographies. Further, indiscriminate exploitation, intensive agricultural practices and of late climate change induced weather aberrations are causing damage to the finite natural resources. As the luxury of horizontal spread of cropping is drying up and squeezing in some states, the only option left is vertical intensification for producing more per unit area to maintain the supply of adequate and nutritious food to all. The sustainability of natural resources is the concern of all in the realm of competing demands of the various land uses and the problem of not only depleting but also deteriorating natural resources. The available estimates show that about 37% of the total geographical area of India i.e., ~120 million ha (Mha) is under different types of land degradation (NAAS 2010). Further, widespread deficiency of secondary and micronutrients, over exploitation of groundwater, irrigation induced salinization, increase in area under current fallows, increasing diversion of prime lands to non-agricultural uses and declining factor productivity in most of the crops particularly in the irrigated lands are the major bottlenecks in agricultural development. The over-dependence of groundwater and non-sustainable use of surface water resources has caused negative environmental consequences on availability of water quantity as well as quality. It is imperative to address the twin challenges of preventing the degradation of land and water resources and simultaneously increasing their productivity. The aquifers are contaminated with boron, fluoride, arsenic, iron and even uranium and it has severe consequences on human/animal health, if used for irrigation/drinking purposes. The governance of irrigation systems and its management is even alarming. While agriculture is the major user of the water, the water governance rests with other agency of the states. The delivery of the surface water is marked with very low efficiency. It is estimated that the major and medium irrigation projects operate at very low irrigation efficiency of around 38%. However, the groundwater irrigation system has relatively better irrigation efficiency (65-70%). The efficiency of surface irrigation system can be improved from about 35-40% to around 50-60% and that of groundwater from about 65-70% to 72-75% (Planning Commission 2009). The National Water Mission under National Action Plan for Climate Change has set the target to improve the efficiency of water use by at least 20%. The climate change impact would further affect the agricultural production systems in India. The recent study of World

Bank revealed that India would lose 2.8% of its GDP by 2050 on account of climate change impacts causing significant reduction in living standards (Mani et al. 2018). The major challenges for sustainable agriculture in the coming years include increase in rainfall, high inter annual variability, intense and frequent heat waves, increase in temperature (1.5 to 4.0 ^{o}C) and rise in sea level (IPCC 2021). These stresses may hit the small farmers the most. India has ~23% of small farms of the world. Hence, production systems of the small holders are risk prone and challenging. However, diversified agriculture could help sustaining the natural resources and increase the income of small farms. This chapter focuses on the Natural Resources Management (NRM) initiatives of Indian Council of Agricultural Research (ICAR) in the post-independent India, accomplishments made and the success stories under diverse agro-ecologies of the country.

2. Achievements in natural resources management

Indian Council of Agricultural Research through its research institutions and All India Coordinated Research Projects (AICRPs)/Network Projects (NPs)/Consortia Research Platforms (CRPs) with wide network of cooperating centres under NRM Division are conducting research on conservation of natural resources in different agro-ecologies of arid, semiarid, coastal, hill and irrigated areas. The milestones (Table 1) and salient achievements made in the post independent India are briefly presented below.

2.1. Land resource inventorization for conservation and management

Efficient land management encompassing soil and water conservation is the building block for sustainable agricultural development. All India Soil Survey scheme, started in 1943 for the systematic soil survey, prepared the first comprehensive information on soil survey in 1953. The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) was established in 1976 following the recommendations of Task Force on Land and Soil Resources for focused research on soil correlation, classification, uniform nomenclature and proper mapping. Since then, the soil map of the country at 1:1 million scale (Fig. 1), state's soil maps at 1:250000 scale, district soil maps at 1: 50,000 scale and several thematic maps were brought out. Presently, land resource inventory at 1:10000 scale (Fig. 2) is under preparation using high-resolution remote sensing data and digital elevation models and ground truthing for block level land use planning. In order to address eco-region-based solutions, the Agro-Ecological Region map of India was brought out in 1990. The country was delineated into 20 agro-ecological regions and 60 Agro-Ecological Sub-Regions. The agro-ecological region map was revised in 2016 using new soil data set, climatic resource data base of 600 weather stations and new estimates of the length of growing periods (LGP). The land degradation map of India was developed in 1994 which was further refined in 2010 using the harmonized data base of land degradation of other agencies (Fig. 3). The estimates showed that about 120.4 Mha of total geographical area of the country is affected by various kinds of land degradation (NAAS, 2010). This includes water erosion (82.6 Mha), wind erosion (12.0 Mha), chemical degradation (24.8 Mha) and physical degradation (1.0 Mha). The large chunk of these degraded soils (104.2 Mha) comes under arable lands. As Soil Organic Carbon (SOC) is a universal indicator of soil health and quality, the extent and spatial distribution of SOC was depicted through the SOC map of India (Fig. 4) which is now a part of Global SOC map published by FAO. Recently, BHOOMI Geo-portal, a Gateway to Soil Geospatial database has been developed and dedicated to soil resources of the nation.

Fig. 1. Soil map of India

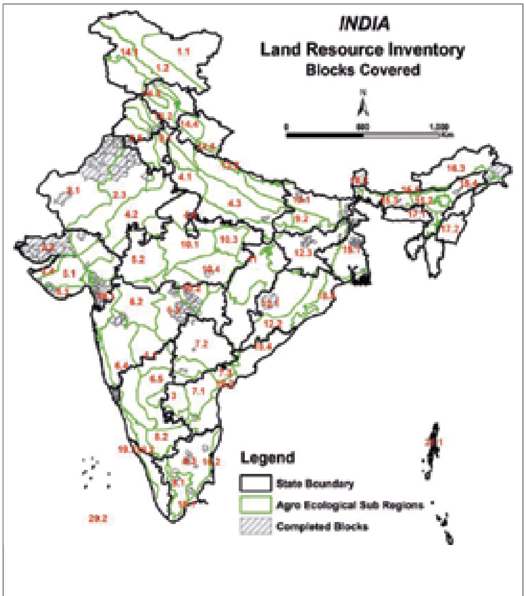

Fig. 2. Blocks covered under soil survey at 1:10000

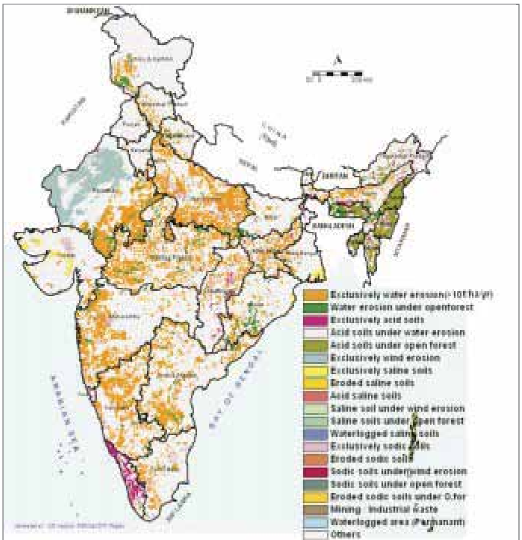

Fig. 3. Wastelands and degraded lands of India

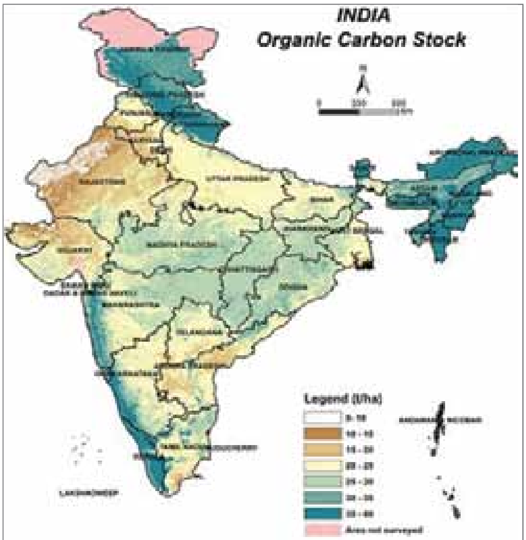

Fig. 4. Soil organic carbon map of India

Table 1. Milestones in conserving and managing natural resources

Year	Milestone
1967	Targeted yield concept was for determining fertilizer requirement.
1970	Developed gypsum technology for reclamation of sodic soils.
1971	Sand-dune stabilization and shelter-belt plantation techniques was developed to control desertification in arid zone.
1975	• Optimum irrigation schedules were formulated for different crops using surface and drip irrigation. • Neem oil as a nitrification inhibitor was formulated to enhance nitrogen use efficiency.
1982-83	Developed 47 model watersheds.
1983	Estimation of soil erosion in India.
1984	Developed sub-surface drainage (SSD) technology.
1988	Improved *Doruvu* system developed for sub-surface water harvesting in coastal areas.
1990	Prepared Agro-Ecological Region Map of India.
1992	National guidelines were formulated for using saline and alkali water for irrigation purpose.
1994	National groundwater quality map was prepared for irrigation purpose.
1999	Prepared Agro-Ecological Sub-region map of India.
1991-2000	Soil degradation maps of the country (1:4.4 million scale) and different states of the country (1: 2,50,000 scale) were prepared.
2001	Atlas of pre-dominant cropping systems covering 17 states and 14 agro climatic zones was prepared.
2001-2010	Soil maps of the states (1:250,000 scale) and several districts (1:50,000 scale) of the country were prepared.
2005	Developed liming technology for amelioration of degraded acid soils.
2006	• Developed citrus rejuvenation technology for north-eastern hill region. • Developed tank-cum-well system for eastern plateau region. • Developed InfoCrop simulation model.
2007	Prepared district level agro-met advisories.
2009	Developed *Jalkund* and *Doba*, a low-cost rainwater harvesting structure in hill and plateau region.
2010	• Prepared wastelands and soil degradation map of India using harmonized database. • Formulated liquid biofertilizers with higher shelf life.
2010-15	Developed 40 agro-forestry models for 20 agro-ecological regions.
2011	National Innovation on Climate Resilient Agriculture (NICRA) project launched.
2012	• 100 climate resilient villages established. • Automatic Weather Stations (AWS) network of ICAR established at 100 locations.

Year	Milestone
2012-20	Integrated weed management practices for 21 cropping systems.
2014	• Prepared atlas of vulnerability of Indian agriculture to climate change. • Developed ICAR Flexi Rubber Check Dams for Rainwater Harvesting in Watersheds.
2015	• Developed Mini Soil Lab-*Mridaparikshak*. • National Agromet Advisory Services initiated.
2016	• Revised Agro-Ecological Region map of India. • Initiated real time monitoring of crop residue burning in the Indo-Gangetic Plains using satellite data.
2017	Prepared agri-voltaic system for energy, agriculture and water management.
2018	• Prepared soil organic carbon map of India. • Prepared agricultural contingency plans for 650 districts.
2018-20	• Prepared desertification map of Rajasthan. • Upscaled Climate Resilient Villages to 446.
2019	• Prepared agricultural land use plans for 27 aspirational districts. • Developed 64 prototype IFS models suitable to 26 states.
2020	• Prepared *BHOOMI* Geo-portal, a gateway to soil geospatial data base. • 68 organic packages evolved suitable for 16 states. • Prepared micro and secondary nutrients deficiency maps of India. • Initiated natural farming research in 20 centers.
2021	• Mapped agroforestry in the country using RS2/LISS-3 data. • Developed GypKit for rapid assessment of soil sodicity and estimating gypsum requirement.

Timely cognizance of the problems of soil erosion due to rainwater in India encouraged the establishment of Central Soil and Water Conservation Research & Training Institute (renamed as Indian Institute of Soil and Water Conservation) at Dehradun in 1954. The institute has estimated loss to annual production is about 13.4 million tons (Mt) worth US$2.51 billion due to water erosion in major rainfed crops (Sharda et al. 2010; Sharda and Ojasvi 2016). The pioneer work on operationalizing the watershed management through soil and water conservation technologies during 1970s led to development of 47 model watersheds in 16 states. The success of the model watersheds formed the basis for the National Watershed Development Programme for Rainfed Areas (NWDPRA) in 1991 and is being implemented in 29. The bottom-up participatory concept of integrated watershed development emerged as a new paradigm for efficient management of land, water and other natural resources. The results of soil carbon sequestration in various degraded lands of India revealed that adoption of technological options for erosion control would help to sequester 19 to 27 Mt C yr^{-1} (Mandal et al. 2020).

Development of techniques for sand-dune stabilization and shelter-belt plantation to control wind erosion/desertification in arid zone was the milestone achievement of Central Arid Zone Research Institute (CAZRI), Jodhpur (Fig. 5). Recently, the desertification map of Rajasthan has been developed in GIS environment at 1:500,000 scale (Fig. 6). The estimates showed that about 21.23 Mha (62.06%) of the state is under desertification/ land degradation in 2018-19, which is 3.87 lakh ha less compared to that of 2003-05. Wind erosion is the major cause of land degradation/desertification (43.37%) in arid ecosystems.

Fig. 5. Sand-dune stabilization and shelter-belt plantation

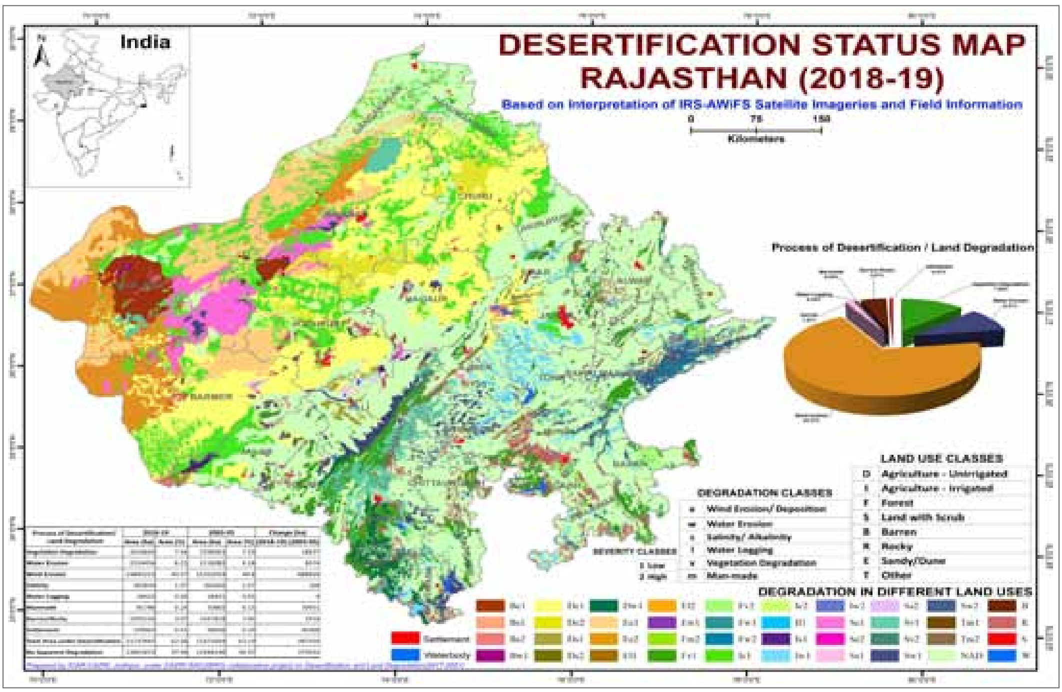

Fig. 6. Desertification map of Rajasthan

2.2. Soil health management

The United Nations (UN) Millennium Development Task Force on hunger included soil health enhancement as one of the five recommendations for increasing agricultural productivity and fight hunger. In India, the first mobile soil testing van was acquired by Indian Agriculture Research Institute (IARI) from United States Agency for International Development (USAID) during 1950s for collecting soil samples at the farmers' fields and on-spot soil test reports and fertiliser application advisories. The soil testing laboratory established at IARI in 1955-56 was the main coordinating centre of soil testing activity in the country. The large-scale use of chemical fertilizers 1960s onwards with the introduction of high yielding dwarf varieties of rice and wheat and development of irrigation facilities led to Green Revolution. Therefore, a landmark in fertilizer research, *the targeted yield concept* to determine the fertilizer requirement was initiated in 1967 (Ramamoorthy et al. 1967). For the first time, widespread micro- and multi-nutrient deficiencies under intensive cropping systems was reported by Dr. B.V. Mehta. The twin developments led to launch of AICRPs on Soil Test Crop Response (STCR) and Micro and Secondary Nutrients and Pollutant (MSNP) elements in soils and plants (Chhonkar et al. 2015).

The development of nutrient index-based soil fertility maps and fertilizer prescription equations for various crops under AICRP-STCR formed the basis of a nationwide programme on Soil Health Card under the National Mission for Sustainable Agriculture (NMSA). The five-decade long research under AICRP-Long Term Fertilizer Experiments (LTFE) proved micro and secondary nutrients deficiency as the yield limiting factor even under recommended doses of NPK. The e-atlas delineating soil micro and secondary nutrient deficient zones of the country prepared under AICRP on MSNP based on the analysis of 2,42,827 surface soil samples from 600 districts revealed deficiency of available Zinc and Boron in 36.5 and 23.4% soil samples, respectively (Fig. 7). In order to maintain soil fertility besides improving soil physical and biological health, Integrated Nutrient Management packages

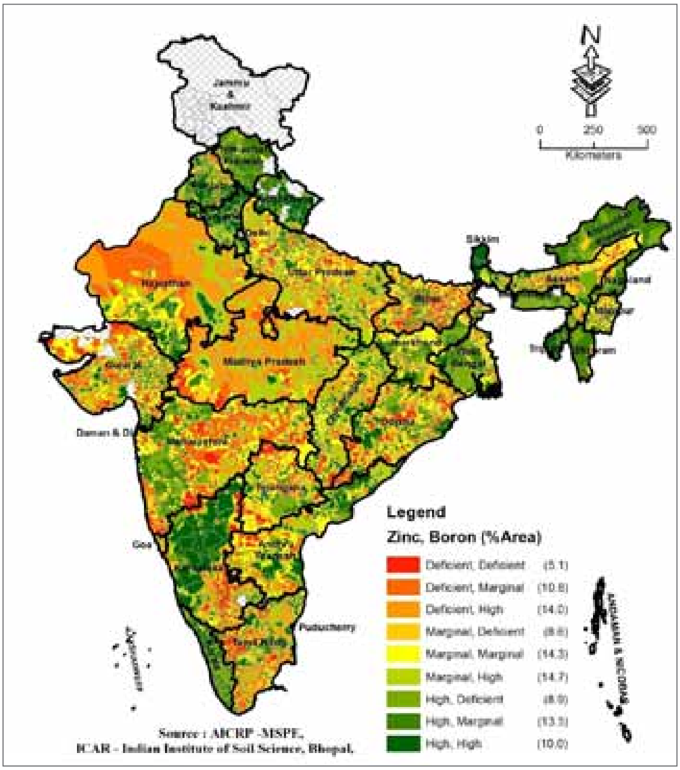

Fig. 7. Zinc and boron deficiency map of India

for more than 60 major cropping systems have also been documented for use by the farming community. As an attractive alternate source of plant nutrition, the improved and efficient strains of bio-fertilizers and liquid biofertilizer formulations with longer shelf life have been developed, and potassium and zinc solubilising bacteria have been identified. The technology to prepare phospho-compost, vermi-compost, bio-enriched compost, municipal solid waste compost etc. from various organic wastes was developed and standardised. Recently, a portable soil test kit/mini lab (*Mridaparikshak*) has been developed by Indian Institute of Soil Science (IISS), Bhopal to facilitate analysis of 12 soil parameters included in the soil health cards at farmer's door step (Fig. 8). The soil samples analysed using *Mridaparikshak* contributed for 14% of the 28.8 million soil health cards issued in the country. The pine oleoresin coated slow-release urea and nano formulations, 4G nano-based nutritional agri-inputs (phosphorus, magnesium, zinc, and iron), nano ZnO and nano rock phosphate for higher nutrient use efficiency were also developed.

Fig. 8. Mridaprikshak for soil testing

The work on enhancing the efficiency of nitrogenous fertilizers was initiated in 1970s including nitrification inhibitors and slow-release nitrogenous fertilisers, which subsequently led to the development of neem-coated urea (Chhonkar et al. 2015). In addition to enhancing nitrogen use efficiency, neem-coated urea also mitigates emission of nitrous oxide, a greenhouse gas with 310 times global warming potential than carbon dioxide (Pathak 2016). Currently, 100% of urea fertilizer used in the country is neem-coated.

The early work on the role of earthworms on soil quality was initiated in 1951 and on soil arthropods in 60s (Singh and Mukherjee, 1971). The solubilization of insoluble plant unavailable P with soil microbes was shown in 1957 (Sen and Paul 1957). The research on rhizobium and legume root nodules and blue green algae (BGA) and their role in rice cultivation was the centre stage of research in soil microbiology in the 20th century. During the 1990s, the research on plant growth promoting rhizobacteria (PGPR) in chickpea, pigeonpea, groundnut, soybean, etc. started.

The work on problem soils at Central Soil Salinity Research Institute (CSSRI), Karnal since 1969 led to development of technologies for reclamation of alkali soils, subsurface drainage, bio-drainage, waterlogged saline soils and development of salt tolerant crop varieties. The gypsum technology has helped reclamation of 2.07 Mha sodic soils. The GypKit has also been developed for rapid assessment of soil sodicity and estimating gypsum requirement to reclaim sodic soils. The sub-surface drainage (SSD) technology proved very effective to reclaim 72000 ha waterlogged saline soils and convert the unproductive land into a fertile land. The SSD technology has helped enhancing cropping intensity, crop yield and farm income (Bundela et al. 2017). Salt tolerant high yielding varieties of rice, wheat, Indian mustard and chickpea were developed and released for cultivation in salt affected areas of the country. Cost-effective liming technology was also developed for soil acidity amelioration.

2.3. Water management

Systematic research on water management for efficient use of irrigation water commensurate with increased agricultural production and sustained soil productivity was initiated in 1967 with implementation of AICRP on Water Management by ICAR with three centres one each located in three major river valley projects of Bhakra, Hirakud and Tungabhadra. Later on in 1971, AICRP on Optimization of Groundwater Utilization through Wells and Pumps was established for the assessment of basin-wise groundwater potential, evolve groundwater management strategies for its safe development and utilization and to develop efficient hardware. In 2012-13, both the AICRPs on water were subsumed into AICRP on Irrigation Water Management (IWM). Since the inception of the project in 1967, optimum irrigation schedules of surface irrigation system based on depth of irrigation water (IW) to cumulative pan evaporation (CPE) ratio were standardized for 57 crops which resulted in improved yield, economizing on water use and higher income to the farmers. The fertigation schedules were also developed for 64 crops in 13 ago-ecological regions.

Safe disposal of rainwater in rainy months and water conservation in post-rainy drier months are the distinct water management issues in the eastern region of India. The Water Technology Center for Eastern Region (WTC-ER) was established in 1988 and subsequently elevated to Directorate and to Indian Institute of Water Management (IIWM) in 2015 with research focus on management of rainwater, canal water groundwater and on-farm water management technology dissemination. During the past 3 decades, technologies for rainwater harvesting and recycling, multiple uses of water, conjunctive use of rain, surface and groundwater resources, micro-irrigation and optimum irrigation scheduling, seed bed configurations, alternate furrow irrigation, mulching, direct seeded rice (DSR), system of rice intensification (SRI), alternate wetting and drying were developed/standardized to enhance irrigation water use efficiency and water productivity. Tank-cum-well system technology along the drainage line in a watershed suitable for plateau areas having slope of 2 to 5% has also been developed (Fig. 9). A flexible rubber dam has been designed to harvest rainwater and regulate flow of water in streams (Fig. 10) and installed at 34 locations in 8 states. Development and standardization of sensor-based drip irrigation in banana improved the productivity of banana with water saving of 20% compared to manual drip irrigation.

Fig. 9. Tank cum well system for rainwater harvesting for eastern plateau region

Fig. 10. A flexible rubber dam for water harvesting in watershed

Research on use of saline water and alkali water for irrigation under different agro-climatic regions was initiated during 1970s. National groundwater quality map for irrigation purpose was prepared after survey, characterization and groundwater quality classification (Fig. 11). The National guidelines for use of saline and alkali water for irrigation was prepared in 1990 and published as Indian Standard (IS 11624: 2019) for Quality of

Irrigation Water-Guidelines. These guidelines are being adopted in the states of Haryana, Uttar Pradesh, Andhra Pradesh, Karnataka and Gujarat. To tap and use the shallow good quality groundwater floating over the subsurface saline water in coastal region, developed and standardized skimming well/*Doruvu* technology locally called "*Doruvus*" in Andhra Pradesh (Fig. 12).

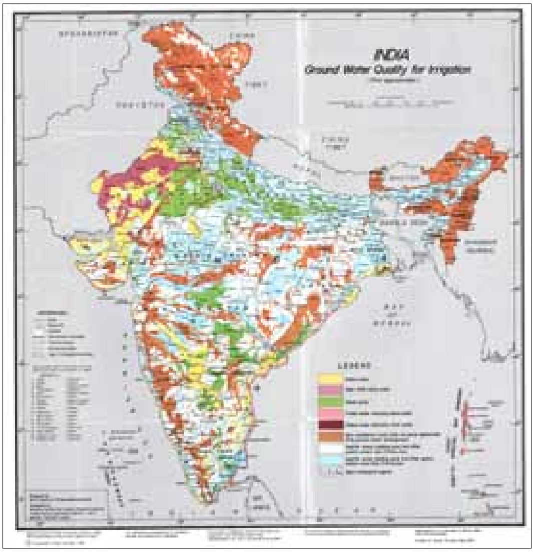

Fig. 11. Groundwater quality map for irrigation

Fig. 12. Skimming well in Coastal Andhra Pradesh

2.4. Sustainable production systems

The report of Dr. A.B. Stewart of Macaulay Institute of Soil Research, Aberdeen (U.K.) submitted to Government of India in 1947 led to initiation of Simple Fertilizer Trials on Cultivators' Fields scheme during 1952-53. This scheme helped popularization of fertilizer use and increase in crop productivity in the early days. In 1956, 'Model Agronomic Experiments' were added and All India Coordinated Agronomic Experiments Scheme started as an ICAR Project. In 1968-69, the reshaped All India Coordinated Agronomic Research Project (AICARP) with two components, namely, Model Agronomic Experiments and Simple Fertilizer Trials was implemented with the broadened objectives of Model Agronomic Experiments to study the response of high yielding varieties of cereals to intensive use of different inputs like fertilizer, irrigation, weed control, liming, etc. AICARP contributed appreciably for the development of package of agronomic management practices for newly introduced high yielding varieties and played a critical role in bringing green revolution in India.

Intensification and diversification of cropping/farming systems: Although the system-based research was initiated during early seventies but got focus with the establishment of Project Directorate for Cropping Systems Research (PDCSR) in 1989. The on-station and farmers participatory on-farm research were included in the new set up. Network Project on Organic Farming was started in 2004-05 as a new scheme. With the changing dynamics of cropping moving towards multiple enterprises within the farms for enhanced income and livelihood support, the scope of PDCSR was further broadened to move from cropping system to farming system in 2010. Later on in 2014, the Project Directorate was elevated to Indian Institute of Farming Systems Research (IIFSR). The designing and development of cropping systems resulted in double cropping in 25% of the single crop area in a year. The irrigation expansion also added to it. The various land configurations evolved like bed and sunken furrow, dyke and pond, etc. over the years offer scope for growing more than two crops at the same time in the same piece of land. In limited land and water plus ecologies, the dyke and pond system helped to evolve vertical cropping systems.

Integrated farming systems: The IFS is the potential tool for enhancing farm productivity and income of small and marginal farmers. A total of 64 prototype IFS models including 8 integrated organic farming system models (IOFS) suitable for 26 States/UTs have been developed. Thirty-one IFS models suitable for 22 States have been identified as bankable for financing from banks by NABARD. These models provide scope to double the farm income apart from meeting the sustainable development goals. IFS models developed are being promoted through convergence mode by Union and State Governments. Till March 2022, Kerala, Odisha and Tamil Nadu State Governments have promoted the IFS models by involving 21040, 942 and 28,490 farm households, respectively with a financial outlay of Rs 279.19 crores. These IFS models have the potential to increase the income by 3 to 5 times than existing systems/practices of farmers in a period of 3 to 4 years.

Organic farming: Network Project on Organic Farming (NPOF) was initiated in 2004 at 13 centres to promote organic farming. During 2017, number of centers was increased to 20 in order to represent various niche areas identified for organic and natural farming in the country. The project helped in developing package of practices for organic production of 68 cropping systems suitable to be adopted in 16 States and identification of 104 varieties suitable for growing under organic farming. Besides 8 IOFS models, biochemical characterization and molecular identification of microbes in 5 indigenous organic preparations were also attempted. Through convergence with central sector schemes like *Paramparagat Krishi Vikas Yojana* (PKVY) and Mission Organic Value Chain Development for North Eastern Region (MOVCD-NER), the organic farming is being promoted in niche areas identified by the Government of India.

Agroforestry interventions: Over the years, agroforestry (AF) has evolved as an assured land use system against crop failure as it plays a role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks. In addition to productivity role, it also contributes towards ecosystem services- water, soil health and biodiversity. There are number of options which can be integrated with AF to ensure livelihood security in rural areas such as apiculture, sericulture, lac cultivation, gum and resin and medicinal and aromatic plants. In order to strengthen AF research, National Research Centre (NRC) on AF was established in May, 1988 at Jhansi. For network research, AICRP-AF was started since February, 1983. Based on the objectives and mandate of the institute in national perspective, the NRC-AF was upgraded to Central Agroforestry Research Institute (CAFRI). So far, the institute has developed 40 AF models suitable for 20 agro-ecological regions of the country. The institute has also mapped the area under agroforestry in the country besides developing location specific AF models. The National Agroforestry Policy (NAP), adopted by the country in 2014 is instrumental to implement focused program on AF in different states. The NAP of India is a comprehensive policy framework designed to improve agricultural livelihoods by maximizing agricultural productivity for mitigating climate change impact. AF research and extension is being supported under several schemes/projects of Govt. of India like National Bamboo Mission, National Horticulture Mission, National Biofuel Policy, Task Force on Greening India (2001), National Policy on Farmers (2007) and Green India Mission (2010). The National Bank for Agriculture and Rural Development (NABARD) also provides financial and banking institutional support for promotion of agroforestry models developed by the ICAR.

Reducing chemical footprints in agriculture: Realization of higher agricultural production has been associated with higher chemical footprints in the environment. Unbalanced use of fertilizers in agriculture in certain crops /regions is leading to land degradation, water and air pollution, unhealthy ecosystem, and adulterated food posing risks to human health. This has brought focused attention of all concerned to chemical free farming including organic farming technologies that recover, revitalize and restore the soil and the environment. Looking into the emerging scenarios and need to develop alternate production systems, ICAR initiated pilot study on chemical free farming since 2017 under All India Network Programme on Organic Farming. The experiment for evaluation of concoctions of zero budget farming practices in basmati/coarse rice-wheat system was conducted during 2017-2020 at 4 locations. The natural farming concoctions of Jeevamrit, Beejamrit and Ghanjeevamrit were compared with integrated crop management and AI-NPOF developed organic farming package. Since kharif 2020, evaluation and validation of Beejamrit, Jeevamrit, Ghanjeevamrit; intercropping; mulching and Whapasa have been initiated at 20 locations in 16 States.

2.5. Management of challenged agro-ecologies

Arid agriculture: The arid zone of India covers about 12% of the country's geographical area, and occupies over 32 m ha area of hot desert and ~7 Mha under cold arid zone. In order to address the challenges of arid agriculture, Central Arid Zone Research Institute, Jodhpur was established in 1952 which owes its origin to Desert Afforestation Research Station (DARS) for undertaking research work on stabilization of sand dunes and establishment of shelterbelts. DARS was reorganized as Desert Afforestation and Soil Conservation Station (DASCS) in 1957 which was renamed as Central Arid Zone Research Institute (CAZRI) in 1959 and brought under the umbrella of ICAR in 1966. The institute has developed various agroforestry models for arid environment and more recently, an agri-voltaic system of 105 kW for crop production and electricity generation from a single land use resulted in 1,29,266 kWh annual power output. The short statured kharif and rabi pulses, spices and vegetables were successfully grown in the inter panel spaces. ICAR-CAZRI agri-voltaic concept has been utilized for the development of majority of the 13 operational agri-voltaic systems in the country at present. The institute has also developed a technology for gum exudation from *Acacia senagal* with its adoption in western Rajasthan, Madhya Pradesh and Gujarat.

Fig. 13. Inter-crops with solar panels in solar farming in Rajasthan

Agriculture in northeastern hill region: Agriculture in the Himalayan region is marked by mono-cropping, small and fragmented land holdings, high rate of soil erosion, soil acidity, lack of mechanization and water scarcity. Shifting agriculture, the major land use in northeastern hill region, is quite distinct from settled agriculture practiced in other parts of the country. On an average, 10-15 years of *jhum* cycle was considered to be sustainable. Of late the *jhum* cycle has reduced to 4-5 years, which is a major threat to the resource conservation and food security. In order to provide alternatives to shifting agriculture, ICAR Research Complex for North Eastern Hill (NEH) Region was established at Barapani, Meghalaya in the year 1975 with its regional stations in all the northeastern states including Sikkim. Farming system research is the core strength of the institute and developed six IFS models for long term data generation. The institute has also developed seven Intensive Integrated Farming System (IIFS) models for achieving food and nutritional security besides value addition, product diversification and needful employment opportunities and replicated these models at 36 different locations of entire NEH region. Further, to move towards chemical free agriculture in niche area of hill agriculture, Integrated Organic Farming System (IOFS) suitable for the region has been developed and promoted in the clusters through MOVCDNER. Livestock based enterprises, soil acidity amelioration, *Citrus* rejuvenation, bamboo and alder based agroforestry systems, *jalkund* are some other important technologies developed by the institute besides varietal development in rice, maize, vegetables, guava and pulse crops.

Coastal agriculture: The coastal region of India is spread over 75 coastal districts in 9 states (Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha and West Bengal) and 2 UTs (Daman and Diu & Dadra and Nagar Haveli and Puducherry). Poor productivity of crops, livestock and fisheries, sea water ingression and salinity, small and marginal land holdings etc. are the major challenges faced by coastal farmers. To improve productivity of crops, livestock and fishery and augment farmer's income, Central Coastal Agriculture Research (CCARI) has developed four rice varieties; four cashew varieties and a cowpea variety. The institute has also developed IFS models for coastal region. Cumulatively, all the technologies benefitted around 1.40 lakh farm families and generated an employment opportunities of 5.21 lakh man-days.

2.6. Rainfed agriculture

Rainfed agriculture accounts for about 50% net sown area in India and is crucial to country's economy and food security since it contributes to about 40% of the total food grain production. It also supports two-thirds of livestock and 40 % of human population and influences livelihood of 80% of small and marginal farmers. Climatic risks like droughts, unseasonal high intensity rainfall events and floods, poor water and nutrient retention capacity of soil and low soil organic matter (SOM) impact highly vulnerable, rainfed agriculture requiring a different outlook and strategy. To address these challenges of rainfed agriculture, the Government during 1969-74 emphasized on the participation of dryland farmers in the agricultural development process and in response to this, ICAR launched AICRP for Dryland Agriculture (AICRPDA) in collaboration with the Canadian International Development Agency (CIDA) in 1970-71. In 1976, the Operational Research Project (ORP) was introduced for technology assessment, refinement and transfer. In April 1985, the Project Directorate was upgraded to Central Research Institute or Dryland Agriculture (CRIDA) to undertake basic and strategic research while adaptive research continued with AICRPDA. The institute has developed 75 location specific doable dryland technologies/practices such as *in situ* and *ex situ* rain water harvesting and conservation, alternate and efficient cropping systems, integrated nutrient management, drought tolerant varieties etc. and are integrated in to package of practices in the states where drylands are common and have been disseminated through KVKs/SAUs. Also identified 46 climate resilient varieties of rainfed crops to cope with delayed onset of monsoon in various agroclimatic zones in 15 states and also demonstrated Real-Time Contingency Plans (RTCPs) to manage weather aberrations in cluster villages in 23 districts. Dryland technologies have been integrated in to National schemes/programme such as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), National Mission on Sustainable Agriculture (NMSA), Rashtriya Krishi Vikas Yojana (RKVY), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), National Rural Livelihoods Mission (NRLM) etc. and at various state level programmes/schemes.

2.7. Climate resilient agriculture

In India, the estimated agricultural production loss in 2030 due to climate change will be over US$7 billion severely affecting the income of 10% of the population. This can be reduced by 80%, if cost-effective climate resilience measures are implemented (ECA 2009). Rainfed crops are likely to be worst hit by climate change because of the limited options for coping with variability of rainfall and temperature. To meet the challenges of sustaining domestic food production in the face of changing climate and to generate information on adaptation and mitigation in agriculture, ICAR launched a flagship network project on National Innovations in Climate Resilient Agriculture (NICRA) in 2011. The project was launched to conduct research on climate change, demonstrate resilient technologies and build capacity of farmers and other stakeholders. The project is implemented through components viz. strategic research, technology demonstration and dissemination and capacity building in 151 clusters of villages in each one of the identified climatically vulnerable districts to demonstrate proven technologies and enhance adaptive capacity of farmers.

In the 1980s, research on climate change impacts on crops was initiated. Simulation models were found to be very useful in assessing climate change impacts and in 1984, the first crop simulation model named Wheat Growth Simulators (WTGROWS) was developed. In 2006, a generic crop simulation model for the assessment of crop yields, losses due to pest, and environmental impact of agro-ecosystems in tropical environments named InfoCrop was developed (Aggarwal et al. 2006). Analysis of the impact of climate change on crops using both the models showed that rainfed rice yields in India are projected to reduce marginally by 2.5% in 2050 and 2080 scenarios. Similarly, irrigated rice yields are projected to reduce by 7% in 2050 and by 10% in 2080 scenarios. Climate change is projected to cause reduction in wheat yield in the timely sown irrigated wheat by 6% in 2020 scenario from existing levels. However, late and very late sown wheat yields are projected to decrease by about 18% in 2020, 23% in 2050 and 25% in 2080 scenarios. Yields of maize cultivated in monsoon season can reduce mostly in southern plateau (up to 35%), winter yields will reduce in mid Indo-Gangetic Plains (up to 55%), while upper Indo-Gangetic Plains will be relatively unaffected. Climate change in 2050 and 2080 scenarios is projected to reduce the irrigated *kharif* maize yields by 18 to 23%. On the other hand, it was also predicted that crops like soybean, groundnut and chickpea would be benefited by climate change.

Risk and vulnerability assessment: Assessing vulnerability to climate change and variability is an important first step in evolving appropriate adaptation strategies to changing climate. Adopting the definition of vulnerability given by IPCC, vulnerability was assessed for 572 rural districts of India. Thirty-eight indicators reflecting sensitivity, adaptive capacity and exposure were chosen to construct the composite vulnerability index. Climate projections of the Providing Regional Climates for Impacts Studies (PRECIS) model for A1B emission scenario for the period 2021-2050 were considered to capture the future climate. The data on these indicators were normalized based on the nature of the relationship. They were then combined into three indices for sensitivity, exposure and adaptive capacity which were then averaged with weights given by the experts to obtain the relative vulnerability index. Based on the index, all the districts were divided into five categories with an equal number of districts. One more district was added to 'very high' and 'high' vulnerability categories. The analysis showed that districts with higher levels of vulnerability are located in the western and peninsular India. It is also observed that the highly fertile Indo-Gangetic plains are relatively more sensitive but less vulnerable because of higher adaptive capacity and lower exposure. The recent study on risk and vulnerability assessment of agriculture to climate change by ICAR showed that out of 573 districts, 109 were falling under very high risk prone and 201 are highly prone (Rama Rao et al. 2019). This document is helpful for prioritization of resources related to climate change action plans for adaptation and risk reduction.

Contingency plans: In the face of increasing climate variability, adoption and implementation of the District Agricultural Contingency Plans (DACPs) is a priority for many state Governments. ICAR has prepared DACPs for 650 districts of the country recommending location specific climate resilient crops and varieties and management practices for use by the State departments of agriculture and farmers. These DACPs cover drought (delay in monsoon onset, long dry spells in monsoon causing early, mid and late-season droughts, delayed or limited release of water for irrigation), floods, unseasonal rains and heat wave, cold wave, untimely and high intensity rainfall, frost, hailstorm, cyclone, pest and disease outbreaks. The two-step implementation of district plans involves preparedness and real-time activation of the contingency measures (Srinivasarao et al. 2020).

Greenhouse gas (GHG) emission and mitigation: One of the major contributions of NRM research in the country has been rationalization of methane emission from Indian rice fields. In the 1990s, based on very limited measurements, Indian rice fields were attributed to emit 37.5 Mt of methane. Systematic and multi-location measurements showed that the Indian rice fields covering an area of about 44 Mha emit 3.3 Mt of methane (Pathak 2015). Current GHG emission inventory of the country shows that agriculture sector emits 407,821 Gg of CO_2 during 2016, which is 14% of the emissions of India. India is on its way to meet its commitment to reduce its emissions intensity of GDP by 33-35% below 2005 levels well before 2030 (MoEFCC 2021). A network of GHG emissions from different production systems has been established to develop region-specific emission factors for reporting GHG inventory from agriculture sector. Practices which can further reduce the GHG emissions like improved systems of rice cultivation, fertilizer management, improved fertilizer materials, crop diversification, etc. are explored from the rice-based systems. Further, conservation agriculture (CA) can reduce GHG emission by 15-20%.

Climate Resilient Villages (CRVs): The concept of climate resilient village has been initiated to provide stability to farm productivity and household income and resilience through livelihood diversification under extreme climatic events (Srinivasarao et al. 2016). Location specific climate resilient technologies (CRTs) were demonstrated for coping with climate variability in vulnerable districts to generate awareness and build capacity of farmers and other stakeholders and to evolve innovative institutional mechanisms at village level so as to enable the communities to respond to climate stresses. The interventions included natural resource management, crop production, livestock and fisheries. Innovative institutional interventions such as Village Climate Resilience Management Committee (VCRMC), Custom Hiring Centres (CHC), seed and fodder production systems were established in the NICRA villages enabled to sustain the activities envisaged and scaling up of interventions. The program started with 100 villages representing 100 climatically vulnerable districts during 2011 and subsequently expanded to 151 districts covering of 446 villages. One village cluster from each of the 151 districts were selected by the respective KVK in the district for farmer participatory programme implementation. The CRV models have been adopted for upscaling by State Governments of Maharashtra and Bihar and several National and International funding agencies (NABARD, ADB, World Bank). The carbon sink also increased due to adoption of resilient practices suggesting reduction in net GHG emissions.

Human resource development under NICRA: The NICRA project enabled to network with 1200 scientists and 872 young research fellows in the climate change research. The skilled scientific man power and state of the art research infrastructure established at several ICAR institutes and State Universities encouraged students to take-up research work for the award of 126 Ph.D. and 85 M.Sc. degrees. During the past 10 years 17,250 capacity building programs were conducted benefiting 5,25,816 stakeholders. Bibliometric science mapping and meta-analysis of 424 research articles published under NICRA over the past one decade (2010-20) indicated that the collaboration index was 3.1, with 6.17 co-authors per scholarly publication, showing the inter-disciplinary team approach among the researchers in the network. The sustained and long-term funding support also showed increased publication of research articles in peer reviewed journals (growth rate of 20.87% per annum).

3. Impact of NRM technologies

Impact assessment of promising technologies has been carried out. Technology development on watershed management showed that nearly 57.61 Mha area has been developed under various watershed development schemes. Meta-analysis of 311 watersheds in India revealed that watershed interventions have been found to be very effective in terms of prevention of land degradation, water conservation and production enhancement besides mitigating adverse impact of flood and drought. The mean benefit-cost ratio of watershed program in the country was quite modest at 2.14 with internal rate of return of 22% (Joshi et al. 2005). Technology generation on reclamation of problem soils was able to rehabilitate 1.8 Mha of sodic soils, 0.80 Mha of saline soils and 0.1 Mha of waterlogged saline soils. Subsurface drainage technology proved increase in cropping intensity by more than 100% with improvement in yield of paddy (45%), wheat (111%) and cotton (215%). Standardized fertigation schedules have showed promising outcomes with 9-80% higher yield, 11-71% irrigation water saving and 18-25% fertilizer saving in various crops grown under varying soil textural classes across the country. ICAR flexi check dam (Rubber Dam) for watershed resulted in enhancement of rice productivity (22 to 62%), pulse productivity (46%) and vegetable productivity (22 to 48%) besides increase in cropping intensity (31%), cultivated land utilization index (40%), multiple cropping index (152.5-190%) and crop diversification index (0.39 to 0.49) with a benefit cost ratio of 2.30 (Jena 2018). Intervention on neem coating of urea was able to improve the nitrogen use efficiency by 10%. Development of *Mridaparikshak* helped in distribution of about 28 million soil health cards to the stakeholders. Similarly, a total of 31,891 organic clusters were formed during 2015-16 to 2018-19 to promote organic farming in 2.38 lakh ha area. Likewise, adoption of resource conservation technologies has brought nearly 2.0 Mha area under zero tillage and bed planting in Indo Gangetic Plains. The integrated farming system (IFS) models have been able to ensure food and nutritional security at household level besides making the farming as a profitable venture. On an average, stakeholders could achieve the increase in their income to the tune of 1.5 – 3.6 lakh per annum by adopting IFS. Area under agroforestry land use has been estimated to be 28.427 Mha i.e., 8.65% of the total geographical area of the country. Bio-intensive efficient alternative cropping systems for different agro-climatic zones with potential productivity ranging from 16 to 35 t $ha^{-1}yr^{-1}$ have also been developed. These alternative systems along with production packages have been included in the Crop Production Guide /package of practices of respective states. The system approach enhanced the resource recycling by 25-30% with increase in rural employment by 25-30% besides enhancement of farm income by 2-3 times.

4. Way forward

The past 75 years of independence could saw a significant progress in the field of natural resource management starting from a concept of simple fertilizer response experiments to estimates of greenhouse gas emission and phenomics for crop phenotyping to identify the climate resilient traits. The next phase of research should orient towards reducing the chemical foot prints and studying water foot prints in the system mode approach. The fifth-generation technologies like remote sensing, GIS, artificial intelligence, etc. need to be refined and validated for soil health management in diverse agro-ecologies. In order to enhance water productivity, (i) promotion of less water consuming crops (ii) promotion of efficient irrigation methods including piped network for water conveyance (iii) promotion of solar photovoltaic pumping systems for groundwater pumping (iv) conjunctive use of rain, surface and groundwater resources (v) encouraging community/group tube wells for efficient use of groundwater resources (vi) canal automation for improving water productivity in irrigated ecosystems and (vii) use of Internet of Things (IoT) enabled Sensor based Smart Irrigation Management System for precise irrigation water application and efficient use of water need to be standardized and upscaled through proper convergence mechanisms. Crop diversification should also be promoted to achieve low water foot prints in intensive agricultural ecosystems. The changing climate would further reduce the availability of fresh water for irrigation of crops. Hence, the district climate change adaptation plans need to be developed and risk assessment at sub-district level which will enable prioritization of resilient practices in the district. Under strategic research of

NICRA, germplasm collected, screened and genes identified in several crops for different climatic stresses should be used in breeding programs to develop new climate resilient varieties. The NICRA model villages need to be expanded in more risk prone districts as per the revised risk and vulnerability assessment through convergence mechanisms with DAFW, MoRD, Corporates, NGOs and MoAHF&D. Establishment of India-Flux Network with trained manpower for estimating emissions at landscape level for major cropping systems is need of the day to generate accurate and precise data on GHGs from agriculture sector. Development of climate resilient livestock modules using indigenous breeds, life cycle analysis for estimating carbon foot prints and digital tools for pest prediction are some of the future activities contemplated to deal with changing climate in agriculture sector. Upscaling of climate smart agriculture through large scale adoption of proven farming system models, organic/natural farming practices and conservation agriculture is very much essential to meet the Sustainable Development Goals (SDGs).

5. Conclusion

As the agricultural development progressed, the food production increased substantially but with a heavy cost to soil health and the environment. Widespread land degradation, spatial and temporal variability of monsoon rainfall resulting in frequent drought and floods, deteriorating soil health, low nutrient and water use efficiency and low water productivity are some of the major challenges in the agriculture today. As the Indian agriculture is typified as small holders farming, the major burnt of these challenges are faced by this vulnerable class of farmers. The vulnerability of these households to climate change is very high due to diversity and less capacity to purchase the inputs. ICAR through its multifaceted location specific research outfits helped designing and development of new cropping systems for irrigated and rainfed areas, integrated farming systems for different strata of farmers, micro level land use planning, bio-engineering measures for soil and water conservation, reclamation and amelioration technologies for salt affected, waterlogged and acid soils, integrated nutrient management, resource conservation technologies, conjunctive use of rain, surface and groundwater resources, efficient and energy saving irrigation methods, multiple use of water and participatory watershed management including agro-forestry interventions for sustainable natural resource management. These technologies coupled with application of geo-informatics, information and communication technology as well as climate smart agricultural practices may go a long way in managing natural resources *vis-a-vis* improving land, water and crop productivity. While assessment of climate change impacts on crops, natural resources, livestock and fisheries is a continuing process, the development and deployment of proven resilient technologies are important for adaptation and mitigation. ICAR has moved on this path with the demonstration of CRTs in 151 village clusters one each in the identified climatically vulnerable districts. The appetite for upscaling of the adaptation and mitigation practices evaluated under NICRA has been apparent with the states and other agencies coming forward for upscaling the proven CRTs across the country.

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Farming on reclaimed soil in eastern ghats

12
Chapter

Achievements in Agricultural Engineering in Independent India

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Summary

Agricultural development in India is the outcome of coordinated interplay of man-machine-material interface. While the food grains' production touched the record high of 314.51 million tons (Mt) in 2022 with similar increase in other food and non-food commodities, we are encountering the simultaneous increase in input cost and degradation of natural resources with inefficient input utilization. With the changing economies at micro and macro level, the demand for food is diversifying towards better quality processed and raw foods. As the luxury of putting more area under cultivation has dried up, increasing the per unit land and labour productivity in agriculture in the realm of over 69% of the marginal farmers having less than one hectare land is the only option. The land holding is continuously declining and about 86% farmers are small and marginal. Farm mechanization also offers an opportunity to retain youth in agriculture by improving comfort as compared to that in the traditional farming, and enhancing the income. The demand for mechanization is consistently increasing and farmers, manufacturing industries with their network, government and NGOs are engaged in promoting appropriately mechanized agriculture. ICAR with its network of specialized institutions has actively been engaged in need-based research and development of mechanized tools, equipment, machinery for production and post-harvest operations in food, feed, fodder, fibre, natural resins and gums.

Independent India started with indigenous manual or animal-driven agricultural tools followed by their improved precision versions. The farm mechanization got a real boost as a response to intensive cropping strategy during the Green Revolution resulting in a mass scale import and adoption of mechanically powered tools, equipment and machinery. As the technological advancements took place in cropping and resource management, the tractors and mechanically powered equipment made inroads in the agriculture. Research focus also reoriented from animal traction to mechanically powered equipment. The exponential growth in tractor sector during past three decades resulted in more than 7.5 million tractors

in the fields today and farm power availability increasing from 0.3 kW ha^{-1} during 1960 to 2.54 kW ha^{-1} in 2020. Along with tractors, significant growth in power tillers, combine harvesters, diesel engines and electric motors has also been noticed vis-à-vis positive crop productivity. India has emerged as the largest tractor producer in the world with about 0.8 million annual sales of tractors. The farm mechanization dominated by tractor powered improved implements and machinery has improved timeliness and precision in field operations, saved labor, inputs and operation cost besides 20% higher yield. The threshing of major crops is now completely mechanized and overall mechanization of primary processing of food grains is 68.2%.

India now produces a huge range of agricultural implements designed in the country with large pool of manufacturing industry. ICAR designed and developed machines, equipment and tools are also mass produced by the industries in the country. These developments during last couple of decades contributed to achieve 47% overall farm mechanization of crop production in the country. The needs of precision agriculture using artificial intelligence technologies is the emerging area for automated farm mechanization and post-harvest operations. This will bring precision while addressing the problem of scarcity of human labor.

Formal research in the field of post-harvest processing in India was initiated in third quarter of previous century with primary focus on minimizing post-harvest crop losses and later transformed into development of agro-processing technologies and value-added food products. Creation of new Ministry of Food Processing Industries in 1988 provided impetus to developments in this sector. ICAR has significantly contributed in development of mechanized processing and value addition of cotton, jute and other fiber crops that facilitated significant amount of exports. The utilization of crop residues and by-products for animal feed, production of organic manures and energy generation has taken a center stage during past decade. The technological interventions and infrastructure development have reduced post-harvest losses by 2% (compared to period 2005-06 to 2013-14)thereby saving about 30 Mt of foods annually.

The demand of precision machinery, equipment and instruments is continuously increasing. A wide array of new technologies such as automated hardware and software, autonomous ground vehicles, drones, GPS guidance, robotics, sensors and telemetric, clean and green energy, sensor-based harvesting, storage, smart packaging, non-destructive evaluation of food safety and quality are being developed. With the improvements in smart technology and digitalization, the future of agriculture machinery for food production and processing is highly promising. Large size of machines and their high operating costs are the major constraints for the small farms to switch from conventional farming to smart farming. ICAR's research focuses on development of affordable and reliable smart farm machines for small farmers. The future technology needs to be portable, plug-n-play type with better chances to be successful and sustainable. Advanced mechanization systems will play a significant role in quality agriculture production and post-harvest processing technologies for sustenance of agriculture in the future and ensuring not only food security but also nutritional security.

1. Introduction

Fig. 1. Sir C.V. Raman inspects the work of CIRCOT, Mumbai in mid-1950s

Agricultural mechanization, both pre- and post-production, has shifted from subsistence farming to robotics and artificial intelligence between the years 1900 and 2020. During the period from antiquity to around 1900, farming was done with manual labour with animal as power aid to some extent. Primitive and traditional artisan tools were used during this period. Tractors, implements, machinery and sprayers helped farmers during 1920 - 2010 through various research institutions (Table 1) to produce more with less effort. After ICAR took over the Technological Laboratory of Indian Central Cotton Committee in Mumbai, Jute Technological Research Laboratory Kolkata and Indian Lac Research Institute Ranchi the agricultural engineering work started in 1950s with introduction of improved agricultural equipment and machinery. The combine harvesters were introduced in Northern India at the beginning of green revolution and their number grew from 800 in 1971-1972 to over 50,000 at present. The farm technologies pushed agriculture into the economic edge and produced lots of commercial crops that have established new agri-businesses or industrial agriculture.

After the year 2010, agricultural mechanization and post-harvest processing entered the new age of technology called precision agriculture and post-harvest processing. Precision technologies help judicious application of seeds, fertilizers, chemicals, water, etc. Similarly, harvesting, packaging, transport, storage, processing and marketing using digital technology reduces the post-harvest losses to minimum. Presently, precision agriculture research is at initial stage and technologies such as sensor based embedded systems (soil nutrient, temperature, fertility, and moisture gradients), guidance systems (often enabled by GPS, GNSS, RFID), variable-rate input technologies (VRTs), automated machinery (automatic control and robots) and advanced imaging technologies (including satellite and drone imagery), NIR spectroscopy, hyper-spectral, X-ray and magnetic resonance imaging are being developed to map the variability and to manage it during field operations, threshing, storage, processing, quality evaluation and safety assessment in market yards.

The new digital farming (DF) or smart farming technology is focused on real-time agricultural data acquisition and decision making. The digital farming also integrates the concepts of precision farming, smart farming, and a wide range of technologies, most of them are having multiple applications along the agricultural value chain. These technologies include cloud computing/big data analysis tools including block chain and smart contracts, the internet of things (IoT), digital communication technologies (mobile phones), image processing and digital platforms (e-commerce, agro-advisory apps, e-extension websites). The government of India has planned to digitize farming system for sustainable agricultural productivity. Agricultural research institutions, universities, and other organizations are working on DF to solve various agriculture related problems.

The future agricultural engineering challenges are to stimulate right solutions for agriculture value chain through advanced technologies using the principles of precision farming involving equipment for unmanned operations and autonomous decision support systems (ADSS). It implies the use of robots and different forms of artificial intelligence (AI) platforms that can gather large amount of data from public websites. Presently, the AI based on machine learning (ML) and deep learning (DL) is not extensively used in Indian agriculture for automatic data acquisition, analysis, decision making and controlling the various tasks using different algorithm and mathematical models.

The AI with computer vision and robotics is able to build next-generation agricultural equipment, which can identify defects in fruits, vegetables and fibres, detect stresses in crops, assess nutrient deficiencies in soil, reduce chemical application and harvest high value crops. There is a growing interest in applying AI to develop smart farming practices to minimize yield losses in crops by early warning and secondary agriculture for utilization of complete biomass of a particular crop and commodity for developing high value and low volume products for agro-industrialization and enhancing employment opportunities in the sector.

2. Farm mechanization

The faster growth in mechanically powered equipment during past six decades significantly influenced crop productivity and established a direct correlation between farm power availability and food grain productivity. The mobile farm power sources (tractors, draught animals, power tillers, combine harvesters) as well as stationary power sources (diesel engines and electric pumps) have significantly contributed in growth of food-grains productivity in India. The percentage of agricultural workers to total workers in India declined from 59.1% in 1991 to 54.6% in 2011 and 39.4% in 2021. The draught animal population reduced from 78.42 million in 1971-72 to 38.74 million in 2018-19 resulting in reduction in the combined share of agricultural workers and draught animals in total farm power availability from 60.8% in 1971-72 to less than 10% in 2019-20. Total farm power availability from all sources during 1960 was 0.3 kW ha^{-1} and it increased to 2.54 kW ha^{-1} during 2019-20 (Fig. 2).

Net sown area per tractor reduced from 487 ha/tractor in 1975-76 to 18 ha/tractor by 2019-20 as population of working tractors rose to 7.5 million. In addition, power tillers, combine harvesters, diesel engines and electric motors increased to the extent of 0.50, 0.05, 11.50 and 7.50 million, respectively. The target of average farm power availability by 2030 is 4.0 kW ha^{-1} for timely and precise field operations.

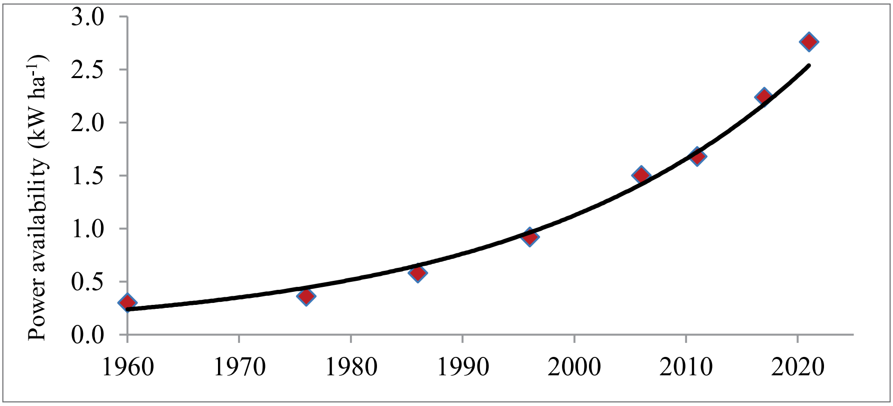

Fig. 2. Power availability (kW ha^{-1}) in agriculture over the years

The current level of farm mechanization assessed for major cereals, pulses, oil-seeds, millets and cash crops indicate that the seedbed preparation is highly mechanized (more than 70%) and harvesting is the least mechanized at less than 32%. About 65% of wheat area is mechanically sown but planting/transplanting of sugarcane and rice are mechanized only up to 20 and 30%, respectively. Harvesting and threshing of wheat and rice is 60% mechanized. The harvesting of cotton/jute fibre and lac crop is yet to be mechanized. The overall mechanization level is 69% in wheat, 50% in rice, 45% in maize, 41% in pulses, 38% in oilseeds, 35% in cotton and 33% in millets and sugarcane. The overall farm mechanization level in the country is 47%, much lower than China (59.5%) and Brazil (75%).

Numerous machinery/equipment for farm mechanization in independent India have been developed. The wheat thresher and combine harvester commercialized during 1960s played critical role in the success of the green revolution. The combine harvester also helped in timely harvesting of wheat during nation-wide lockdown due to COVID-19 pandemic. Some machinery developments like laser leveler, zero tillage equipment, happy seeder and inclined plate planter have become very popular in recent years.

3. Irrigation, soil and water engineering

The demand for foodgrains in India is projected to be around 355 Mt and 180 Mt vegetables by 2030 and strategies to attain them are water-intensive. India uses over 80% of its fresh water for agriculture, the efficient use of which is paramount. We also use water inefficiently through surface irrigation with an irrigation efficiency of about 40%. Micro-irrigation is an effective scientific alternative for higher irrigation efficiency of 70-90%. The evolution in micro irrigation during past two decades has broken the myth that this system is only applicable to wider spaced perennial horticultural fruit crops. The micro-irrigation has made inroads in field crops like wheat, sugarcane, vegetables, pulses etc. In some of the non-traditional areas like sand dunes of western Haryana, micro irrigation made wheat cultivation possible. In recognition of the importance of micro irrigation, the Government laid larger emphasis on it since 1992 and launched a scheme in 2006 which later upgraded into the National Mission on Micro-irrigation in 2010. Later in 2015, the micro-irrigation became the part of *PM Krishi Sinchayee Yojana* (PMKSY).

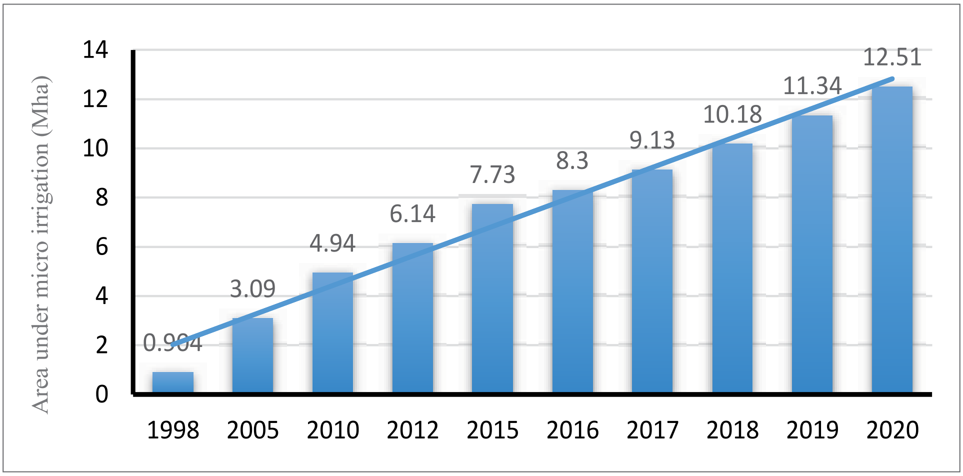

Fig. 3. Growth in the micro-irrigation over the years

Realizing the importance of 'more crop per drop' and complementing the ongoing developmental initiatives in micro irrigation, ICAR initiated research on micro-irrigation system for mango, guava and ber orchards as early as in mid-eighties. The infrastructure for testing of drip emitters and filters was created and large scale field demonstration installed on micro-irrigation systems and their overhead components for the benefit of farmers and other users of the technology. Sub-surface drip lateral laying machine and trencher for installation of main/sub-main pipes were developed by ICAR. The cumulative R&D efforts enhanced the area under micro-irrigation from 0.90 million ha (Mha) in 1998 to 12.91 Mha in 2021.

4. Post-harvest processing and value addition

4.1. Food crops

The post-harvest processing research in ICAR started primarily after starting ICAR-All India Coordinated Research Project (AICRP) on Post-harvest Technology in 1972 and there was hardly any scientific data for post-harvest losses during the period. The hand-operated winnowers were among the first primary processing equipment introduced during 1950-55. They were very popular for blowing away of lighter impurities after manual or animal-assisted threshing. This is the time when mechanized or industrialized rice milling was also introduced with cleaning and grading devices operated by motor or engines. The hullers, the main equipment used for milling of paddy were replaced by rubber roll sheller based rice milling during later years. The equipment like air screen cleaners, de-stoners, specific gravity separators and other pneumatic devices for efficient cleaning, grading of raw materials besides making them free from impurities like stones or metal scrap were developed by ICAR-AICRP on PHT centres and ICAR institutes and introduced in primary processing of durable commodities especially food grains. Adoption of imported colour sorters for rice got initiated by 1990.

The major technological interventions in the post-harvest processing remained limited to the crops like cereals, pulses and oilseeds and to a very limited extent in spices. In case of durable commodities, different types of mechanical and electric-operated grading devices were imported from Europe, America and Japan and installed in the organized-sector processing plants. During 1960s and 1970s, most of the states enacted and enforced Agricultural Produce Markets Regulation (APMR) Acts which introduced Agricultural Produce Market Committee (APMC) to frame the rules for marketing and standards for the sale of the produce under APMCs. Moisture content became an important quality standard of the produce. Initially, moisture measurement was carried out mostly using oven drying method.

In 1980s, the imported electronic moisture meters were introduced in Food Corporation of India (FCI) and *mandis* and the resistance type moisture meters became popular among FCI, Central Warehousing Corporation (CWC), State Warehousing Corporation (SWC) which are still used with certain amount of calibration. The 'bag in warehouse' type storage was made popular since 1950s and FCI, CWC and SWC helped in augmentation of storage capacity for food grains. In recent past many privately owned warehouses have been constructed with support of the government. This has helped in increasing the storage capacity during last one decade in organized sector.

Drying has been one of the major methods for preventing post-harvest losses. The most economical method for drying is open-sun drying. Use of plastic sheets for spreading of commodities for sun drying introduced in 1960s is still popular. Introduction of field dryers has been very limited to certain crops such as rice and some spices. The LSU type dryer for drying of rice was introduced in 1980s with limited popularity. In-bin drying has been used very sporadically and could not be made much popular because the majority of food grains and pulses are stored in bags rather than in the bulk storage modules.

In the area of milling, the flour making popularly known as '*atta-chakki*'; rice milling, dal-milling, oil-milling, and spice milling have become popular over time. Introduction of electric motor driven high capacity machines in place of manual grinding has been a major 'game changer' in the grain milling. The number of motor operated grain mills which was about 53,000 by 1970 increased over five folds by 2000. Roller flour mills were introduced in 1960s and their number reached to 200 by 1970. They became so popular that their number increased by 35 times by 2000. Introduction of hammer mills increased versatility of the machines since they could also be used easily for variety of products including spices and also for wet-grinding. In the decade of 1980 hammer mills of house-hold capacity were introduced in the market. Variety of gadgets was in use in different parts of the country to mill rice from paddy. By the year 2000 there were approximately 0.1 million hullers/shellers and about 30,000 modern rice mills in operation. In the year 2016 there were nearly 1.30 lakh modern rice mills in operation with significant contributions of ICAR scientists. The mobile mini rice mills operated by tractor PTO (power take off) have also been introduced in 2019 with input from ICAR institutions and collaborations with private companies.

Stones-based burr mills have been used traditionally for milling of pulses into *dal*. Emery roller mill-based machines were introduced at the time of independence and by 1950 around 500 *dal* mills were in operation. It was estimated during 2001 that there were around 12,000 *dal* mills in operation. The industry has been using custom made emery rollers for milling of *dal* and polishing of rice. In 2002, ICAR introduced use of pre-fabricated emery stones for *dal* milling, which is now popularized for both rice polishing and *dal* milling.

Extraction of oil from oilseeds involved use of animal driven cold presses (*Kachchi Ghanis*) during pre-independence and early post-independence periods. Gradual replacement of these with screw type oil expeller started in 1970s. In 2018, there were approximately 15,000 oil mills, 600 solvent extraction plants, 465 vegetable oil refineries and 250 hydrogenated vegetable oil (*Vanaspati*) processing units in operation. R & D work of ICAR institutes in improvement of processing and machinery in these fields are commendable.

The perishable horticultural commodities were not processed traditionally at commercial level except for drying, pickle making and some ready to eat products. Even the fresh products were handled in bamboo baskets, gunny bags or transported bulk in open carts or carriers. Large scale adoption of plastic crates for handling of fruits and vegetables started in late 1990s, whereas some fruits were packaged in wooden boxes/crates, the practice is still on. The cardboard/ paper boxes were also introduced for packaging of grapes and some other fruits and vegetables in 1990s. Research and development on post-harvest processing and value additions was in nascent stage for a long time in the country. It started with opening of some agricultural engineering colleges/departments in 1960s and actually has taken a lift during 1980s. The first and second systematic studies on 'harvest and post-harvest losses' were carried out by ICAR-AICRP on PHT in 2006 and 2014, respectively and average post-harvest losses in the ranges of 6-18 % and 4-16 %, respectively in 2006 and 2014 were reported. The third study for assessing harvest and post-harvest losses is under way by Ministry of Food Processing Industries. The interim reports, not yet publicly available, indicate that percent post-harvest losses have further reduced significantly due to technological interventions, infrastructural development and government policy implementations.

4.2. Fibre crops

4.2.1. Cotton

Cotton is the most important commercial crop as it provides 59% of raw material to the Indian textile industry and contributes 29.1% to the total textile exports. In terms of value, cotton contributes 4.9% to the value of agricultural output while the textile industry contributes about 4% to the GDP. In terms of exports, raw cotton is exported to the tune of 50-70 lakh bales while the textile industry is the largest exporter of cotton yarn (26.7%). At the time of independence, majority of domestic cotton production was short staple and almost 30% of our requirement was met through imports. Today we are the largest producer of cotton and the third largest cotton exporter in the world and more than 90% of cotton produced is of long staple. ICAR-CIRCOT Mumbai is a major technological partner in development of improved cotton varieties under AICRP on Cotton and contributes to the development of technologies in post-harvest processing of cotton. Mechanization in cotton cultivation and harvesting is at minimal level, while at primary processing level it is almost 100%. Several value added products, high value fabrics and machines for their processing have been developed and commercialized.

4.2.2. Jute and other natural fibres

The first jute mill in India was established at Rishra, on the River Hooghly near Calcutta in 1855 when Mr. George Acland brought jute spinning machinery from Dundee (UK). Four years later, the first power driven weaving factory was set up. By 1869, five mills were operating with 950 looms. Several issues and problems of jute were hindering the development of jute industries, and therefore, a Jute Technological Research Laboratory (JTRL) was established in 1939 in erstwhile Calcutta. In the nineties Govt. of India recognized importance of allied fibers and these were added in the mandate of JTRL and the institute was renamed as National Institute of Research on Jute and Allied Fibres Technology (NIRJAFT). Field preparation, seeding etc. operations are almost fully mechanized. Mechanization level in harvesting is almost nil while primary processing levels are more than 90%. Recently numerous value added products of natural fibres especially from flax, hemp and banana pseudo-stem have gained momentum in both National and export market.

4.2.3. Natural resins and gums (NRG)

Several forest products have significant importance in social and economic life in tropical areas. Non-Wood Forest Products (NWFPs) are more profitable than timber. In the recent decades, as a result of the international shift to multifunctional sustainable forest management, the interest in NWFPs has increased. Within this framework, the promotion and utilization of NWFPs is identified as a priority area by the FAO. The NRGs of commercial importance like lac (mainly from *Kerria lacca*), pine resin (*Pinus roxburghii Sarg*.), guar gum (*Cyamopsis tetragonoloba* L.), gum karaya (*Sterculia urens* Roxb.), dhawada gum (*Anogeissus latifolia* Roxb.), tamarind gum (*Tamarindus indica* L.), char / piyar gum (*Buchanania lanzan* Spreng.) and babool gum (*Acacia nilotica* L.) are produced in our country. India holds monopoly in international trade over some of the NRGs such as lac, gum karaya and guar gum. The NWFPs based on their chemical composition are classified in three categories namely natural resins, natural gums and gum-resins. Natural resins are solid or semi-solid materials, usually a complex mixture of organic compounds called terpenoids, which are insoluble in water but soluble in certain organic solvents.

Resins are secretion of several plants, particularly coniferous trees. India is among the leading producers of NRGs in the world, with an estimated output of about 2.80 lakh tons. India is the largest producer of Lac, Guar and *Karaya* gum. Besides these, large number of other minor gums are also produced in India and their production and processing research is spearheaded only by ICAR-Indian Institute of Natural Resin and Gums (IINRG), Ranchi.

5. Major milestones

Agricultural tools and techniques are being used for cultivation and processing since ages. Engineering interventions in non-food items such as cotton, jute, lac etc. were thought formally in pre-independent India by establishing research Institutes on these commodities. The formal education in agricultural engineering was initiated in 1942 by establishing first agricultural engineering degree programme in Allahabad Agricultural Institute, Allahabad. After independence country has seen several institutional milestones (Table 1) towards achieving agricultural mechanization and post-harvest processing and value addition.

Table 1. Institutional milestones in agricultural mechanization and post-harvest processing

Year	Milestone
1924	Technological Laboratory (TL) of Indian Central Cotton Committee (ICCC) established in Mumbai.
1924	Indian Lac Research Institute (ILRI) established at Ranchi, Jharkhand.
1931	Indian Lac Cess Committee constituted by Govt. of India.
1939	Technological Laboratory (TL) of Indian Central Jute Committee (ICJC) established in Kolkata.
1942	First Agricultural Engineering College established in Allahabad. (now Prayagraj)
1952	Agricultural and Food Engineering Department established at IIT Kharagpur, West Bengal.
1958	Grain Storage Research and Training Institute established at Hapur, UP.
1965	ICAR took over TL of ICJC and named as Jute Technological Research Laboratory (JTRL).
1966	ICAR took over ILRI and TL of ICCC and named as Cotton Technological Research Laboratory (CTRL).
1972	AICRP on Post-harvest Technology initiated and renamed in 2013 as AICRP on Post-harvest Engineering and Technology (PHET).
1975	AICRP on Farm Implements and Machinery initiated.
1976	Central Institute of Agricultural Engineering (CIAE) established at Bhopal.
1983	AICRP on Energy in Agriculture and Agro-based Industries initiated.
1986	Ginning Training Centre of CTRL established at Nagpur.
1987	AICRP on Utilization of Animal Energy with Enhanced System Efficiency initiated.
1988	Ministry of Food Processing industries set up.
1988	Agricultural Engineering Division established at ICAR Headquarter.

Year	Milestone
1988	AICRP on Application of Plastic in Agriculture initiated and now renamed as AICRP on Plastic Engineering in Agricultural & Environment Management (PEASEM).
1989	Central Institute of Post-harvest Engineering and Technology established at Ludhiana.
1991	CTRL renamed as Central Institute for Research on Cotton Technology (CIRCOT), Mumbai.
1996	AICRP on Ergonomics & Safety in Agriculture initiated.
1998	JTRL renamed as National Institute of Research on Jute and Allied Fibres Technology (NIRJAFT).
2007	ILRI rechristened as Indian Institute of Natural Resins and Gums (IINRG).
2019	NIRJAFT renamed as National Institute of Natural Fibre Engineering and Technology (NINFET).

5.1. Farm mechanization

Indian agriculture is typified with small land holdings distributed in 2-3 parcels within a village or two which make introduction of mechanization unviable and against 'economies of scale' for individual ownership of farm machinery. The improved manual tools and animal drawn farm equipment on individual ownership basis are best suited to small farms mechanization. For high-capacity farm machinery custom hiring mechanism is the tried and tested model taking deeper roots in the rural areas and getting popular. The medium and large farms, however, prefer individually, the advanced high-capacity farm machinery.

Technological milestones

1957	Crop threshers
1970	Combine harvester
1991	Zero till drill
1992	Inclined plate planter
2005	Laser guided land leveller
2010	Direct seeded rice drill
2017	Modified happy seeder

Though the degree of farm mechanization varies amongst the commodities and operations, the overall level of mechanization is about 47% in India. This could happen due to development and popularization of large number of self-propelled, power tiller/tractor operated implement and machinery. The technological advancements during last 75 years could be gauged from the fact that starting from a simple thresher in 1957 it reached to high capacity and energy efficient machinery such as laser guided land leveler, rotavator, planters, zero till drill, self-propelled rice transplanter, threshers and combine harvesters (pl see box). Not only that the machines were developed, the mechanism and institutions that enhance their reach to those who cannot afford these high-cost skill intensive machines individually was also established under custom hiring mode. Today very high-cost farm machinery such as combine harvester, sugarcane harvester, potato combine, paddy transplanter, laser guided land leveler etc. are being made available through custom hiring.

The advanced machines such as tractor operated laser guided land leveler, mobile phone-based remote controlled water flow pumps, air assisted sprayers, ULV sprayers, ultrasonic sensor-based sprayers, canopy sprayers and electrostatic sprayers have improved the efficiencies of water, sprays and thereby reduced their cost as well as pesticide requirement and pollution of soil and ground water.

The research in precision agriculture, digital farming, precision irrigation, AI powered machinery, drones, robotics, etc. has gained momentum further to enhance level of efficiency in pre-sowing, post-sowing and post-harvest operations. ICAR along with SAUs, IITs, NITs and some private organizations are developing technologies based on precision agriculture, digital agriculture and AI.

Numerous technologies, machinery, tools and gadgets have been developed, licensed and commercialized and their economic impact is more than Rs. 7210 crores annually besides social gains like easing of operations, improving comfort, health benefits, and income of stakeholders.

5.2. Irrigation engineering

The sector has achieved several technological milestones and attention of government in initiating numerous projects/ schemes (please see the box) in Independent India. To minimize the wastage of water in agriculture sector, the scientific methods of water application systems such as micro-irrigation is the game changer for better on-farm water management practices. ICAR institutes and AICRP centres have developed several irrigation scheduling, protocols, structures and systems for major crops of the country. Protocols for covered crop cultivation, use of plastics in agriculture, lining of channels, canals, and ponds are some of the major achievements during the period (Please see the technological milestone box). These systems are being adopted mostly in horticultural crops and of late in field crops such as sugarcane, cotton, wheat, chickpea etc. R & D work in water, soil conservation and irrigation systems picked up in 1960s. Sprinkler and drip irrigation systems were introduced in 1970s. The research findings and benefits reaped by the farmers in recent years clearly indicate the advantages of adopting micro-irrigation systems for higher water productivity, enhanced fertilizer use efficiency, reduced input energy and labour, etc. The average penetration rate of micro-irrigation in India is about 19%. In the year 2019-20,

Technological milestones

1948	First Multipurpose River Valley Project (Damodar Valley Corporation, Jharkhand)
1955	First Major Irrigation Project (Bhavani Sagar Dam, Tamil Nadu)
1967	First Masonry dam in Independent India (Nagarjuna Sagar Dam, Telangana)
1977	Introduction of low-density polyethylene plastic in irrigation system
1978	Beginning of marketing of drip irrigation system by Netafim, Israel in India
1985	Centrally Sponsored Scheme on use of plastics in agriculture
1996	Accelerated Irrigation Benefit Programme
2006	Centrally Sponsored Scheme on micro irrigation
2010	National Mission on Micro Irrigation
2015	Pradhan Mantri Krishi Sinchayee Yojna

about 11 lakh farmers have benefited by the adoption of these systems. During the last five years, an area of 4.8 Mha has been covered under these systems.

5.3. Renewable and bio-energy

Solar, wind, geo-thermal, bio-mass energy can fulfil around 33% and 75% of India's and rural areas' energy needs respectively. According to the Central Electricity Authority of India, about 50% of the country's power supply will be generated by renewable energy sources by 2030. Solar energy can be used in rural India, especially for agriculture and post-harvest processing and value addition. However, the fluctuating need of torque depending on the agricultural field conditions presents a major technical hitch. The use of batteries for storing and releasing power is another concern for long term use of solar photovoltaic (SPV) gadgets.

A Government of India scheme on "Promotion of Agricultural Mechanization and Machinery for In-situ Management of Crop Residue" has been implemented in the states of Punjab, Haryana, Uttar Pradesh and NCT of Delhi during 2018-22. Adding ex-situ management techniques would make these efforts more sustainable. Bio-CNG has emerged as an option for ex-situ management of crop residue. Biochar generation, briquette production and conversion into bio-crude are three major options for value addition to crop residue. Biomass-based electricity generation systems are already in use at national level. Thermo-chemical and bio-chemical conversion based electrical power routes are available and there is a need to promote these with better incentives. There is also a need to develop the energy efficient and cost effective techniques for use of locally available energy sources to make rural India energy self-reliant, and self sufficient.

ICAR institutes have developed gasification and pyrolysis systems, briquetting technologies, biomass-based electricity generation systems which effectively aid in the process of utilizing farm biomass and those are being adopted rapidly through various schemes and initiatives by the Governments and finally moving towards renewable energy self-sufficiency.

A biomass based decentralized power generation system was developed for converting crop residues into electricity. Complete package of technology has been developed/refined and demonstrated for utilization of crop residues to convert into briquettes and then gaseous fuel to generate electricity. The cost of electricity generation is on par with the tariffs of grid electricity for commercial application. Fuel cost of electricity generation for biomass based decentralized power generation is four times lower than the commercial diesel engine generating set.

5.4. Post-harvest processing and value addition

5.4.1. Food crops

Mechanization of post-harvest activities and value addition started with the technological advancements in agro-processing sector and boost in engineering innovations. The design of agro-processing machinery and IT application in agriculture has facilitated the growth of the sector. The labour demand during peak harvesting season required an intervention of mechanization for harvesting. Primary and secondary processing operations at field level have the potential to increase the basic income of the producer. The ICAR through its engineering and commodity-based institutes and AICRPs has provided game changing interventions especially for on-farm and/or cottage scale post-harvest processing industry. Machinery, equipment, tools, process protocols and new products for major commodities are available. Many of them are licensed and commercialized. Some technological milestones of the field are listed in the box. The economic impact estimation of a few technologies indicates that it has increased the income of users/manufacturers 1.5 to 2 times in a span of 3-5 years duration.

Technological milestones

1950s	Warehouses for bag storage
1950s	Rubber roll-based rice mills, roller flour mills
1960s	Metallic storage bin, mechanical winnower, solvent extraction of edible oil
1970s	Solvent extraction plants for soybean, food extrusion
1975	First hot air dehydrator for raisins, apricot, etc.
1980s	Electrical moisture meters, LSU dryers, Introduction of Agro-processing centers
1982	Frozen seafood & RTE meals
1988	Launch of SAFAL–organized retail network of fruits and vegetables
1990s	Introduction of colour sorter for rice
1993	Air Dried, Freeze Dried and IQF products
1996	First local brand of 100% pure natural fruit juices
1997	First Indian cold room as per international standards
2000s	Hermetic storage of food grains
2004	Non-destructive methods for food safety & quality
2004	Indigenous tomato and kinnow processing plant
2006	CIPHET-Evaporative cooled storage structure for fruits & vegetables
2012	Special horticulture train for fruits & vegetables
2013	Commercial unit of makhana popping machine
2020	Introduction of Kisan rail (dedicated train for perishables)

The share of the food processing sector is about 32% of the value-added food in grocery market and the annual growth rate is about 8% since 2014. The food processing sector is the fifth-largest industry in terms of production, consumption, exports and there is growth potential. However, there are significant losses at various stages of post-harvest operations. ICAR, conducted two nationwide studies to assess the post-harvest losses in the country during 2005-06 and 2014. The latest study revealed that nearly 4.7-6.0% of cereals, 4.6-15.9% of fruits and vegetables and 6.4-8.4% of pulses are lost annually which together valued Rs. 92,651 crores per year at 2014 prices. The increase in food processing level reduces these losses, thereby increasing income. The study also indicated saving of 2% post-harvest losses in 2014-15 as compared to 2006-07 means a saving of roughly 30 Mt of food and indirectly saving of invaluable natural resources and reduction in carbon emissions. The food processing sector is one of the most labour intensive sector and thus generates gainful additional employment.

ICAR pioneered the concept of Agro-Processing Centers (APC) since 1980 in production catchments by providing technical guidance and monitoring. These APCs have an impact in terms of reduction of storage and processing losses, higher recovery, cost saving, energy saving, timeliness of operation, premium price for better quality, maintaining hygienic conditions and improved comforts and social and economic wellbeing of different stakeholders. Two hundred and sixty APCs have been established through explicit intervention of ICAR, each of which generates direct employment to 4-6 persons and average annual profit of Rs. five lakhs.

5.4.2. Protected/covered crop cultivation

The Department of Chemicals & Petrochemicals, Ministry of Chemicals and Fertilizers, first considered the promotion and development of use of plastics in agriculture and irrigation for improving agricultural yields, quality of produce and improving input use efficiency in 1977. National Committee on use of Plastics in Agriculture (NCPA) was set up in 1981 to identify areas for use of plastics in agriculture, R&D programmes and to suggest plan for implementation. Plasticulture Development Centres (PDCs) were started in 1985-86. NCPA was transferred to the Ministry of Agriculture and Farmers' Welfare in 1993. NCPA was renamed as National Committee on Plasticulture Applications in Horticulture (NCPAH) and the PDC was renamed as PFDC (Precision Farming Development Centre). At present there are 22 PFDCs all over India.

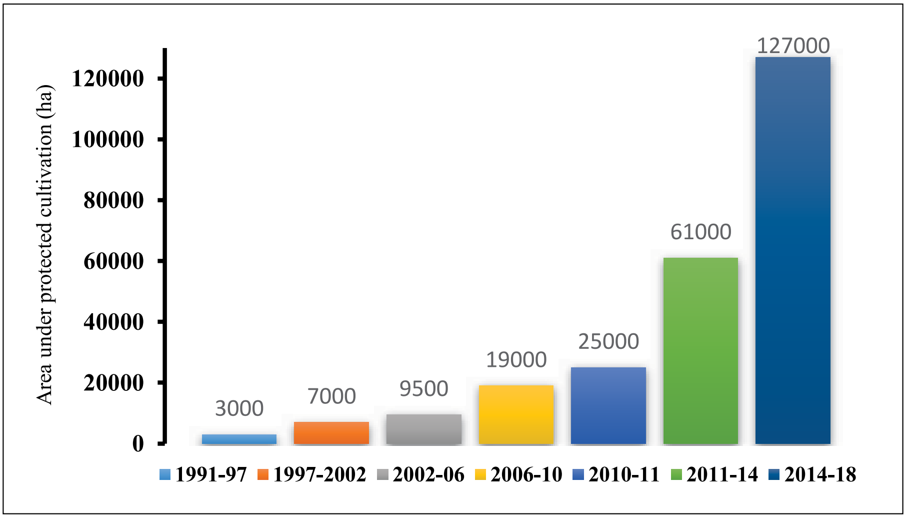

Fig. 4. Growth in the protected cultivation

ICAR initiated AICRP on Application of Plastics in Agriculture in 1988 which was renamed to AICRP on Plastic Engineering in Agricultural Structures and Environment

Management in 2021. The first polyhouse was designed and set up in 1985 at Leh (J&K). The greenhouse cultivation started during VIII plan with total area of 3211 ha. The total area under protected cultivation in 2018 was 2.51 lakh ha. On an average 80% area of protected cultivation is covered under plastic mulching and remaining under greenhouse, tunnel, shade-net and anti-hail net. ICAR has promoted extensive research to provide cultivation strategies, irrigation and fertigation scheduling, indigenized tools and machinery for various unit operations within polyhouse, shade-net house, low-tunnels etc. Benefits of plastic mulching have also been demonstrated. The scheme also effectively demonstrated and promoted plastic lined water harvesting tanks; and fibre reinforced plastic (FRP) carp hatchery for carp fish breeding, hatching and rearing of seed. In lean season, this system is being used for rearing of ornamental fish or common carp breeding and water storage.

5.4.3. Cotton mechanization and post-harvest processing

Ginning is the first step in post-harvest processing of cotton. Research and development in ginning and capacity building have brought down the trash content of Indian cotton to less than 5% and improved the quality. About 32% of the ginning factories have adopted the pre-cleaning system developed by ICAR-CIRCOT, Mumbai. As a result, the net benefit to the ginning factories due to bale value improvement and incremental ginning out-turn is estimated to be over Rs. 438 crores annually. The portable ginning machine has been adopted in market yards, by cotton breeders and seed companies for assessment of ginning percentage and fibre quality evaluation. It holds the key for implementation of lint-based marketing and to enable farmers fetch premium price for cotton with ginning percentage over and above 34%. One percentage increase over and above 34% ginning percentage will fetch the farmers minimum additional premium rate of Rs. 100/- per quintal of seed cotton. India is net exporter of the ginning machinery to the tune of Rs. 300 crores per year. ICAR has also aided technically to Indo-African Forum Summit in the establishment of "Regional knowledge cluster cum training centre for post-harvest processing and ginning technology" at Bohicon, Benin and helped in capacity building of over 200 stakeholders of African nations in cotton post-harvest processing and ginning activities. The bulk of the seed cotton (~66%) is cottonseed which is used as cattle feed but is a rich source (18-21%) of edible oil once the gossypol is removed from it. Till 1969 only 0.18 Mt cotton seed oil was produced and majority of the cottonseed

Technological milestones

1956	First lab model ginning machine
1961	Commercial ginning machine manufacturing
1987	First high volume tester (HVI) in India for objective testing of cotton
1996	Indigenous cotton pre-cleaner
1997	Indigenous calibration cotton (reference material) development
2015	First nanocellulose pilot plant of Asia at CIRCOT Mumbai
2016	Cotton based active wear
2017	Specialty grade cotton pulp exceeding currency paper specification
2019	Cotton crop residue-based crematorium

was being directly fed to cattle. The cotton seed crushing and oil extraction technologies helped increase in cottonseed oil production to about 1.4 Mt in 2020. It is contributing approximately 12-13% to the total domestic vegetable oil production with savings of about Rs 117 billion of foreign exchange. It has further scope of increase by 20% over the current level with adoption of scientific processing methods developed by the ICAR.

The annual cotton stalk biomass production is 25 Mt which can be converted into value-added products by improving supply chain logistics. ICAR-CIRCOT has developed a viable logistics model for supply of cotton stalks to industries which comprises of uprooting of cotton stalk, sun drying and shredding. The chipped cotton stalk can viably be transported to industries within the radius of 50 km. This model proved promising and adopted by farmers' groups in Maharashtra and Gujarat with average earning of about Rs. 5 lakhs @ Rs 1000/ton per season. Presently, about 10-15 lakh tons chipped cotton stalks are being supplied mainly to pelleting and briquetting industries. It is generating about 1 lakh man-days employment in rural India and Rs 100-150 crore additional income to farmers. A technology developed for preparation of premium grade pellets from cotton stalks using local binders in different proportions is also available. The premium grade cotton stalks pellets have 4150 kcal kg^{-1} heating value, less than 5% ash content and over 99% durability index and are also about 25-30% cheaper than saw dust pellets. To facilitate use of high ash cotton biomass pellets, ICAR-CIRCOT has developed specialized pellet stove and this stove and cotton biomass pellets are being used by several stakeholders.

5.4.4. Jute and allied fibres

India is the largest producer and consumer of jute in the world with 85% production used to meet domestic demand. The Jute Packaging Materials Act, 1987 makes it compulsory to use jute fibres for stacking in packing commodities. The pioneering work of ICAR-NINFET Kolkata on jute diversified products (JDP) and finer fibres with higher strength are in high demand for producing value-added products of jute. The JDPs are the area of future growth of jute industry. India's share in global exports of raw jute was 4.9% in 2018. Over the past ten years, the exports of jute and jute products have grown at an annual compound growth rate of 0.7%. The share of JDPs in exports has increased during the last five years, while share of jute yarn and hessian has declined. India has a great export potential as the demand for natural fibre is increasing. There is a need to improve production and fibre quality along with promotion of high-end value-added products.

Jute retting process has a vital role in producing quality jute fibre and ensuring better prices to farmers. The traditional retting technology causes severe pollution from anaerobic bacteria fermentation, putrid odour, pollution with higher cost. It requires large volumes of water which is constraint at farmer's level. Low volume water retting technologies NINFET-Sathi (an improved retting accelerator) and CRIJAF-Sona, (microbial consortium) developed reduce retting time by 6-8 days and water requirement by 50%; and improve quality of fibres by 1-2 grades and productivity by 10-12% besides reducing labour cost and enhance jute farmers' income.

The moisture regain during procurement is prescribed by JCI between 16-20%. ICAR-NINFET has developed digital moisture meter and digital instruments like semi/automatic bundle strength tester, digital fineness meter and digital colour and lustre meter which provide accurate and reliable results in recent years. Now-a-days JDPs have received greater attention in domestic and international market. ICAR has made significant contributions towards the development of fine yarn with reduced hairiness, ornamental yarns, and blended yarns, bleached and dyed yarns, decorative and fancy fabrics, non-woven fabrics to help promote JDPs.

Technological milestones

1962	The first fibre bundle strength tester
1968	Portable air-flow jute fibre fineness tester
2011	Digital multiple fibres grading instruments
2011	Nonwoven & bio-composite technologies
2016	CACP introduced digital instrumental jute grading system for MSP
2016	Natural fibre extractors machine
2016	Jute-Yak Blended fabric and products
2020	BIS standard for digital grading IS 271:2020

Other notable technologies are extraction of pineapple leaf, banana, flax and nettle fibres; development of home textiles using flax, nettle, banana PALF yarns; diversified jute nonwoven for agro and geo textiles; and bio-composite for automobiles and house hold furniture. The yak fibre is exploited for making of jute blended winter garments. Jute leaves are used to extract naturally occurring nutrient enriched bio-resource for health supplement beverages and natural personal care products. The leaf is rich in antioxidant properties (3/4th of tea leaves) and it has good DPPH (2,2-diphenyl-1-picrylhydrazyl), FRAP (Fluorescence Recovery After Photobleaching) and ABTS (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) scavenging properties. A protocol has been developed and patented for preparation of jute leaf-based drinks.

ICAR-NINFET Kolkata has developed activated carbons from jute (JAC) stick with diversified applications. The high surface area (1100-1250 m^2/g) activated carbons from jute sticks are utilized to treat polluted water with heavy metals like cadmium or synthetic textile dyes like reactive dyes, acid dyes or basic dyes which hold immense application potential for water treatment applications similar to commercially available products. For the first time, specially designed low surface area (200-350 m^2 g^{-1}) activated carbon derived from jute stick, are evaluated for its cleanup efficiency in a mixture of 181 multi-class pesticide residue testing food materials like okra, spinach, pomegranate and tea. The cleanup effectiveness showed superiority over the commercially available and non-renewable graphitized carbon black. It was estimated that JAC will be 1100 times cheaper than the commercially available activated carbon. Application of JAC therefore in food testing will reduce testing cost.

5.4.5. Natural resins and gums mechanization and post-harvest processing

Natural resins and gums (NRG) are low volume, high value produce. To promote the primary lac processing at village level, small scale lac processing units (capacity 100 kg day^{-1}) comprising of Lac crusher, Lac washer, Lac Grader and Lac winnower have been developed and commercialized. An integrated small scale lac processing unit (100 kg day^{-1}) has been developed for making seedlac, a semi-refined product thus reducing manpower requirement, time and drudgery. Lighter coloured seedlac with wash water having dye content above 50% compared to 30-35% dye from conventional process is obtained. Tamarind gum possesses numerous dynamic properties but due to requirement of heating/ boiling to get clear solution, its exploitation was limited. To make it cold water soluble, a new method has been developed through which purification is achieved in less time with significantly high yield (70-75%). The purified gum retains all the properties of native gum with improved solubility. Guar gum derivatives have been synthesized by semi-dry and non-aqueous method which involves eco-friendly and non-toxic organic solvent. The derivatives are - *Carboxy methyl (anionic, Hydroxypropyl (non-ionic), Hydroxypropyl trimethyl ammonium chloride (cationic).*Lac-based coating formulations for fruits, vegetables, seed spices, paper packaging; lac wax policosanol-based plant growth regulator formulation, natural nail shine, lac dye based natural *alta*, jute lac based bio-composite board, gum based silver nanoparticles, novel super absorbent hydrogels, dietary fibre from gum Arabic and guar gum, gum ghatti and guar gum hydrogel based nanoparticles for wound healing, herbal *gulal* from *Palas* flower have been developed. Gummy mass (GM) is prepared from effluent which comes out during industrial manufacturing of Aleuritic acid and constitutes about 80-85% of lac resin. The GM was modified with natural as well as synthetic resins and utilized in manufacture of tackifier and natural adhesive for *Agarbatti*, thermal resistant insulating varnishes, fibre-glass reinforced sheets and in particle board as a binder adhesive.

Technological milestones

1992	New colour variant of lac insect 'cream'
1998	Rearing of lac insects away from plant-host
2000	Yellow trivoltine lac insect
2002	Small Scale Lac Processing Unit
2007	National Lac Insect Germplasm Centre
2008	Early *kusmi* intensive lac cultivation on bushy plant *semialata*
2008	Late *kusmi* lac cultivation on *ber*
2010	Small Scale Integrated Lac Processing Machine
2015	Lac Integrated Farming System Model
2015	Process for dewaxed decolorized lac
2019	Process for cold water soluble tamarind seed gum
2020	Lac based formulation for fruits and vegetables coating
2021	Jute-lac based bio-composite

6. Adoption of implements, equipment and technologies

ICAR has licensed key farm equipment designs to large number of manufacturing industries for mass production enabling large scale adoption of the products by farmers. The most impactful technologies have made a significant impact on Indian agriculture in terms of visibility, spread and increasing net returns of farmers (Table 2). The economic gains of the technologies mainly derived from (a) reduction in cost of operation owing to enhanced operational efficiency and saving of input cost on seed, fertilizer, labour, etc.; and (b) yield gains due to increased input use effciency. The cumulative economic impact of selected only five farm machinery technologies is around Rs. 7032 crore per annum.

Table 2. Economic impact of some equipment and machines

Name of equipment	Adoption (No. in lakh)	Returns/annum in 2018 (Rs. in crore)
1. Cono weeder	2.50	2612
2. Paddy drum seeder	0.65	3020
3. Inclined plate planter	1.00	1157
4. Animal drawn 3 row planter	0.70	128
5. Twin wheel hoe	1.50	115

6.1. In-situ management of crop residues

The Government of India scheme on *in-situ* management of crop residue in the states of Punjab, Haryana, Uttar Pradesh and NCT of Delhi was implemented from 2018-19 to 2020-21 to check burning of crop residue in fields and thus address the issues/problem of air pollution. ICAR's interventions helped in reduction in burning of paddy residue by more than 52% in 2019 as compared to 2016.

Fig. 5. Machines for in-situ management of crop residues

6.2. Inclined plate planters

The inclined plate planting mechanism was designed to pick-up single seed and to maintain seed to seed spacing. After vigorous testing on farmer's field, the designs were released for use by farmers and licensed to industries for mass production. The tractor and animal powered models of inclined plate planter with multiple adjustable row spacing improved precision in planting of major crops like groundnut, gram, soybean, maize, sorghum, pearl millet, pulses, mustard, cotton etc. Inclined plate planter use on Broad Bed and Furrow

(BBF) system of cultivation became very popular in dryland agriculture owing to its benefits in soil moisture conservation and precision seed placement. More than 1.0 lakh units have been adopted by farmers for own use and custom hiring. The planter was used for irrigated Bt cotton sowing in last week of April to mid of May under very high temperature which requires 12 cm deep seed placement and 4-6 cm soil cover on the seed. This was successfully adopted in Haryana during 2006 through custom hiring services. The monetary benefits accrued to the country due to this technology have been estimated as Rs. 1157 crore/annum.

Fig. 6. Inclined plate planter

6.3. Threshers and combine harvester

The combine harvesters were commercially introduced during 1970s and have become very popular during last two decades. Prior to it, the famous tractor drawn Ludhiana thresher for wheat was introduced during 1956-57, which threshed, cleaned and bagged the grain and simultaneously made the quality straw (*bhusa*). This followed the development of low horsepower threshers from 1965 onwards. The most widely used simple design of spike tooth cylinder thresher with reduced weight and lower cost with higher output capacity was commercially marketed in the country around 1970. These threshers are available in various sizes operated by 30-40 hp tractors. Power threshers for rice with high grain output at lower operation cost were developed for different output capacity of 20, 45, 500 and 1200 kg/h. Japanese pedal type threshers and 5 hp axial flow thresher were also introduced for small farm holders. Introduction of power threshers reduced threshing time and saved 15-20 person-h ha^{-1}. The new designs of rice threshers can also handle wet or high moisture crop and thresh 4.0-5.0 q h^{-1}. The multi-crop thresher designs were introduced in the country and are commonly used. Some important threshers developed for rice included CIAE multi-crop thresher, IRRI-Pant thresher, PAU paddy thresher, VL paddy and multi-crop thresher, TNAU paddy thresher (Rasp bar type) and APAU all crop thresher. Now-a-days, multi-crop and crop specific high-capacity threshers have been commercialized and are used by farmers. Introduction of combine harvesters and power threshers had a significant stake in timely threshing and saving huge field and threshing yard losses of harvested crop.

6.4. Mini dal mill

ICAR-PKV mini dal mill was developed during 1986-1990 and several improved models have come thereafter. The commercial production of this mini dal mill was started in 1990. Presently 31 authorized manufacturers are involved in its commercialization with average annual production of 900-1000 units. Total number of machines manufactured till date authorized manufactures is more than 7,000 units making economic gain in crores of rupees annually.

6.5. Tomato processing, kinnow waxing and grading plant

The ICAR designs of tomato processing and kinnow waxing-grading plants have been adopted throughout the country. The kinnow waxing-grading-packaging plants in Punjab and Rajasthan cut down the losses by 50%. So far about 100 kinnow waxing plants are operational in Abohar and Ganganagar regions. There are also small mobile units available in the market as per demand. This technology enhanced shelf-life of kinnow by 50-60 days in addition to improving shining that fetches better market price. This also enabled capturing long distance markets of Delhi, Tamil Nadu, Karnataka, Maharashtra, Gujarat and NEH region and exports to Dubai, Bangladesh, Indonesia, Philippines and Russia.

6.6. Pedal-cum power operated air screen cleaner

About 1300 units of a medium-capacity pedal-cum-power operated air screen cleaner developed for separation of foreign matter from agricultural grains have been sold by the licensed manufacturers. Considering a capacity of approximately 5 q h^{-1}, annual use of 350 h for each machine and value addition of Rs. 150 q^{-1}, the direct benefit due to use of these machines comes to about Rs. 35 crores, besides there is indirect benefit of reduction in transport and storage losses.

6.7. Octagonal hand maize sheller

A fin type hand maize sheller is a light weight simple device to remove maize grains from the dehusked cobs. One person can shell 18 to 22 kg h^{-1} grains as compared to 10.5 kg h^{-1} in the traditional method causing physical drudgery. It saves about 3.5 h per 100 kg of shelling and results in saving of Rs. 87 q^{-1}. The design has been licensed to industry which has sold about 47650 units with monetary benefits of Rs. 10.90 crores/annum.

6.8. Makhana popping machine and value added products

The traditional processing of *makhana* seed for popping is laborious, painstaking, drudgery prone, smoky, and unhygienic and requires a specialized skill. ICAR-CIPHET Ludhiana developed complete electronically controlled line of *makhana* popping machine that produces improved quality of *makhana* than that of traditional method. The design has been licensed to three industries for mass production and so far ten plus plants have been established in Bihar and other states of the country. The demand for machine popped *makhana* is increasing continuously due to better hygiene, product quality and storability. An additional income of Rs. 105 crores have been generated. This technology

Fig. 7. Makhana popping machine

has positive impact on 10% annual growth in area expansion of crop. The developed value-added products such as instant *makhana kheer* mix, fat free flavored *makhana,* etc. have also been licensed to more than 5-6 entrepreneurs and created about 40% more demand of *makhana* and its value-added products in national and international markets.

6.9. Retting technology of jute and mesta

The retting technology (NINFET-Sathi) developed by ICAR-NINFET has been included in Government Schemes like, Jute-ICARE Scheme, NFSM (CC) and SCSP and enabling its large scale adoption by farmers. During 2018-21 the technology reached to 25,000 farmers under the scheme. It has been earmarked as one of the 'flagship technology' by ICAR by identifying it for mass media awareness campaign. The grading system of jute was adopted by the Bureau of Indian Standards (BIS) in 2003 as it was earlier done by highly subjective visual and feel method that deprived farmers from quality based remunerative price. This technology facilitated the recommendation by CACP, Government of India to reduce number of grades from eight (TD-1 to TD-8) to five (TDN-1 to TDN-5) and adopted TDN-3 as basis for MSP recommendations. The Bureau of Indian Standards (BIS) has notified the new grading system (IS271:2020) based on ICAR work during 2020. The development and promotion of jute diversified products (JDPs) have been well adopted by entrepreneurs. About 22000 youth were trained who in turn created small scale enterprises in the country for the manufacture of environment friendly products. The share of JDPs in total exports of jute products increased steadily from 32.5% in 2017-18 to 43.4% in 2019-20. India is now trade surplus country in jute products with annual export growth rate of 1.9% during the last 10 years.

6.10 *Kusmi* lac cultivation on *semialata* and *ber*

Technological intervention by ICAR in natural resins and gums using suitable lac insect-host plant combinations has significantly increased *kusmi* crop production on *ber* leading to price gain of about Rs. 180 kg^{-1} because of improved product quality, thus yielding Rs. 130 million additional annual returns to farmers. Similarly, technology of intensive lac cultivation of early *kusmi* breed on *semialata* for sustainable production has led to 8 folds increase in area of *semialata* plantation during last one decade. At a conservative estimate of yield of 12 q ha^{-1}; an additional 5676 q lac valued at Rs. 102 million is produced every year. Small and medium lac processing plants and value-added products of natural resins and gums are proving a major source of livelihood for different stakeholders involved in the lac producing states of the country.

7. Way forward

7.1. Sensors, robotics and drone-led automation and mechanization

Precision farming technologies based on micro-processor and decision support systems for enhancing input application efficiency in production agriculture has been initiated at ICAR.

The project aimed at development of micro-processor-based precision equipment for site-specific precise application of inputs such as seeds, fertilizers, herbicides and water. The research in this area was initiated during 2009 and continued later under CRP on Precision Farming. A few potential precision agricultural technologies such as ground speed sensor based fixed rate seed cum fertilizer drill, low cost SPAD meter, spectral reflectance (NDVI) based fertilizer applicator, uniform rate sprayer, real time soil moisture-based sprinkler irrigation system, automatic irrigation system for rice, automatic yield monitor for indigenous combine harvesters etc. are some of the strategic research components.

Fig. 8. Low cost CIAE SPAD meter for input management

The ICAR is geared to address the future challenges in agricultural engineering research and includes application of AI and IoT based appropriate technologies for timeliness, precision, maximizing input use efficiency, reducing losses, value addition and conserving energy and natural resources. The emerging smart agriculture mechanization is combination of precision farm management tools (GPS/GNSS, DSS, and VRT), end user applications (apps, mobiles, machines, Agri-bots) and data solutions (data IoT, information, and tech empowered tools). These technologies not only make agriculture machinery smart and efficient but also help making agriculture more sustainable. The focus will be on development of precision machinery for improved input use efficiency; autonomous guidance and real time monitoring system for tractors, power tillers and self-propelled machinery; application of drones for spraying and crop health scouting; AI and IoT-based smart irrigation and fertigation systems for field and horticultural crop; agricultural robots for harvesting, post-harvest handling of crops and commodities.

Future agriculture will be dominated by precision systems using cloud-based data systems supported by smart tractors, unmanned aerial vehicles, wireless technology and unmanned autonomous vehicles for multi-purpose field works. The focus will be on simplifying these technologies with cost-effective features enabling higher adoption.

7.2. Fruit maturity testing

The visible and near infrared (VIS and NIR) based 'on-tree non-destructive techniques' for quick detection of maturity and ripening stage for mango has been developed for on-site/on-field application. The technology has been granted a patent and licensed for commercial use. This is a first model in the country and requires further research and development for wide adoption.

Fig. 9. Determination of maturity of mango in tree

7.3. Automation in quality detection

Image processing based graphic user interface (GUI), a MATLAB based application has been developed for determination of color values, browning index and freshness of selected commodities. Quality sensing system for predicting the quality in terms of the freshness and spoilage of packaged mushrooms has been developed under MAP environment using LED indicators. This system works on the principle of correlation of carbon-dioxide concentration with colour and microbial quality parameters with 84-87% accuracy.

7.4. Fruit sorter and grader

Mechanized sensor based automatic as well as semi-automatic sorters and graders for fruits and vegetables have been developed. The machine uses sensors to accept or reject a product using its colour and is able to carry out real time sorting of spherical horticultural produces based on weight and colour with real time sorting efficiencies 88% and 92%, respectively.

Fig. 10. Fruits sorting and grading machine

7.5. X-ray based fruit scanning device

X-ray imaging techniques are gaining popularity in agriculture and food quality evaluation. These techniques are commonly used in medical applications but now being explored for internal quality inspection of various agricultural products non-destructively. Although, there is concern of safety of operators and testing time, the non-destructive nature of these techniques have great potential for wide applications in agricultural produce. The X-ray machine has been developed for the internal quality inspection of mango; now machines are being developed for other commodities such as gherkins, corns, etc.

Fig. 11. X-ray machine for internal quality inspection of mango

7.6. Acoustic detection of insects

Detection is the basic step in any insect pest management system. Stored grain pest cause huge losses and is one of the serious issues. Early detection of pest in storage can save the damage. Several detection methods are available to detect insects at different stages of their development. The acoustical detection of sound emerging from insect activities like feeding and crawling was used to monitor internal and external movement of bruchids. The result corroborated that bioacoustics detection technique with ANN may be a reliable monitoring technique for bruchids in storage in the coming years.

7.7. Sensor assisted fumigation chamber

Completely automated, leak proof chamber for fumigation (SO_2 & CO_2) of grapes and standard operating procedure (SOP) of treatment protocol was developed by ICAR. The fumigation chamber with capacity 1.5 ton grapes per batch is commissioned at M/s Sahyadri Farm, Mohadi, Nasik, Maharashtra state for export of grapes to New Zealand and Australia. The technology needs upscaling for effective commercial application.

7.8. RFID-based quality tracing system for environmental monitoring and supply chain management of agri-food products

A radio frequency identification device (RFID) based quality tracing system for real time monitoring of environmental parameters like temperature, RH, ethylene gas in the vicinity of food products stored in cold stores/warehouses and ripening chambers has been developed. The system is integrated with a temperature sensor (-40 to 80 °C), RH (0 to 100 %) and ethylene sensor (0-2000 ppm). The system is sensitive towards ethylene generations by various food products especially perishables (Banana, Tomato, Guava etc.) and is suitable for monitoring deviations in environmental parameters. It can also be utilized for tracing origin and movement using IoT and block chain technology. It requires further research to use the technology for multiple commodities in the country.

7.9. Sensor-assisted vacuum hermetic fumigation for stored grains

Vacuum Hermetic Fumigation (VHF) is a hermetic based technology in which vacuum is utilized for modification of the interstitial atmosphere of the storage ecosystem. Vacuum reduces the water vapour and oxygen content of the storage ecosystem that kills the insect due to hypoxia and dehydration. The vacuum of 100 mm of Hg was found suitable for killing insects within three days. Although for storage of longer duration requires 300 mm of Hg for effective insect control. The VHF is effective against all life forms of insects i.e., egg, larva, pupae and adult. The flexible hermetic bags made of PVC are available in market at an affordable price and these bags can be used for VHF storage. The flexible bags shrink over the stored commodities due to vacuum. Regular maintenance of the vacuum level is very critical for successful storage under VHF. The sensors and actuators would be useful for automation of such VHF storage systems. The VHF stored food grains are without any fumigants hence the market acceptability is comparatively high. The VHF can be used in combination with the carbon dioxide, biogas and botanical derivatives for enhanced protection against insects during storage.

7.10. Sensor-based rapid food quality and safety detection

Hyperspectral imaging (HSI) is one of the advanced methods of assessing quality, safety and authenticity of the food. The spatial and spectral information obtained for a food sample via HSI requires rigorous computation task and data mining. Protocols for rapid detection of aflatoxin-B1 (25 to 500 ppb) in maize have been developed using Vis-NIR hyperspectral imaging. The pioneering work on non-destructive methods for quality evaluation of mango using NIR and colour has been granted a patent to ICAR-CIPHET in 2019. It is on 'Methods of Predicting Maturity Stage and Eating Quality of Indian Mangoes using Near Infrared Spectroscopy'. Spectral models/algorithms have been developed for determining quality parameters and maturity index of mango using NIR spectroscopy. Some major contribution includes IR Model for banana quality, mango sweetness, authentication of mango variety, mango maturity, and adulterants including aflatoxins in milk and fruit juices. Current projects with focus on automation based on image processing include automatic insect detection in grains and development of automatic machine for grading/ sorting of pomegranate and tomato. Adulteration in chick pea flours or besan using NIR spectroscopy has also been developed. ICAR institutes have facilities and capabilities to excel further in application of spectroscopy field in food quality and safety. Web based application for smart mobile phones in this era of ICT are getting momentum. Virtual demonstrations, trainings, problem solving and status monitoring of any commodity remotely are the needs of the hour.

8. Conclusion

The past of on-farm mechanization and off-farm mechanization have been significant and added value in food, feed, fodder, fibre, natural resins and gums. Some important achievements include a mass scale adoption of rotavator, laser guided land levelers, zero till drill, paddy drum-seeder, seed-cum-fertilizer drills, inclined plate planters, micro-irrigation systems, combine harvesters, threshers, mini dal mill, maize sheller, *makhana* popping machine, accelerated jute retting system, diversified jute products, cotton ginning technology, small and medium lac processing plants, non-destructive diagnostic tools and methods for fruits and vegetables *etc*. ICAR's engineering technologies have improved socio-economic status of populations many folds and are driving force for numerous start-ups that are not only generating employment but also enhancing comforts and making the Indian agriculture gender friendly.

Indian agriculture needs reimagining. The way we have been looking at and practicing agriculture must require a change. The current and future demand and supply side challenges and opportunities have to be factored in while developing the future plans of R&D in agriculture and more so in agricultural engineering. The new agriculture demands a much sophisticated and efficient mechanized option for improving precision in production, post-production and marketing and trade operations.

ICAR's agricultural engineering research program has yielded significant results and has impacted manifold positively delivering new technologies that have been commercialized and adopted by the farmers. The future of agriculture revolves around producing and processing locally and trading globally. The improving of productivity and sustainability shall involve adoption of new age tools of sensor technology that leads to improved precision and automation using robotics, drones and AI for quality production and postharvest operations. The agri-robotics, sensor technology, and artificial intelligence will have to be integral component of new agricultural engineering program. The tangible socio-economic impact of various mechanization and post-harvest technologies to farmers and other stakeholders also calls for more attention on these fields which somehow, took backseat in the past. It now requires focused efforts with greater allocations and spreads in manpower for fulfilling accelerated demands in very near future. The present farmers and farming want ease of doing operations, automation, efficient but cost effective agricultural tools, implements and machineries. The post-harvest sector is even challenging but full of opportunities. The agri-food system is needed to be considered in entirety rather than pieces.

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CIAE high clearance multipurpose vehicle

CIAE real time uniform spraying system for field crops

13
Chapter

Achievements in Agricultural Education in Independent India

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Summary

The first ever structured attempt to induce higher agricultural education based on scientific learnings and research came into being in India during 1901-1905 with 6 agricultural colleges established in different parts of the country. Later, in 1929, the Imperial Council of Agricultural Research was established. Post-independence following the recommendations of the first Joint Indo-American Team 1955, the establishment of SAUs on the land grant pattern of USA took place. Since then, agricultural higher education underwent several changes as number of state agricultural universities were established. Today, India, with 74 Agricultural Universities (AUs) comprising State Agricultural Universities (SAUs), Deemed Universities (DUs) and Central Agricultural Universities (CAUs) is one of the largest agricultural research, education and extension systems globally. The uniformity, assessment, maintenance and strengthening of standards and quality of higher agricultural education through institutional mechanism has been put in place by ICAR for human resource development and quality reforms.

1. Introduction

Our ancient text viz. Bhagavad-Gita, Rig Veda and Atharva Veda contain very specific details on agriculture like crops, their cultivation, manuring, classification of herbs and information on different varieties of plants. People started the agricultural practices such as ploughing, sowing, reaping and harvesting on auspicious days as these were linked with religious customs and also studied the nature of crops and plants, through proper understanding of weather and monsoons. Unlike the modern techniques, in ancient times Indians used to perform *yagnas* or *homas* before farming which they believed helped them to increase yield. *Krishi Parashar (Krushi Prasha-1)* with two hundred and forty-three verses is the theory of agriculture expounded in manner so as to benefit the farmers. It mentions symbiotic relationship, organic farming techniques, crop management, holistic farming or rather sustainable use of available resources. Vrikshayurveda (Nene 2012) means Ayurveda which deals with the science of plant life such as procuring, preserving and treating of seeds before planting, selection of soil pH, nourishments and fertilizers, plant diseases and plant protection from internal and external diseases etc.

The Chenab colony served as the richest agricultural hub in Punjab. Different innovative enhancements, for example, the utilization of high return assortments of seed, more effective gear and apparatus, enhanced water system framework, better animals, new methods of development e.g., a superior arrangement of pivot of harvests, utilization of manure, control and keeping away from yield maladies and a superior marketing framework for agrarian items existed. New cash crop culture, growing of tobacco, sugar stick and cotton emerged. The approach of the administration was exhaustive and the government was keen in the agricultural produce of the land and hence an Agriculture college and research institute was established at Lyallpur in 1909 (now Faisalabad, Pakistan).

The need for modern day higher agricultural education was felt after witnessing the impact of availability of trained human resources for technology driven increase in food grain production in the early years of green revolution. This led the state governments to set up agricultural universities. Human resources have played an important role in attaining the self-sufficiency, food security and surplus food grains, in the face of continuous challenges. An effective and functional higher education system is vital for building human capital and trained manpower for fore sighting of the emerging problems and provide matching cost-effective solutions.

Dr. Zakir Hussain, the then Vice-President of India, at IARI Campus for the 2nd Convocation Address (1962)

Technology of dwarf varieties of wheat and rice, modification of their grain characteristics according to the needs of our chapatti making and phenomenal rise in production of food grains leading to self-sufficiency was possible only due to the excellent collaborative efforts of agricultural scientists, extension workers, receptivity of farmers and policies of government. Therefore, Green Revolution was the time in India's history during which began the introduction of technology and transformed agriculture into a modern agricultural systems. Since then, the trained human resources availability not only increased the production of food grains but also milk, egg, fish, meat and vegetables and have played an important role in attaining the self-sufficiency, food security and surplus food grains, in the face of continuous challenges. The need for an effective and functional higher education system was therefore considered vital for building human capital and trained manpower to meet the challenges that agricultural sector faces. The major impact was that by 50th anniversary of India's independence, the yield revolution was observed and in wheat from 29 million ha of area under wheat cultivation in the country, 96 million tons was produced (Swaminathan 2013).

Table 1. Major milestones in higher agricultural education

Year	Milestone
1948	First University Education Commission of India to review all higher education.
1955	Report of first Indo-American team proposal to the Government of India for establishing Land-grant style universities.
1958	Deemed University Status to IARI.
1960	Report of second Joint Indo American Team on agricultural research, education and extension to frame specific proposals for the third five-year plan.
1960	Emergence of SAUs, starting with Pantnagar, based on the recommendations of Joint Indo-American Teams (7 SAUs established by 1964).
1962	Report of Cumming's Committee to advise state governments on the legislation for establishment of agricultural universities.
1965	Standing Committee on Agricultural Education replaced the Education Panel.
1965	ICAR reorganization with four Divisions including Agricultural Education.
1965	1st Deans' Committee constituted.
1966	Report of the Education Commission (1964-66) for establishment of agricultural university in each state.
1966	First Model Act developed by ICAR for uniformity across agricultural universities.
1966	JRF initiated for M.Sc. Students.
1973	Second reorganization of ICAR with the establishment of Department of Agricultural Research and Education (DARE) to provide greater autonomy to ICAR, and Regional Committees to take care of regional needs, and creation of Agricultural Research Services (ARS) and Agricultural Scientists Recruitment Board (ASRB).
1974	Norms and Accreditation Committee (NAC) replaced Standing Committee on Agricultural Education.
1995	Agricultural Human Resource Development (AHRD) project, with World Bank Support, launched (ended in 2001).
1994	Centres for Advanced studies established.
1996	International Scholarships started.
1996	Establishment of Accreditation Board for Higher Agricultural Education replacing NAC.
1997	Initiation of All India Entrance Examination for Admissions.

Year	Milestone
1998	ICAR initiated Post Graduate Scholarship (PGS).
1999	ICAR initiated National Talent Scholarships (NTS).
2006	Niche Area of Excellence started.
2008	1st Broad Subject Matter Area Committee (BSMA) constituted for revision of PG courses.
2015	Student READY Programme launched.
2016	Post-Doctoral Fellowship initiated
2016	Declaring the UG degrees in agriculture and allied subjects as Professional Degree Courses.
2017	Initiation of Ranking of agricultural universities. National Agriculture Higher Education Project implemented.
2021	Implementation Strategies of National Education Policy-2020 in Agricultural Universities by ICAR.

2. Evolution of Higher Agricultural Education (HAE) in India

Higher education in agriculture was not much in demand before independence. In 1876, the Madras Veterinary College was started in Chennai to offer diploma and certificate course in veterinary and animal sciences. Later in 1903 it attained the status of a college and got affiliated to University of Madras in 1936. The first ever structured attempt by British Government for higher agricultural education was made during 1901-1905 when 6 agricultural colleges were established at Coimbatore, Kanpur, Layallpur (now in Pakistan), Nagpur, Pune and Sabour. In 1927, Bihar & Orissa Veterinary College was established having the distinction of being the 5th oldest veterinary college of undivided India. The college started functioning from 7 April 1927 and became fully operational in 1930 and was known for its research in various branches of veterinary medicine and disease control. In 1948, only 17 agricultural colleges (13 Agriculture, 3 Veterinary and 1 Agricultural Engineering) existed in India with facilities for training of only 160 postgraduate research students (Randhawa 1986).

After independence, a need was felt for a scientific and pragmatic policy to reconstruct higher education including agricultural practices. This became imminent with the appointment of University Education Commission in 1948 by Government of India. The commission gave the concept of rural universities, thereby opening the way for setting a new pattern for initiating agricultural education. However, the setting up of SAUs became a reality only after the recommendations of the first Indo-American Team in 1955.

Relationship of Indian Agricultural Universities with the U. S. Land Grant Universities, started with the USAID program, that started in India in 1955, was on a regional basis for agricultural education. The trend one Agricultural University for each state took shape in 1960 and all AID support was on a state basis. By the year 1968, there were eight agricultural universities being assisted by the agency for International Development through 6 US Land Grant Institutions. This university-to-university relationship became the bridge to scientific and cultural understanding between two great democracies. These relationships

Box 1: Report of first Indo-American Team- Set up Universities on the Land Grant pattern


Inauguration of the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar by the then Prime Minister, Pandit Jawaharlal Nehru

Education Commission of India (1948) headed by S. Radhakrishnan had recommended setting up rural universities in India on American land-grant pattern as a solution to solve the problem of lack of university education in rural India. The Government of India, in view of growing food shortages however, approached United States Technical Cooperation Mission for solution. Consequently, a Joint Indo American Team was constituted in 1954 (Tamboli and Nene 2013). The Team in its report submitted to the Government in 1955 grant pattern as a solution to solve the problem of agricultural education. The team recommended strengthening of post graduate teaching and research in agricultural subjects as well as effective coordination of agricultural education, research and extension. These recommendations laid the foundation for the creation of agricultural universities and research in agricultural sciences. The contracts were signed with the 5 US land grant universities. According to contracts, each contracting US university had to work with agricultural colleges and research station in India for some definite period.

The task of mentoring the proposed university in UP was assigned to the University of Illinois. The University was dedicated to the Nation on 17 November 1960. Illinois faculty served the university in designing its education system and putting in place an effective research and extension system for a period of 12 years (Singh 1999). In 1958, the second joint Indo American Team on Agricultural Education Research and Extension was appointed to frame proposals for third Five Year Plan. The Team reinforced proposals to adopt land grant pattern, with autonomous status, integrating agriculture and allied areas as well as teaching research and extension.

The initial establishment of Govind Ballabh Pant University of Agriculture and Technology (GBPUAT) university brought about a revolution in agricultural education, research and extension, and it paved the way for setting up of 29 other state agricultural universities in the country by the year 1999 (Venkataraman 1999).

were: Uttar Pradesh Agricultural University and the University of Illinois; Punjab Agricultural University (1962) and the Ohio State University; University of Udaipur (1962) and the Ohio State University; Orissa University of Agriculture and Technology (1962) and the University of Missouri; Andhra Pradesh Agricultural University (1964) and Kansas State University; Jawaharlal Nehru Krishi Vishwa Vidvalaya (1964) and the University of Illinois; Mysore University of Agricultural Sciences (1964) and the University of Tennessee; and Maharashtra Agricultural University (1968) and Pennsylvania State University (Randhawa 1968).

Box 2: Agricultural universities as "Harbinger of Green Revolution"

The importance of triple dwarf material of wheat was recognised by India and IARI, requested for the services of Norman E Borlaug in 1962.The Mexican wheat varieties, developed by Norman Borlaug were tested in IARI, GBPUAT, and PAU and new plant types to suit the needs of intensive agriculture and desirable qualities for Indian bread making were repatterned in these institutions. Subsequently, locally adaptable selections, like Kalyan Sona and other improved varieties were released for farmers. The Kalyan Sona variety of wheat was selected independently at PAU, Ludhiana and IARI, from the material received from CIMMYT, Mexico. PAU named it as Kalyan and IARI named it as Sona. All the three centres became a significant force in the development and transfer of High Yielding Variety seeds and related technology. The GBPUAT utilised its 16,000 acres (65 km^2) of land to launch one of the largest seed production programs at that time, under the brand name Pantnagar Seeds. The contribution of the university was recognised by Norman Borlaug, who described Pantnagar as "Harbinger of Green Revolution".

Through USAID and these U.S. Universities, assistance was given for training of faculties of Indian Agricultural Universities, specialists from the U. S. Universities serving with Indian counterparts in teaching, research and extension education. All of these inputs - participants, specialists and equipment aided the Indian Agricultural Universities to become real centers of new ideas and practices for India's agriculture.

Box 3: Strengthening of higher agriculture education in India

The impact of AUs on agricultural production during 1966-68 i.e., during green revolution, convinced the states that innovative approach of linking research, teaching and extension was needed in agriculture and hence, during the period 1969-1978 fourteen new AUs came into existence. Recognizing the importance of higher agricultural education, each state subsequently established agricultural university. Originally established in 1905 at Pusa (Bihar) with the financial assistance of an American Philanthropist, Mr. Henry Phipps, the Indian Agricultural Research Institute (IARI) started functioning from New Delhi since 1936 after its relocation following a major earthquake which, damaged the Institute's building at Pusa (Bihar). IARI is the country's premier institute for agricultural research, education and extension. It was given the Deemed-to-be-University' status in 1956 by the UGC and to award Masters and Ph.D. degrees in various agricultural disciplines. Mathura veterinary college established in 1947 became the first college to introduce the degree of B.V.Sc. & AH. Currently, there are 17 universities offering degree in various courses of veterinary and allied sciences. The course on agricultural engineering leading to bachelor degree was initiated for the first time in 1942 at Allahabad Agriculture Institute. First exclusive Fisheries College was established at Mangalore in 1969 under the auspices of the University of Agricultural Sciences, Bengaluru. From the very humble beginning, agricultural universities now impart education in the various disciplines of agriculture viz Agriculture, Agricultural Engineering, Forestry, Horticulture, Veterinary and Animal Husbandry, Dairy Science, Food Technology, Fisheries Science, Agribusiness Management, etc. AUs now impart education at the level of diploma, degree, masters and doctoral level.

3. Growth of agricultural education institutions

The establishment of SAUs that started in 1960 with GBPUAT being the first in the country picked up gradually and by 2001, almost all the major States except NE States had at least one SAU, some bigger States such as undivided Bihar, UP, Maharashtra, Karnataka, undivided MP and West Bengal had two or more. The number soared up to 74 in 2017, of which 63 are SAUs. This happened partly due to creation of 3 new States in 2001 (Fig. 2). While some States like Gujarat, Rajasthan, Karnataka and UP established full-fledged SAUs, a new trend of establishing sectoral universities started cropping up. Consequently, 4 universities for Veterinary and Animal Sciences, 2 in Horticulture and one in Fisheries were opened during 2012-17 in various states. With the increase in universities, the colleges in agricultural and allied science also increased substantially enabling access to agricultural education to a large number of students (ISAP Report 2020).

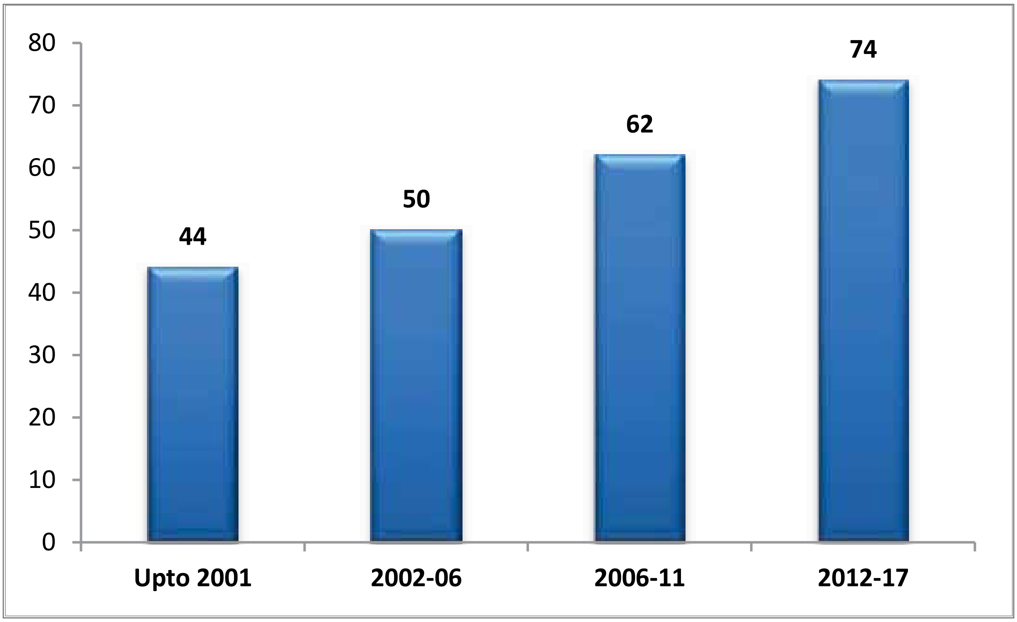

Fig. 2. Growth of state agricultural universities

Presently, Uttar Pradesh has 9 AUs and states of Karnataka, Maharashtra and Rajasthan have 6 AU's each; Gujarat has 5 AUs; West Bengal and Haryana have 4 AUs; Andhra Pradesh, Bihar, Kerala. Madhya Pradesh, Tamil Nadu, Telangana each have 3 AUs; Chhattisgarh, Himachal Pradesh, Jammu & Kashmir, Punjab, & Uttarakhand have 2 AUs each, and Assam, Jharkhand, Manipur, Nagaland, Odisha, & Delhi have only one AU each (Fig. 3).

The number of constituent colleges increased with the increase in the number of AUs. While there were only 170 constituent colleges in 1996 the number increased to 227 in 200. Further, between 2006 and 2017, 152 new constituent colleges were established making the number to 379 constituent colleges. The concomitant increase in the number of constituent colleges enabled access to higher agricultural education to a large number of students and the enrollment increased by over 16% in higher agricultural education within five years. During 2012-2017, maximum increase was in agricultural colleges (42), followed by 11 new colleges in the discipline of horticulture and forestry. The number of home science and agricultural engineering colleges has not increased to the similar extent. The number of food science & technology colleges remained relatively less despite tremendous scope for food processing and value addition. The AUs established during 1960-70 had strong departments/colleges for basic sciences, however, most of the universities established later paid little attention to this discipline. Basic science discipline also needs special attention with the growth of agricultural education.

Fig. 3. Distribution of agricultural universities across the country

4. Reorganization of ICAR and establishment of Division of Agricultural Education

Though ICAR aimed to undertake, aid, promote and coordinate agricultural education in the country, however, it had a very limited role before 1966, as it had neither financial resources nor statutory authority to discharge this responsibility. In 1966, ICAR was reorganized and a full-fledged Division of Agricultural Education was established to coordinate and support the development of AUs (Randhawa 1986). The various fellowship schemes for staff development and student welfare were initiated. ICAR developed first Model Act in 1966 to provide legal base for establishment, functioning and uniformity of agricultural universities across AUs (Makwana 2013).

The quality assurance of higher agricultural education was given the major thrust through policy support, accreditation, academic regulation, personnel policies, review of course curricula and delivery systems, development support for strengthening and creating infrastructure, improvement of faculty competence and admissions through All India competitions.

The ICAR through its Agricultural Education Division strives for maintaining and upgrading quality and relevance of higher agricultural education through partnership and efforts of the ICAR-Agricultural Universities (AUs) system. In 1973, ICAR went through another major re-organisation. The new Department of Agricultural Research and Education (DARE) was created under Ministry of Agriculture to provide ICAR required linkages to deal directly with central and state governments as well as international organizations.

5. Academic reforms and quality assurance

5.1. Agricultural Human Resource Development (AHRD) Project (1995-2001)

Implementation of the AHRD project with World Bank support helped the country to modernize its agricultural sector through improvement in agricultural education. The programme covered only 4 SAUs viz. CCSHAU, Hisar; TNAU, Coimbatore; ANGRAU, Hyderabad (now in Guntur); Animal Science University (now TANUVAS), Chennai. The educational reforms made under this project spread to non -AHRD SAUs too. Major reforms /initiatives of ICAR under the project were establishment of accreditation Board, All India Entrance Examination for admission to SAUs, introduction of sabbatical, revision of course curricula, faculty trainings, development of instructional material, infrastructure development, etc. (DARE/ICAR Annual Report 2001).

5.2. Deans' Committee and Broad Subject Matter Area Committees

The Education system has to be dynamic as the higher agricultural education system has to match with the changing demands and needs. Therefore, an institutional mechanism in the form of Deans' Committees was put in place by ICAR for the first time in 1965. The Committee was entrusted with the task of defining the course curriculum and other activities of UG and PG degrees keeping in view the demands of the markets, industries, specialists and the needs of the agriculture in general. Besides, recommendations for uniformity in UG and PG degree nomenclature; restructuring of UG programmes for increased practical and practice contents; central assistance for strengthening of higher agricultural education; guidelines for assessing training needs and performance of teaching faculties; reforms in governance of SAUs; developing a Model DPR for establishment of a new college, etc. were also given to the Dean's Committee. So far 6 Dean' Committees have been constituted in 1965, 1979, 1995, 2005, 2013 and 2021.

The First Deans' Committee report was bought out in 1967. Subsequently, the progress of AUs was reviewed in 1977 by the AUs Review Committee headed by Dr. MS Randhawa on the recommendation of which the second Deans' committee was constituted in 1979. The Committee submitted its report in 1981. The skill development courses were introduced following the 3rd report of Dean's Committee bought out in 1995. The 4th Deans' Committee report was brought in 2008 and 5th Dean's Committee report in 2016-17 (ICAR 2017). Post- NEP-2020 (National Education Policy-2020), the 6th Deans' Committee has been constituted to suggest alignments in the Course Curricula to adjust according to its provisions. Quality assurance in higher agricultural education, pursued by ICAR/DARE/ SAUs, involves accreditation, framing of minimum standards for higher education, norms for establishing new colleges academic regulations, personnel policies, review of course curricula and delivery systems, support for creating/strengthening infrastructure and facilities, improvement of faculty competence and admission of students through All India Examination.

The ICAR's Fifth Deans' Committee Report (ICAR 2017) restructured the course curricula to underpin relevant practical skills, entrepreneurial aptitude, self-employment, leadership qualities and confidence among graduates, and attracting and retaining youth in agriculture.

New courses have been initiated in order to harness regional requirements and to meet region-specific needs, certain optional courses such as Coastal Agriculture, Hill Agriculture, Tribal Agriculture etc. were formulated. New degree programmes and courses were recommended in emerging fields like genomics (biotechnology), nanotechnology, GIS, precision farming, conservation agriculture, secondary agriculture, hi-tech cultivation, specialty agriculture, renewable energy, artificial intelligence, big data analytics, mechatronics, plastics in agriculture, dryland horticulture, agro-meteorology and climate change, waste disposal and pollution abatement, food plant regulations and licensing, food quality, safety standards and certification, food storage engineering, food plant sanitation and environmental control, emerging food processing technologies, sericulture, community science, and food nutrition and dietetics.

Box 4: Student READY: (Rural Entrepreneurship Awareness Development Yojana) -Introduced in Vth Deans Committee report

Hon'ble Prime Minister launched the Student READY (*Rural Entrepreneurship Awareness Development Yojana*) in 2015 for the development of agri-entrepreneurs. This has been introduced in the UG programme in all the disciplines of agricultural and allied sciences as approved in Fifth Deans' Committee. It is one complete year activity integrated with the last year of the UG programme of Agriculture, Agriculture Engineering, Biotechnology, Community Science (earlier Home Science), Dairy Technology, Food Technology, Forestry, Fisheries, Horticulture and Sericulture. It aims developing young agri-preneurs for emerging knowledge intensive agriculture. The programme integrates activities for skilling in project development and execution, decision-making, individual and team coordination, accounting, quality control, marketing and conflict resolutions, etc. with end-to-end approach (Verma et al. 2019).

The NEP-2020 has now proposed several changes in the education system of India, including higher agriculture education system. Subsequently, ICAR in September 2020 constituted a National Level Committee to develop a roadmap to comply with various provisions of NEP-2020 in Agriculture Higher Education in India. The Committee suggested implementation strategy for NEP-2020 in agricultural education system which, inter alia, included constitution of 6th Deans Committee. The ToR of the 6th Dean's Committee includes, among others, the recommendations for restructuring the on-going UG programmes in AU's system to accommodate the one-year certificate and two-year diploma provisions of NEP, 2020. All these changes will be considered by Sixth Deans' Committee. ICAR has been given the responsibility of Professional Standard Setting Body (PSSB) for the Agriculture Education under the NEP-2020.

Initially, the PG course and syllabus were also mandated to the Dean's Committee which were delegated to Broad Subject Matter Area (BSMA) Committees constituted for formulation/ revision of PG courses. The first BSMA committee was constituted in 2008. Revision of PG course curricula and syllabi has been periodically taken up through the BSMA committees (ICAR 2021). The course curricula and syllabi for Masters and Ph.D. was last revised in February, 2020 and the report of the BSMA committee was released on National Agriculture Education Day i.e., 3rd December, 2020. Presently, the postgraduate education in agricultural sciences is being offered in about 79 disciplines.

Box 5. National Education Policy-2020 and Agricultural Education in India

The New Education Policy-2020 (NEP-2020) of India was rolled out on 29th July, 2021. NEP-2020 provisioned that "the design of agricultural education will have to be strengthened towards developing professionals with the ability to understand and use local knowledge, traditional knowledge and emerging technologies, while being cognizant of critical issues of declining profitability and/or productivity but enhanced economic aspirations of farmers, climate change, food sufficiency, etc.".

Based on the principles and philosophy of NEP-2020, a roadmap and implementation strategy for NEP-2020 in Agricultural Education System has been prepared and released on 28 September, 2021 during the Annual Vice-Chancellors Conference in New Delhi (ICAR 2021).

Some of the major highlights of NEP 2020 are: enhancing the GER, defining Minimum Standards of Quality of Agricultural Education and ensuring their adherence by all stakeholders, improvement in research contributions, importance of staying relevant and providing placement along with right skills. Various timelines for implementation of NEP by AUs were also defined by the committee.

Starting with multiple exit and entry points into higher education, relaxation of the residential requirements of UG, PG and Ph.D. programmes, restructuring and reformulation of the UG curriculum in accordance with the new system advised by NEP, compliance with Academic Bank of Credits as per the directives of the Ministry of Education, Deemed universities of ICAR may initiate process for transforming them into Multidisciplinary Education and Research University (MERU).

By 2022-23, common entrance test may be conducted by ICAR for admission of the students in all the AUs, AUs to start increasing seats on annual basis by 10% until the target is achieved. By 2025-2030 all institutions, located in the same premises, offering either professional or general education may aim to organically evolve into multi-disciplinary institutions/clusters offering education both seamlessly, and in an integrated manner. By 2035, achieving 50 per cent Gross Enrolment Ratio (GER) in higher agricultural education including vocational education, All higher education institutions (HEIs) should aim to become multidisciplinary institutions by 2040.

5.3. Accreditation for quality assurance

The UGC was initially looking after the assessment and accreditation of higher agricultural education. ICAR assumed this responsibility in 1965. After further reorganization of ICAR in 1973-74, the Standing Committee on Agricultural Education was replaced by the Norms and Accreditation Committee (NAC) in 1974. The NAC was charged with the responsibility for determining norms for accreditation of AUs. In the past, the focus was therefore, on standards and has now shifted to quality.

Box 6. Setting up of National Agricultural Education Accreditation Board (NAEAB)

To further improve and sustain the quality of agricultural education, Accreditation Board was set up in 1996, and institution of new accreditation system for Agricultural Universities and combining functions through three sectoral Committees. Now this activity is being done by National Agricultural Education Accreditation Board (NAEAB) established by the Council with well-defined guidelines. The NAEAB has been strengthened by establishing four regional Centres in North, East & North-East, South and Western regions at IARI, New Delhi; CRIJ&AF, Barrackpore; IIHR, Bangalore; and CIFE, Mumbai respectively, along with new guidelines in order to make accreditation process more objective. Further, the entire process of submitting documents for Accreditation is now online (since 2020) through dedicated accreditation portal (Agrawal et al. 2021).

5.3. Ranking of agricultural universities

Ranking of Agricultural Universities was initiated in 2017, in line with the National Initiative on Ranking of Indian Institutions, with a larger objective to improve the ranking of Indian universities in World University Ranking. National Academy of Agricultural Sciences (NAAS), developed evaluation methodology, alongwith robust, transparent and simple indicators for ranking of agricultural universities. During 2020, the Education Division of ICAR developed an online portal for inviting applications for ranking, to make the system more efficient, paperless and more transparent.

Box 7. Agriculture as Professional Degree

Indian Council of Agricultural research declared all UG courses in agriculture and allied subjects which include Agriculture, Horticulture, Agricultural engineering, Dairy Technology, Forestry, Veterinary & animal sciences, Food Technology, Biotechnology, Fisheries, Sericulture, Community Science and Food Nutrition & Dietetics as professional degree courses in 2017.

UGC decided in its 538th Meeting held on 29th January, 2019, that agriculture degree programmes are prohibited in Open and Distance Learning (ODL) mode from the

academic session 2019-20. As per UGC notice *"Professional programmes" means a programme other than programmes in engineering, medicine, dental, pharmacy, nursing, architecture, physiotherapy and programmes not permitted to be offered in distance mode by any Statutory Councils or Regulatory Authorities*.

6. Human resource development and capacity building

6.1. ICAR Post-doctoral fellowship

ICAR Post-doctoral Fellowship (ICAR-PDF) programme was introduced w.e.f. academic session 2019-20 under the ongoing scheme 'Strengthening and Development of Higher Agricultural Education in India' of ICAR. The programme aims to identify and support, motivated young researchers for conducting research in frontier areas of agriculture and allied sciences and to build the national capacity. It provides a platform to develop an independent researcher capable of initiating a new programme in nationally important priority areas under the supervision of a mentor. There are 25 positions of PDFs at the four ICAR-Deemed Universities for a period of one year. So far, 14 PDFs have been awarded by ICAR to ICAR-DUs.

6.2. ICAR National Professor/National Fellow Scheme

ICAR in 1978-79, initiated this scheme to promote excellence by establishing and nurturing novel school of thought and strong centres of agricultural research and education around outstanding scientists through 10 positions of National Professor Chairs and 25 positions of National Fellows. The National Professor Chairs includes the prestigious BP Pal Chair in Genetics and Plant Breeding at IARI, New Delhi and Norman Borlaug Chair in International Agriculture located in the ICAR-AU system.

National Professor component was initiated to promote excellence by recognizing outstanding scientist with proven output and outcome for creating a culture of basic research through their project work in the National Agricultural Research System (NARS) and establishing and nurturing a novel school of thought around the recognized person. From 1995 till date, 22 National Professors have been selected under the programme. National Fellow was initiated to promote excellence at national level in agricultural research & education and recognize the meritorious contribution of individual agricultural scientists/teachers and facilitate their research and related activities in agriculture. 50 researchers have been awarded National Fellow from 1994 till 2022. The contribution of National Professors and National Fellows in the form of technologies, patents, copyrights have immensely benefited the knowledge pool of the country.

6.3. ICAR Emeritus Professors

ICAR Emeritus Professor program for tapping brain and skill bank of the outstanding superannuated professionals of NARES was initiated during 2016-17 so as to utilize their talent in teaching courses and other related activities, student research guidance and developing instructional material/text books including e-learning resources for use in national agricultural education programme and distance education in the field of agriculture and allied areas and improve the quality of education across SAUs by addressing the shortage of faculty. Till date 73 superannuated faculties have been awarded Emeritus Professor.

6.4. ICAR Emeritus Scientists

This programme initiated in 1973-74 to utilize the services of outstanding superannuated scientists/teachers from NARES by allowing them to complete the nationally important research already underway and also for initiating a new programme in nationally important priority areas, teaching specialized courses, developing quality instructional material for use in national agricultural education programme including distance education. The programme has helped to make use of the experience of retired professionals for remedying manpower imbalances in some of the crucial areas of research (Agrawal et al. 2021). 109 researchers have been selected as Emeritus Scientists from 2015 till 2022.

Box 8: Centre of Advanced Faculty Training (CAFT)

In order to identify the potential major disciplines/departments in SAUs/ ICAR institutes which have developed facilities and leadership in their specialization and to provide need-based financial assistance for further accelerating the programmes of identified disciplines/departments so as to make them capable' in undertaking advanced teaching, research, extension and also training to the faculties of other Universities/Institutes for enhancing their capabilities in use of educational innovations, modern teaching and research methodology along with serving as repository of ideas and information in concerned discipline/department, establishment of Centre of Advanced Studies (CAS) in selected ICAR institutes and State Agricultural Universities was initiated in the year 1993-94 which was later renamed as Centre of Advanced Faculty Training (CAFT). Every year under CAFT about 60 capacity building programmes are conducted with average 18-20 faculties/scientists in each programme.

6.5. Summer/Winter Schools (SWS) and Short Courses

Since 1967, ICAR has been sponsoring the organization of Summer School/Winter School/ Short Courses in the discipline of Agriculture, Veterinary, Animal Sciences, Fisheries and Food Technology, etc. across the ICAR-AU system. The purpose of organizing these courses is to bring about qualitative improvement and to update the teachers, researchers and extension specialists with the latest knowledge and techniques in the field of their specialization, provide necessary orientation to contemporary problems, provide a common forum for co-professionals to interact and exchange experiences and also to maintain feedback to make research and education more relevant. This activity has helped to bring out qualitative improvement in their pedagogical skills and also update their knowledge in the specialized/emerging areas thereby contributing to development of skilled human resources for making research and education more relevant. A Capacity Building Program (CBP) portal is operational as a workflow based online management system of all training programs. Each year 70 such programmes are supported by the Council leading to the capacity building of the stakeholders in upcoming newer areas.

6.6. Niche Area of Excellence (NAE)

ICAR initiated this program for building excellence in specific strategic areas in education and research and includes improving specific area of research with quality human resource, along with creating facilities as well as environment for access to information, recognition and interaction with best of peer groups shared competitiveness in agricultural education and research. Total 71 programmes have been supported under this component since its inception in 2006-2007. Under various programs till date, 561 students obtained Masters degrees and 236 students completed Ph.D. degrees. The mandatory training programmes under this component led to horizontal capacity building in cutting edge areas and awareness programmes and demonstrations, which made farmers aware about the newer technologies. A total of 860 capacity building programmes were conducted in various centres across country, leading to capacity building of 3260 faculty, 46672 farmers and 10279 other stakeholders (Jain et al, 2014, 2020).

7. Digitization of learning resources

7.1. e-Courses

The Agricultural Education Division institutionalized, upscaled, supported and enabled development of e-Courses for the degree level programmes in seven disciplines viz., Agriculture, Fishery Sciences, Dairy Science, Veterinary and Animal Husbandry, Horticulture, Home Science and Agricultural Engineering by subject matter specialists of the respective disciplines as per ICAR approved syllabus. On July, 2013 e-Learning Portal on Agriculture Education or e-Krishi Shiksha was made available online at https://ecourses.icar.gov.in/ for agricultural students. For the online delivery of the e-courses, the open-source CMS MOODLE (Modular Object-Oriented Dynamic Learning Environment) and for the offline delivery of the e-Courses, POODLE (Offline version of MOODLE) is being used and courses integrated with POODLE are loaded into the CD's/DVD's and made available offline. This portal provides 24/7 free services for online access to all the teachers and students in the field of agricultural education even in remote area. Till date, more than 60 lakh downloads have been made by students and other stakeholders of various AUs.

7.2. Consortium for e-Resources in Agriculture (CeRA) (http://jgateplus.com)

The Consortium for e-Resources in Agriculture (CeRA) is the first of its kind for facilitating 24x7 online accesses of all major journals in agricultural and allied sciences to all researchers, teachers and students, policy planners, administrators and extension specialists in NARS through IP authentication. Regional stations and KVKs are also members apart from SAUs. CeRA has had a profound impact on the growth of scholarly publications in the fields of Agriculture and Allied Sciences. Online availability and e-publishing system for the ICAR research journals has increased their readership by 4-5 folds, and reduced article processing time substantially. Support for access to e-Resources in Agriculture has provided an online access of around 3,000 journals to 142 CeRA member-NARS institutions throughout India. CeRA helped India improve its research contribution in the field of agriculture. Number of publications in agriculture and biological sciences showed linear growth except in 2013. As per Scimago the number of publications increased from 2,845 in 1997 to 14,072 in 2020. Similar trend has been shown in data extracted from Web of Sciences (WoS). According to data extracted from Scopus the number of publications ha increased from 2,830 in 1997 to 15,506 in 2020 (Fig. 4).

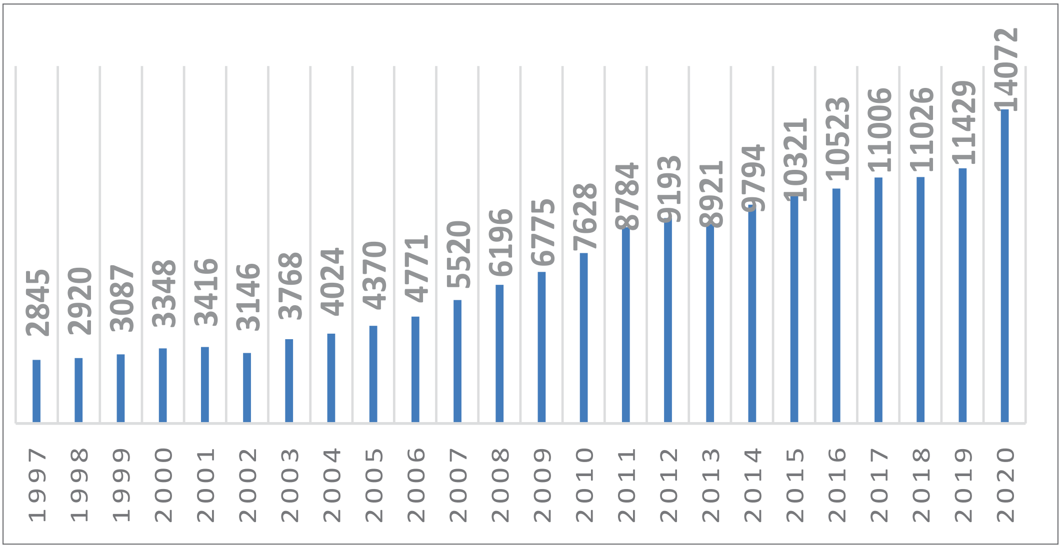

Fig. 4. Growth of publications (as per Scimago)

7.3. KrishiKosh *(http://krishikosh.egranth.ac.in/)*

KrishiKosh is a digital repository which captures, preserves, archives and provides policy-based access to the intellectual output of NARS. It is a unique repository of knowledge in agriculture and allied sciences, having collection of old and valuable books, institutional publications, technical bulletins, project reports, lectures, preprints, reprints, records and various documents spread all over the country in different libraries of SAUs and ICAR Institutions. The KrishiKosh acts as digital platform to preserve institution's intellectual assets and help in providing and managing open access to this literature. Currently, more than 2,70,000 items with 50 million pages have been digitized and stored. Currently, it has 96 member institutions. 1,75,000 theses from various SAUs have been uploaded and since April, 2017 the site has 23 million visits of researchers from 175 countries.

7.4. Agricultural Education Portal *(https://education.icar.gov.in)*

The database of information of all the agricultural universities was developed to provide unified information base for collection, compilation and analysis of information about the activities of the agricultural education system in India. The Education Portal is a Centralized Uniform Solution for, release of funds, scholarships, fellowships, accreditation, AIEEA Admissions, Ranking system, CBP portal, Student Portal & Database Management, etc.

7.5. Information and Communication Technologies (ICT)

The support provided to strengthen the infrastructure under ICT helped in greater dialogue, interaction, communication and coordination with in the Stakeholders of Agricultural Universities. The knowledge sharing improved due to the availability of modern tools and mass media communication strategies. The innovations in education and research are multidisciplinary, and collaborative. It was important to provide connections through high-speed broadband network to SAUs, along with smart classrooms and some virtual classrooms, which has helped build quality institutions with requisite facilities, improved research and education. Video conferencing facilities were also established across Agricultural Universities.

8. Attracting talent in higher agricultural education

In order to attract and retain the talent in higher agricultural education and achieve educational excellence, ICAR provides financial assistance through various scholarships/ fellowships to the admitted students. In addition, the national level examination was started ICAR- All India Entrance Examination for Admissions (AIEEA), in the year 1996-97, to address the challenges of quality manpower development and meet the requirement of much needed talented pool of human resource in the field of agriculture and allied sciences. The primary objective of conducting the exam is curtailing academic inbreeding in agricultural education and promoting national integration by providing a window of opportunity for the students to take admissions outside their domicile states in reputed institutions having state-of–the–art–infrastructure and facilities, infuse merit, encourage talent and promote uniform examination standards across the agricultural universities, thereby leading to an overall improvement in the quality of Higher Agricultural Education (Agnihotri et al. 2014, Rana et al. 2020).

The SAUs annually provide 15% (UG) and 25% (PG and Ph.D.) of their existing seats as ICAR quota seats for filling up through this entrance examination. However, ICAR fills 100 % PG and Ph.D. seats at ICAR-DUs, CAUs. To align with New Education Policy (NEP 2020) and reduce the burden on students for appearing in multiple entrance examination for admissions in State Agricultural Universities (SAUs), ICAR has taken an initiative and offered the SAUs to utilize NTA scores for UG, PG and Ph.D. admissions. During academic session 2021-22, 05 SAUs for UG, 07 for PG and 08 for Ph.D. admissions utilized NTA scores for state quota seat admissions.

National Talent Scholarship (NTS): The NTS -G and NTS-G were initiated to discourage inbreeding to pursue undergraduate and post-graduate studies to all those candidates who are admitted through ICAR-AIEEA and take admission outside their state of domicile and maintain prescribed academic standards.

PG scholarship: Based on their merit in AIEEA (PG), the ICAR-PG Scholarship, is awarded to 600 candidates per year for pursuing Masters' degree for a period of two years who get admission in AUs located in states other than those from where they had graduated.

Junior/Senior Research Fellowship (JRF/SRF): 300 students are awarded this scholarship every year for pursuing Ph.D. degree program in ICAR-AU System subject to the condition that they meet the other prescribed eligibility requirements.

9. Globalization of higher agricultural education

DARE/ICAR implemented India-Africa Fellowship Programme since 2017-18; and India-Afghanistan Fellowship Programme since 2010-11. Till date, 114 African nationals from 17 countries have been enrolled successfully in 33 Indian Agricultural Universities/ CAU/ Deemed Universities under India-Africa Fellowship and 482 Afghan nationals enrolled in 51 Indian Agricultural Universities.

Netaji Subhas-ICAR International Fellowship was initiated in 2010-11 for pursuing doctoral degree in agriculture and allied sciences in the priority research areas to the (i) Indian candidates for study abroad in the identified overseas Universities/Institutions having strong research and teaching capabilities and (ii) to overseas candidates for study in the Indian Agricultural Universities in the ICAR-AUs system is in implementation for last 12 years. The programme provides for 30 such fellowships every year.

The BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) Scholarship on Agriculture has been initiated since 2021-22 for 6 fellowships each at Master and Ph.D. students of Agriculture of Member Nations.

10. Way forward

The AUs and ICAR institutes have been harbingers of the Green and the Rainbow Revolutions, and generating the much-needed scientific manpower, teachers, technologies etc. However, there are issues of i) declining financial resources in agricultural universities/ colleges; opening of new institutions without matching resources and norms; splitting of agricultural universities, ii) Disconnect among agricultural education, employment, and industries' requirements; lack of adequate skill, entrepreneurship and experiential learning and iii) Extensive inbreeding and slow pace of reforms (Singh et al. 2019). System of evaluation, monitoring, impact assessment, accountability etc. needs improvement alongwith digitalization; and governance. In order to make the agricultural universities globally competitive, availability of state-of-the art infrastructure, highly qualified and trained faculty, excellent research, teaching and learning facilities and student amenities, adequate financial support is therefore, a prerequisite, along with evolving appropriate models for strengthening of higher education, addition of newer courses encompassing global initiatives.

10.1. Reforms in quality and academics to attract talent

1. The SAUs need to fare well among world ranked universities. Creation of world class universities will boost the country's position in global rankings. The country needs to reorient existing institutions into world class universities.
2. Expansion of the distance learning mode of education in agriculture in the NEP-2020 with blended model of curriculum transaction and more weightage to project work and experiential learning will be beneficial for wider reach.

3. Industry-SAUs linkages, public-private partnership and other such models needs to be promoted for adequate resource mobilization from alternate sources so as to make the higher agri education institutions self-sustaining institutions.
4. ICAR-SAU system should set up a mechanism for periodically assessing the absorption capacity of agriculture graduates and specialized post graduates in the various industries in India.
5. The farming has been integrated over centuries so is the needs of the farmers as on date. Hence, the process of fragmentation to open segmented SAUs should be reversed and the multi-faculty nature and strength of SAUs should be restored.
6. To attract students to agriculture and allied streams, focus on developing professional opportunities in production, processing, marketing and supply of agricultural products, besides generating new employment opportunities.
7. In order to strengthen degree programmes in the emerging and frontier areas of science and technology, more fellowships need to be earmarked. Separate provision of special research grants should be extended for innovative PG research.
8. Establishing 'Technology Parks' and agri-business hubs, agribusiness innovation centres would serve as innovation platforms, and also encourage rural graduates, entrepreneurs and young professionals to start businesses and bring technological and managerial expertise to rural areas.
9. Institutionalize skill development, entrepreneurship and experiential learning programmes, and invest on non-formal education and vocational training in agricultural technologies.
10. Introducing innovations, introduction of upcoming and relevant areas in course curriculum, initiating new courses in education should be a regular practice
11. Disciplines of social sciences like economics, agri-business management, marketing and rural sociology, and agricultural ethics and policies need to be emphasized for promoting market-driven agriculture.
12. Introduction of diversified credit-based degree system instead of fixed duration system and credit transferability shall enhance opportunities to students to pursue their academic interests.

10.2. Faculty improvement

1. Improving faculty in terms of strength and competence must be recognized as key factor for reinforcing quality in current education system. The components like post-doctoral fellowship, visiting faculty, adjunct faculty should be encouraged. In addition, opportunities for physical exchange of faculty/specialists, creation of necessary infrastructure, for teacher's training at national/international centres.

Prime Minister Shri Rajiv Gandhi delivering the convocation address at IARI, New Delhi

Prime Minister Shri Manmohan Singh in the convocation ceremony of IARI, New Delhi.

2. Inviting overseas accomplished professors and researchers to Indian AUs and research institutes for varying periods of time for imparting training in frontal areas, interaction on curriculum development and education technology would lead to capacity development of a large number of faculty and students, besides formulation and initiation of research programs in frontier areas.

11. Conclusion

Although, the support and interventions from ICAR has significantly strengthen the amenities, encouraged skill development, capacity building of faculty and has helped students be ready for industry and better placements, improved publications. Accreditation process has led many states to expedite the recruitment process in SAUs. It is very important that additional new challenges faced by agriculture are reflected in national curricula and research priorities. Agriculture has to economically viable, globally competitive, socially equitable and environmentally sustainable and all these facts must be internalized in curricula. Agricultural education should engage in global social contract to serve the needs of the society, build leadership, increase collaboration, develop new approaches to deal with challenges. Therefore, it is necessary to undertake human capacity building for developing professionals and entrepreneurs in emerging new areas of specialization. In addition, all AUs have sufficient land available for experimentation, demonstration of various trials to farmers etc. But it is important that all AUs should develop and evolve ways for adequate resource generation and convert themselves into self-governing institutions, which is also reflected in the New Education Policy.

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Achievements in Agricultural Extension in Independent India

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Summary

Agriculture in India has a typical blend of man, machine, animal and material usage and influenced by the behavioral changes. When population was less, single crop in a season with grazing animals and least use of machines and material inputs was a reality rather than exception. As we grew in numbers and in ambitions, the intensive use of man, machine and material started with less use of animals. The man-to-man interface, structured or unstructured, played a catalytic role in this evolution of agriculture. The agricultural extension system in India evolved through phases. Firstly, it helped in the intensive use of inputs and dwarf varieties of rice and wheat, hybrids of maize and other coarse cereals for food security. The community development programme in 1950s, intensive area development programme, T&V programme, lab to land programme in 1970s and oilseeds & pulses promotional programme in 1980s, micro-irrigation and farm mechanizations 1990s onwards and more intensively post MGNREGA are the critical endeavors done by the agricultural extension system in the past that shaped today's technology and skill intensive agriculture. Agricultural extension helped reducing the gaps in potential yields and farm realized yields. While the course of informal extension from farmers to farmers changed to farmers and state-owned subsidized input providing units located at the block headquarters and below and private input dealers, the formal extension bifurcated into mass extension machineries owned by state department of agriculture, and frontline extension under the umbrella structure of NARS led by ICAR during 1970s. This innovation proved the most productive for many out of the box solutions like national demonstrations programme on HYVs, technology mission on oilseeds, accelerated pulses development programme, seed hub programme, etc., which helped ensuring technology dissemination on a large scale. The farmer's knowledge base and the capabilities for adoption of improved agricultural technologies and innovations improved substantially. The unique set up of Krishi Vigyan Kendras (KVKs) started in 1974 has proved one of its kind and the only gateway of frontline technologies in the district. Of late these KVKs are engaged in much complex deliverables related to climate change, nutri-sensitive agriculture, resource conservation, special drives for disadvantaged and aspirational districts in India for agriculture and water resources. While this split proved very successful in the previous years, This chapter discusses the evolution of agricultural extension system over the last 75 years that transformed Indian agriculture.

1. Introduction

The agricultural extension system in India has two broad typologies based on their domain of action- Mass Extension or Field Extension System and Frontline Extension System. Philosophically, the field extension system is concerned with dissemination of established agricultural technologies to the masses by development departments and agencies; and the frontline extension system concerns to testing and demonstration of new technologies in a quick succession, differently in approach and design, which otherwise take very long gestation period to reach to the farmers, as well as capacity development of the related stakeholders. The overall financial governance of frontline extension system is under ICAR with SAUs, some reputed NGOs, State Governments providing the lead role in the states and districts. Apart from the frontline extension, the mass extension in agriculture & allied sectors is under the governance of Department of Agriculture & Farmers Welfare (DAFW), Department of Fisheries, Department of Animal Husbandry & Dairying and the related ministries of rural development through their network of agricultural and related departments at state, district, block and village level. The commodity boards under the Ministry of Commerce also provide mass extension services specific to their commodities. The agribusiness houses and input agencies, albeit some conflict of interest, offer private extension services to farmers. Frontline Extension is a catalytic force for bringing desirable behavioural change, which involves a higher level of knowledge sharing and interaction by qualified resource persons of the research and educational system. The basic philosophy behind frontline extension system is that the scientists who have generated the technologies can demonstrate their technologies better to the farmers in their fields with concurrent and direct feedbacks to them for further refinement in the technology.

2. Role of agricultural extension in addressing agrarian challenges

A number of social workers and philosophers with a philanthropic intent in the pre-independence period came forward for overall development of society through rural reconstruction and upliftment of under-privileged sections of the society. The attempts such as Sriniketan Project, Sevagram, Marthandam Project, Gurgaon project, Firka Development Programme are some important to cite. These were important movements but operated in isolation. The role of extension in addressing agrarian challenges has changed over the decades (Table 1). The major dynamic role of extension affecting agriculture and the rural society is given below.

Table 1. Milestones in agricultural extension in India

Year	Milestone	Impact
1952	Community Development Programme (CDP)	All-round socio-economic transformation of the rural people - by increasing agricultural production; tackling unemployment, improving communications, primary education, public health and recreation, housing, promote indigenous handicrafts and small-scale industries and improve the villager's lot through their own primary effort.

Year	Milestone	Impact
1964	National Demonstration	Precursor to the Green Revolution. Demonstrated genetic potential of improved HYVs leading to large scale adoption.
1964-66	Education Commission	Recommended that a vigorous effort be made to establish specialized institutions to provide vocational education in agriculture and allied fields, which led to establishment of Krishi Vigyan Kendra in 1974.
1966	High Yielding Variety Programme (HYVP)	Attaining self-sufficiency in food suitably blended with HYVs and application of fertilizers, irrigation, plant protection, improved implements, etc.
1974	India's first KVK at Pondicherry	KVK -a successful grassroots level model of frontline extension impacting farmers and extension personnel's behaviour and capacity to deliver the public goods.
	Training and Visit (T&V) System	Dynamic link between farmers, professional extension workers, and researchers. T&V system in its extension network helped in effective technology transfer through scientific mean resulting into increase in food production.
	Operational Research Project (ORP)	Disseminating the proven technology in a discipline/area among farmers on a watershed basis, covering the whole village or a cluster of villages.
1978-79	Integrated Rural Development Programme (IRDP)	Poverty alleviation of small and marginal farmers, agricultural workers and landless labourers and rural craftsmen and artisans.
	Lab to Land	Adopted farm families for improving their farming systems and thereby generating more employment and income.
1983-84	Cabinet decision of 1983/84 which provided for one KVK in each district	Milestone for opening KVKs in all the districts across the country.
1995	Technology Assessment and Refinement (TAR)- Institution Village Linkage Programme (IVLP)	Farmer participatory research for developing location specific usable technologies through technology assessment and refinement.
1998	National Agricultural Technology Project (NATP)	NATP-from discipline-oriented research to production system research. Successfully completed 852 projects.
1999	Agricultural Technology Information Centre (ATIC) as part of NATP	A dedicated single window for dissemination of agricultural technology information to the farmers and other stakeholders.

Year	Milestone	Impact
2006	National Agricultural Innovation Project (NAIP)	Development of viable value chain models to improve livelihood of disadvantaged groups in the disadvantaged districts
2011	National Innovations on Climate Resilient Agriculture (NICRA)	Technology dissemination for adaptation and mitigation against climate change induced stresses.
2015	Attracting and Retaining Youth in Agriculture (ARYA)	Over 42,000 youth facilitated in 25 districts. Project to be extended to 75 districts to covering total 100 districts.
	Mera Gaon Mera Gaurav	Multidisciplinary teams of scientists of ICAR Institutes, State Agricultural Universities (SAUs) scientists have covered 13,500 villages. This is a unique model for ensuring frequent farmer-scientist interface for developing personal rapport, knowledge sharing, facilitating linkage with development departments and agencies and generates and share feedback.
	Farmer FIRST Programme	Enriched Farmer-Scientist interface to create linkages, technology adaptation and application, content mobilization, partnership building for enhanced livelihood.

2.1. Era of food deficiency (1947-74)

India struggled to make available two square meal to its citizens immediately after Independence. Obviously, the prime target of the Government was to bring food sufficiency by leveraging and rejuvenating the Indian agricultural research and extension system. The community development programme provided a fillip to the philosophy of working on a model of land grant pattern of agricultural education and extension. This was the time when integrated system of agricultural research-education and extension was christened. The need for stepping up food production was realized even in the pre-Independence era and Grow-More-Food Campaign was started for increased agricultural production on a pan India approach. The campaign failed to achieve its targets and was redefined by the Government soon after the Independence in 1947 to achieve self-sufficiency in food grains by 1952 with simultaneous increase in the targets of production of other crops. An integrated and coordinated approach was adopted in the entire campaign for increasing agricultural production. Some state governments mobilized the public support in the campaign by setting up of people's committees at the village, *taluka*, district and state levels.

2.1.1. Etawah pilot project

In 1948, Mr. Albert Mayer of USA who came to India as a warrior at a village called Mahewa in Uttar Pradesh, started pilot project for development of Etawah district in UP. The project governance was designed in a way that development officers got posted at every critical level of facilitation down to village level. The 'multi-purpose' village level worker (VLW) was assigned the responsibility of four or five villages. The entire project was sponsored and funded by the Government of Uttar Pradesh. The most convincing achievement of this project was in agriculture, particularly in wheat production due to adoption of improved production technologies. This project solved the problem of unemployment and under-employments

2.1.2. Nilokheri project

This project started during 1948 under the leadership of Sh. S.K. Dey with the primary objective of developing a new township to rehabilitate displaced people from West Pakistan. The project was built in a swampy barren land by refugees with 'self-help and governments' assistance, located around the vocational training centre on the highway of Delhi and Ambala. The scheme called 'Mazdoor Manzil' was launched for construction of township at Nilokheri. This scheme provided the people (i) training on agricultural implements preparation; (ii) cottage industries; and (iii) carpentry etc. The Nilokhari project was a suitable blend of self-sufficiency in all essential requirements of rural cum urban life. Later, this township was handed over to the Government of Punjab and went to Haryana after bifurcation of Punjab.

2.1.3. Community development project

In order to increase agricultural production and bettering the overall economic condition of the farmers, 55 Community Development Projects were started in different parts of the country on 2nd October, 1952 for three years. The Projects covered nearly 25,260 villages and a population of 6.4 million. Each project, in turn, consisted of about 300 villages covering 400-500 square miles and having a population of about two lakhs. The project area was divided into three development blocks, each comprising 100 villages and a population of 60,000 to 70,000. The development blocks, in turn, were divided into groups of 5-10 villages, each group being in the charge of a multipurpose village-level worker.

Field Day on Mechnical Transplanting of Paddy in Sangrur, Punjab

2.1.4. National Extension Service (NES)

The National Extension Service was inaugurated on 2nd October 1953. The scheme of National Extension Service was designed to provide the essential basic staff and a small fund for the people to start the development work essentially on the basis of self-help. The operational unit of this service was an N.E.S. block comprising about 100 villages and 60,000 to 70,000 people. The N.E.S. blocks were later converted into community development blocks which had higher budget provisions in order to take up more intensive development programmes. The pattern of community development programme was further revised (modified with effect from 1st April 1958).

2.1.5. National demonstration

A nationwide programme of demonstrations, known as National Demonstration on major food crops was launched in 1964. It was a nationwide project with a uniform design and pattern. There was a specific yield target and there was no separate control plot. The area of the demonstration plot was about one hectare. The farmers in whose plots the demonstrations were laid out were the actual cultivators with small holdings. The agricultural scientists conducted these demonstrations in association with local extension agencies/workers. The national demonstrations were intended to show the superiority of the demonstrations to the extension agencies.

2.1.6. High Yielding Variety Programme (HYVP)

The HYVP was launched in 1966 as an integrated programme to introduce the high yielding crop varieties and promote the modern agricultural inputs like fertilizers, irrigation, plant protection, improved implements, etc. This aimed at attaining self-sufficiency in food production. The HYVP proved pivotal to realise the 'Green Revolution' in the country. As the programme created demand for the new varieties, the agricultural scientists successfully evolved new high yielding varieties in cereals particularly in wheat, rice and maize. The part of Indo-Gangetic Plain, in the States of Punjab, Haryana and UP (western part) were the original area where this programme got implemented initially. The pervasive influence of high yielding technology spread to other area as of farm production such as animal production, fishery, sericulture, social forestry etc.

2.2. Era of food sufficiency (1975-2000)

Post Green Revolution, the period between 1975 to 2000 saw adequacy of staple food grains and food security ensured barring deficiency of few commodities. However, some glaring problems cropped up. The most serious was depleting natural resources and declining factor productivity. The sustainability issues caught the eyes of all concerned and demand for food security along with focus on input use efficiency, land and labour productivity as well as their use optimization escalated. Resultantly, more systematised efforts of field extension programmes sponsored by Department of Agriculture & Cooperation were launched for all major commodities to support technology delivery and dissemination and capacity building of farmers as well as extension professionals. The following programs were launched which had a different role for extension personnel to play.

2.2.1. Training and Visit (T&V) System

The T&V system was the brainchild of Dr. Daniel Benor (World Bank Consultant) and introduced in India in 1974 for all round development of agricultural extension system in the country. The programmes aimed to have direct observation of the farmers' fields, training and technology transfer to the farmers and extension workers so as to enable them achieving greater productivity and production. Rajasthan and West Bengal were the first states to introduce the programme in 1974 which later spread to 16 states. The dynamic link between farmers, professional extension workers, and researchers created through the T&V system of extension contributed significantly in effective technology transfer through scientific means and ultimately higher food production.

2.2.2. Technology Assessment and Refinement (TAR)-Institution Village Linkage Programme (IVLP)

In 1995, ICAR launched this innovative programme to introduce technological interventions with emphasis on stability and sustainability along with productivity of small-farm production systems. The programme ensured introduction and integration of appropriate technologies to sustain technological interventions and their integration to maintain productivity and profitability taking environmental issues into consideration in a comparatively well-defined farm production system, marketable surplus in commercial on and off farm production system, facilitate adoption of appropriate post-harvest technologies for conservation and on-farm value addition of agricultural products, bye-products and waste for greater economic dividend and national priorities and adoption of appropriate technologies for removal of drudgery, increased efficiency and higher income of farm women. Later on, the project was upscaled at 70 centres with funding from NATP.

2.2.3. National Agricultural Technology Project

The National Agricultural Technology Project (NATP) was launched by the Indian Council of Agricultural Research (ICAR) on June 30, 1998, with the support of the World Bank, to strengthen and complement the existing resources and to augment the output of the National Agricultural Research System (NARS). The NATP was the world's biggest World Bank assisted agriculture project worth Rs. 992 crores developed and executed by NARS. The lifespan of NATP was seven years, from 1998 to 2005. NATP was the first project in NARS to shift the focus from discipline-oriented research to production system research. The NATP was the first project in NARS to involve competitive funding, and have pluralistic approach to involve and fund partners from outside NARS. NATP successfully completed a whopping total of 852 projects. Under NATP, there was a separate component on Innovations in Technology Dissemination (ITD). As part of ITD, Agricultural Technology Management Agencies (ATMAs) were piloted in 28 districts and

44 Agricultural Technology Information Centres (ATICs) were set up in ICAR Institutes and State Agricultural Universities.

2.3. Era of Food Surplus (2000 onwards)

At present, India is not only self-sufficient in food production but also and the 'net exporter of food grains' and several other commodities. This is a matter of great satisfaction to agricultural research & extension system. But alongside, the new cyclic and structural challenges of Indian agriculture has enlarged. The price discovery and realization is the most crucial cyclic problems and land fragmentation is the biggest structural issue in Indian agriculture today. This calls for enhancing productivity of land, labour and applied inputs, addressing gender and nutritional issues, reducing post-harvest losses and food wastes, attracting rural youth in agriculture with entrepreneurship development and business incubation, and managing the perpetual problem of natural resource degradation and depletion under the realm of escalating abiotic stresses.. While many developmental and research programmes were launched for far reaching impacts, the extension system has also undergone a paradigm shift. The Krishi Vigyan Kendra continued to be the knowledge and resource centre at the district level and playing a crucial role of location specific technology development and technology backstopping for the development departments or field extension system. Other than KVKs the following programmes/projects of both frontline and field extension played important role in technology delivery and dissemination.

2.3.1. Agricultural Technology Information Centre (ATIC)

As part of Innovations in Technology Dissemination (ITD) component of NATP, the Agricultural Technology Information Centres (ATIC) were established in the year 2000. These ATICs serve as a single window delivery system for services and products of research for the areas in which the concerned institute is involved. At present, there are 44 ATICs established in ICAR institutes and SAUs.

2.3.2. National Agricultural Innovation Project

The National Agricultural Innovation Project (NAIP) was launched in the year 2006 by ICAR. The overall objective of NAIP is to facilitate the accelerated and sustainable transformation of Indian agriculture in support of poverty alleviation and income generation through collaborative development and application of agricultural innovations by the public organizations in partnership with farmers groups, the private sector and other stakeholders.

3. Frontline extension

The post-independence extension programmes and interventions were more organised and systematic. ICAR started major front-line extension projects, viz. National Demonstration Project (1964-65), Operational Research Project (1972) and Lab-to-Land Project (1979). Another significant development in front-line extension was the establishment of Krishi Vigyan Kendras (KVKs) in 1974.

The activities of all the three previously launched frontline extension programmes i.e., ND, ORP and LLP were merged with KVKs. These KVKs were aimed to improve technical literacy of farmers including rural women on the principle of 'learning by doing' and 'teaching by doing'. These KVKs are currently established and hosted by the ICAR institutes, State Agricultural Universities (SAUs) and nongovernmental organisations (NGOs), Government Departments with financial support and guidance from the ICAR.

Mushroom unit

3.1. Genesis of Krishi Vigyan Kendras (KVKs)

The Education Commission (1964-66) recommended that a vigorous effort be made to establish specialized institutions to provide vocational education in agriculture and allied fields at the pre- and post-matriculate levels to cater to the training needs of a large number of boys and girls coming from rural areas. The ICAR mooted the idea of establishing KVKs (Farm Science Centres) as innovative institutions for imparting vocational training to the practicing farmers, school dropouts and field level extension functionaries. The first KVK, on a pilot basis, was established in 1974 at Puducherry (Pondicherry) under the administrative control of the Tamil Nadu Agricultural University, Coimbatore. The Planning Commission approved the proposal of the ICAR to establish 18 KVKs during the Fifth Five Year Plan Period (1974-79). In the year 1983-84, Cabinet had decided to open one KVK in each district. Since then, several new KVKs were established by ICAR during each 5 Year Plan Period. On the occasion of the Independence Day Speech on 15th August, 2005, the Prime Minister of India announced that by the end of 2007 there should be one KVK in each of the rural districts of the country. By the end of the Tenth Plan (2002-07), the number of KVKs grew to 551. So far, the ICAR has established 731 KVKs across the country and these are hosted by different agencies such as Agricultural/ Veterinary Universities, Deemed Universities, State Governments, NGOs, Public Sector Undertakings and other educational institutions.

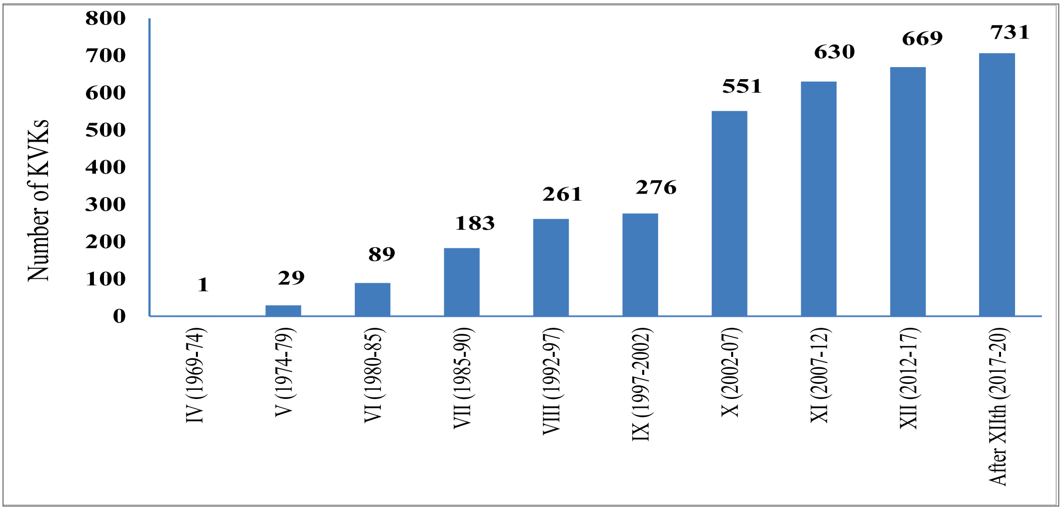

Fig. 1. Growth of the KVK network in India in different Five-year Plans

The KVKs have emerged as critical frontline extension innovation in testing, demonstration and dissemination of agricultural technologies. The mandate of KVK is technology assessment and demonstration for its application and capacity development. In addition, good quality seeds, planting materials, livestock strains, bio-products etc. are produced and supplied to the farmers for the effective adoption.

The KVK system has played a key role in transfer of modern and emerging technologies in agriculture and allied sectors leading to increase in production and productivity, development of high value agriculture like horticulture, livestock and fisheries, introduction of newer varieties for pulses and oilseeds leading to increase in income of farmers and promotion of farm-based enterprises. As technology transfer on large scale is the responsibility of the state line departments and ATMA, KVKs are playing key role in supporting and guiding field extension activities.

Agricultural Technology Management Agency (ATMA) is currently operational in 639 districts of 28 States and 3 UTs. The ATMA provides an institutional mechanism for coordination and management of Agricultural Extension System in the district. The KVK function as a frontline extension system, and ATMA- as a field extension agency.

4. Major extension approaches for priority areas

Extension has renewed itself in many facets as compared to its primordial land grant college pattern of education and top to bottom approach of technology transfer. Over a period of time, the agricultural extension has reoriented itself from production, productivity to income and marketing efficiency; pedagogic education system to on-the-job vocational training; decentralized bottom to top approach; resource exploitation to sustainable agricultural practices etc. The past experiences and learnings from programmes within India and overseas have contributed to change in the form, function and approach of present-day extension. The broad contours of the present approaches to extension are discussed in following para.

4.1. Farmer participatory approach

The entire philosophy behind this approach is to make the farmers 'active participants' at every stage of project formulation and implementation, rather than 'passive recipients' of subsidized agricultural inputs and other incentives. Many of the past projects either failed or could not sustain once the government support was withdrawn simply because of lack of farmers' participation. Farmer participation is required for problem diagnosis, process implementation, monitoring and evaluation and provision of feedback. The traditional knowledge and technologies are to be identified and technologies are to be developed keeping in mind the local conditions. For this, a strong partnership between farmer and extension agent is imperative.

4.2. Para-professional based services

Para-extension workers can supplement the traditional frontline extension system in relatively cost-effective manner. They can also work better at the grassroots level if provided with public funding support and capacity building. Empowering farmers to get control over their own lives and requirements has become essential in the present context. A number of efforts are being taken to empower farmers across the country which is discussed below.

4.2.1 Formation of Farmer Interest Group (FIG)

The main objective behind the group approach is to establish a simple and farmer oriented participatory extension mechanism which enable the government to reach large number of farmers to empower the small farmers with limited resources. The group and farmer's led extension approaches like formation of Commodity Interest Groups (CIGs) and Farm Schools are gaining momentum under the Centrally sponsored scheme on "Support to State Extension Programmes for Extension Reforms" under implementation since 2005-06 in all the States and UTs. In a CIG which is self-managed, independent group of farmers having shared goal and interest, the members pool their existing resources to get better access to other resources and also share the benefits. The institutions of CIGs, Farmer's Interest Groups (FIGs) and farmer's federation also empower farmers to decide their own price of their commodities and bargain with the traders while its marketing.

4.3. Farmer Field School

The Farmer Field School (FFS), a season long on-field training module developed by FAO nearly 25 years ago in Southeast Asia as an alternative to the prevailing top-down extension methods which sometimes do not work in complex and counter-intuitive problem like pesticide-induced pest outbreaks. In a typical FFS a group of 20-25 farmers meet once a week in a local field setting under the guidance of a trained facilitator. The learning-by-doing approach promotes farm-based experimentation, group organization and decision-making. FFS programmes have diversified, including multiple crops and livestock. Farmer involvement in the design and planning of interventions was found to be critical. The FFS farmers gain more knowledge in pest and nutrient management and actively exercise interpersonal networks to share knowledge among themselves, but very little with other farmers, involve in joint decision making, and group capacity building based on learning outcomes. The best change in the behavioral aspect is that the knowledge can be translated into practice in farming (Kumar et. al., 2022). FFS programmes increasingly relied on farmers as FFS facilitators. Short training duration for FFS facilitators raised concern about FFS quality. Even though mechanisms for monitoring and evaluation were mostly in place, capacity for data analysis and data utilization were a concern (van den Berg et al. 2020).

4.4. Private Agricultural Extension System

In India, the private sector involved in agri-business plays active role in agricultural extension, although the conflict of interest cannot be ruled out. It adds to fill the gap in input delivery and customised advisory services. These largely sector include seed and input companies, distributors and agro-dealers, service providers, food processors and retailers, and the content providers for agro-advisories. The legal commitments under contract farming does include among other, the technical backstopping and quality inputs and thus important vehicle for agricultural extension. There are an estimated 2,82,000 input dealers in India which help communities in rural or semi-rural areas and have interest in offering quality services to their farmer clients (Ferroni and Zhou 2011).

Several of private companies like Mahindra & Mahindra, ITC, DCM Shriram Ltd, TATA Kisan Sansar, Rallis, etc. have their own extension wings to reach out to farmers, primarily for the promotion of their products. The TATA Chemicals' *Kisan Sansar* (TKS) launched in 2002, has made an innovative contribution in developing the rural scenario by providing technology, information, and crop advisory services to empower the farmers along with agricultural inputs. It operates on the model of 'hub and spoke". Presently, 32 hubs cater to 681 spokes covering around 22,000 villages and approximately 3.5 million farmers. These TKS are spread across 88 districts in 7 northern and eastern States in India. Over 300 TKS spokes are running successfully in Uttar Pradesh alone (Mukherjee 2011). As the interest for a particular brand always prevail amongst the dealers of a particular company, the conflict of interest and push factor for the product irrespective of farmers' needs is the major drawback of this system. The contradictory messaging by many agencies driven by self-interest may also create confusion to the farmers.

5. Innovations in agricultural extension

With the gradual change in the context of technology application at farmers' fields, a number of new concepts and models research and extension are being evolved. The important innovations are discussed below.

5.1. Farmer Producer Organizations (FPOs)

This innovation is the prime mover for addressing the structural problem of land fragmentation and prevalence of unviable small and marginal farm households in India. This concept safely adopts the 'aggregation of produce' over pooling of land or compromise on physical boundary of the farmers' piece of land. These organizations by virtue of backward aggregation (bulk purchase of inputs for 1000 or more farmers of FPOs) and forward aggregation of output or marketing ensure the much-needed bargaining edge to farmers with input dealers for reduced cost and with the big players in the market for remunerative price of their produce. The cooperative principle underlying the FPOs makes them democratic thus overcoming tyranny of big farmers. The Producer Organizations (PO) of primary producers viz. farmers, milk producers, fishermen, weavers, rural artisans, craftsmen are also forming producer companies, provide sharing of profits/benefits among the members. KVKs have a meaningful role in capacity development of FPOs providing technology backstopping, handholding in business incubation etc. Association of FPOs in different states are also being supported by the ICAR Institutes and KVKs.

5.2. Diploma in Agricultural Extension Services for Input Dealers (DAESI)

Agri-input dealers, having one of the largest networks globally, are an important source of information related to agricultural inputs and activities to the farming community, besides the supply of inputs and informally the credit. Majority of them do not possess formal agricultural education. In order to improve their competency in agriculture to serve the farmers better as para – extension professionals, National Institute of Agricultural Extension Management (MANAGE) has initiated a self-financed "One-year Diploma in Agricultural Extension Services for Input Dealers (DAESI) Program" during the year 2003 with a course fee of Rs. 20, 000. Based on the very positive and encouraging response, the Government decided to extend this programme in all the States. The program is implemented by MANAGE through State Agricultural Management and Extension Training Institutes (SAMETIs), Agricultural Universities (AUs) and KVKs. The Department of Agriculture & Farmers' Welfare incentivize the course fee by 50% and up to Rs. 10,000/- per input dealer.

5.3. Climate-smart extension

Climate change has caused many setbacks and demands concerted efforts for solving some of the multifaceted issues spread across several departments and ministries so far as governance is concerned. The sustainability has emerged as major concern and challenge in the wake of its impact on-farm production systems and resource base. Such complex situation demands smart decisions and approach well interwoven with the active participation of researchers, extension practitioners, farmers, and developmental organizations to develop and design the techniques to combat, mitigate and adapt to risks generated due to climate change.

Under National Innovations on Climate Resilient Agriculture (NICRA) climate resilient technologies applications were carried out with several institutional reforms and community led interventions. Total 151 climate smart villages (CRVs) were developed that consists of implementing the resilient practices at a scale to cover the entire village in a saturation mode depending on the resource endowments of the farmers with one or several interventions for imparting resilience to the production systems. The number and kind of interventions implemented are largely determined by the resources available, and vulnerability status and involvement of communities.

5.3.1 Promoting climate resilience in agriculture

ICAR initiative on Climate Resilient agriculture was scaled up from 121 villages in 2018 to 446 villages in 2020-21. Total Climate resilient practices tailored to context and location specific situation under 4 modules were demonstrated by 121 KVKs. During 2018-20, as many as 30971 participatory demonstrations on NRM; 24737 demonstrations on resilient practices of short duration, drought/flood tolerant cultivars, crop diversification and resilient cropping systems and interventions covering 637890 livestock and fisheries; 4101 trainings covering 76775 farmers; 7575 extension activities covering 141544 farmers were conducted by the KVKs.

The model attracts traction of States in India and in SAARC countries. Maharashtra put the model in 5000 villages under World Bank funded Project on Climate Resilient Agriculture (PoCRA) and SAARC initiated consortium for scaling up climate smart agriculture in South Asia (C-SUCSeS) through Climate Change & Food Security (CCAFS-India) in in its 8 Member States. NABARD entered into an MoU with ICAR for climate proofing of NABARD watersheds.

5.4. Farmer FIRST Programme (FFP)

Farmer FIRST provides an opportunity for the researchers, extension personnel and farmers to work together. Under this scheme, the research initiative is decided based on need and interest of farmers where scientists' role is of facilitators. The project is being implemented at 52 centres across the country covering about 45,000 farm families.

5.5. Attracting and Retaining Youth in Agriculture (ARYA)

ARYA initiative of ICAR was undertaken in 25 districts initially to develop a comprehensive model to attract and empower the youth in rural areas to take up various agriculture, allied and service sector enterprises for sustainable income and gainful employment. The programmes also aimed at enabling the farm youth to establish net work groups to take up resource and capital-intensive activities like processing, value addition and marketing and demonstrate functional linkage with different institutions and stake holders for convergence of opportunities available under various schemes/programmes for sustainable development of youth. Over 42,000 youth have been facilitated by KVKs in 25 districts. The project is planned to be extended to another 75 districts making the total districts under this initiative to 100.

5.6. Mera Gaon Mera Gaurav (My Village My Pride)

The essence of this program is incorporating direct delivery of scientific technology and practice to farming community. Under MGMG, the scientists of ICAR Institutes adopt villages and introduce the technologies developed by ICAR in the villages. A team of four scientists adopt a cluster of five villages based upon proximity and make regular visits to the villages and extend technical guidance to the farmers. Multidisciplinary teams of scientists of ICAR Institutes and State Agricultural Universities (SAUs) have covered 13,500 villages. This is a unique model for ensuring frequent farmer-scientist interface for developing personal rapport, knowledge sharing, facilitating linkage with development departments and agencies and generates and share feedback.

5.7. Nutri-sensitive Agricultural Resources & Innovations (NARI)

Agriculture sector growth has contributed mainly to economic growth in India over the past several decades but improvements in nutrition remains a major concern. NARI is focused on empowering farm women with key areas like innovative practices to promote nutrition-sensitive agriculture, awareness and capacity development of various stakeholders, value chain, literacy campaign, etc. This will encourage intensive exchange of knowledge, good practices and governance related issues to evolve a systematic policy framework for agricultural extension systems to promote nutrition-sensitive agriculture through a network of KVKs. Madhya Pradesh became the third state in the country after Tamil Nadu and Rajasthan to provide 'wholesome' meal to poor at affordable price (Rs. 5) with the launch of *Deendayal Thali* in 49 out of 51 districts (Window to News 2017).

5.8. Knowledge System & Homestead Agriculture Management in Tribal Areas (KSHAMTA)

Keeping a view the importance of the tribal agriculture, the ICAR has thought of initiating another programme called Knowledge System for Homestead Agriculture Management in Tribal Areas (KSHAMATA) in 125 districts where tribal population is 25% or more to facilitate technology support and related inputs to the tribal farmers located in remotest places and have proved to be the nearest to the farming community for technical know- how and do how on crop, livestock and enterprise-based livelihood related activities resulting in socio-economic empowerment and sustainable livelihood security of the tribal farmers.

5.9. Value Addition and Technology Incubation Centre in Agriculture (VATI-CA)

Value Addition and Technology Incubation Centre in Agriculture (VATICA) has been conceptualized by ICAR to create a facility to provide incubation training to rural youth in processing and value addition. ICAR on its own funding support will create 3-4 units as model units in the KVK campuses. KVKs are strategically located and linked with Agricultural Universities and ICAR Institutes to identify different trades and establish trade-specific value addition and incubation centres for educating youth and the farmers to practice various components of technology management at the incubation centres and with the support from different lending agencies, they can establish their own processing and value addition units for commercial purposes.

5.10. ICT-based extension

Digital application in agriculture is the need of the hour given the penetration of mobile technology deeper in the disadvantaged and underprivileged geographies of the country with the focus on hi-tech automated precision agricultural systems. Digital tools and technologies e.g., remote sensing, automation, irrigation devices, Information Communication Technologies (ICTs) have been proving promising to farmers in different ways from production to marketing. The ICT has not only made it easy to deliver the farm advisories to millions of the farmers but escalated the quality of the extension system with complimentary effects. ICT initiatives such as web-based portals (e.g., AGRISNET, DACNET, AGMARKNET), kiosks (e.g., VKC, eChoupal), tele centers (ISRO VRC), call-based (Kisan Call Centers, IKSL), mobile applications (Pusa Krishi app, mKrishi, mKisan), video based (Digital Green initiative), etc. have been acknowledged globally for their access and reach Mass media and ICT tools help to reach out the farmers at remotest corners of the country in cost-effective and timely manner. Some of the pathbreaking ICT initiatives are discussion worthy.

5.10.1. mKisan

The mKisan Farmers' portal was developed in 2012 by the Ministry of Agriculture, Government of India. The information about seeds, fertilizers, pesticides, farm machinery, weather, market price of farm produce, package of practices, programmes and schemes, insurance, storage, credit, minimum support price are provided in local language. SMS Portal was inaugurated by the Hon'ble President of India on July 16, 2013 and since its inception nearly 327 crore messages through more than 1044 crore SMSs have been sent to farmers in the country. More than 90 lakh farmers are being provided advisory by the KVKs. These messages are specific to farmers' needs & relevance at a particular point of time and generate heavy inflow of calls in the Kisan Call Centres where people call up to get supplementary information. This portal has enabled Centre and State Departments of agriculture & allied sectors, SAUs, KVKs, Agro-met Forecasts Units, ICAR Institutes,) to provide information/services/advisories to farmers in their language.

5.10.2. DD Kisan and Community Radio

A dedicated television channel on agriculture DD Kisan was launched in 2015 to supplement and compliment technology dissemination through need based agricultural programmes. Government of India approved a policy to grant licenses for community radio stations (CRS) in December 2002. The programmes are produced by the local people, in their local dialect. Educational institutions, KVKs/SAUs/ICAR Institutes and NGOs/ Community Based Organizations (CBOs) are establishing the CRS. SAUs and KVKs have also established CRS. It benefits farmers within the radius of broadcast of CRS.

5.10.3. Kisan Sarathi

The Kisan Sarathi platform was launched on 16 July, 2021 jointly by the Union Minister for Agriculture and Farmers' Welfare and the Union Minister of Electronics & Information Technology on the occasion of 93rd foundation day of ICAR. It is an interactive digital platform to facilitate farmers to get 'right information at right time' in their desired language. It will help farmers to avail personalized advisories on agriculture and allied areas directly from the respective scientists of Krishi Vigyan Kendras (KVKs). Farmers can also learn new farming methods using it.

5.10.4. Mobile Apps

The mobile phone technology, which is comparatively new form of ICT, provides the electronic capabilities, reaches to customer, provides privacy, anytime and anywhere, contact-less services and most preferred user carry personal item (Nierinck 2008). Several commodity institutes of ICAR across the country have developed the farmer-friendly mobile Apps for crops like chickpea, rice, millets, sodic soil management, etc. The KVKs have also developed 117 mobile Apps as per specific requirements of their district, which are gaining popularity among farmers and other user categories. These Apps offer valuable information about package of practices of different crops, horticulture, veterinary, dairy, fisheries, education, market prices of various commodities, weather related information, advisory services, etc. These Apps are contributing significantly to production and productivity of farmers and can boost farming in India. Further, it is solving problems of farmers at doorstep, providing information about various schemes and improve their livelihoods and awareness.

6. Successful frontline extension: Achievements of KVKs

Farmer-centric approach of KVK scheme of ICAR enabled adoption of an array of science-based initiatives for greater outreach and higher impact.

6.1. Enhancing production and productivity of Pulses through Cluster Front Line Demonstration (CFLD)

The country was deficient in pulses with production around 16-17 million tons (Mt) up to 2015-16. In order to harness the potentials of the improved technologies on pulses productivity, 590 KVKs embarked upon heavily to demonstrate the technology package comprising of improved variety, seed treatment, weeds, pests and diseases management in farmers' fields through cluster frontline demonstrations. The productivity enhancement in the cluster demonstration ranged between 30-40% (2.2 to 3.9 q ha^{-1} in major pulse crops) which resulted in production of over 25 Mt in a short period. Quality seed was the driver of production as 151 seed hubs established at KVKs (97) made available 79725 q certified seed of high yielding pulses cultivars to farmers during 2018-20. Coupled with the price signals and other policy initiatives, these cluster frontline demonstrations proved catalytic to boost the productivity ushering into pulses revolution and making country near self-sufficient in pulses production.

6.2. Kadaknath poultry rearing initiative of KVK Jhabua spreads to 20 States

Kadaknath is an important indigenous breed of poultry inhabiting vast areas of Western Madhya Pradesh mainly the Jhabua and Dhar Districts and adjoining areas of Gujarat and Rajasthan. Uniqueness of Kadaknath desi breed is its richness of protein and unique characteristic of meat quality. KVKs in tribal dominated areas in Madhya Pradesh and Chhattisgarh established hatcheries for promoting scientific rearing of Kadaknath in the region. Promotion of Kadaknath breed by KVKs led to its spread across 20 states. Promotion of better rearing practices in back yards as free-range poultry in existing orchards and commercial production for higher economic returns catapulted the indigenous breed to a well-recognized brand.

6.3. Mass Campaign to Mitigate Crop Residue Management

Poultry farming unit developed by farmers

Burning of paddy crop residue in Punjab, Haryana and Uttar Pradesh causes a lot of environmental issues as well as loss to organic carbon, microbes and nutrients. To address this problem, a programme on Crop Residue Management (CRM) was initiated in these states through KVKs in collaboration with state departments of agriculture. An Information, Education and Communication (IEC) mechanism was built along with creation of custom hiring centres operated by farmers and farmers groups. KVK experts organized 525 hands-on training programs for 16,000 farmers, tractor owners and machine operators on management of crop residue. KVKs organized 24000 demonstrations on operating happy seeder machine and sowing wheat in standing stubbles. More than 400 field days and harvest days, 375 exposure visits to residue-burning free sites, 120 kisan melas covering a total of 6 lakh farmers were organized. Impact of IEC against residue burning is seen in the drastic reduction of burning fire events by 52% in 2021 as compared to 2016.

7. Impact of frontline extension

Investments in agricultural research and extension is low compared to other countries. The spending on extension is not commensurate with spending on research over time. There has been a gradual increase in the share of investment in agricultural research in the total GDP from 0.30% in 1990-1991 to 0.77% in 2010-2011 while the increase in the share of investment in agricultural extension in the total GDP has been modest with 0.12% in 1980-1981 to 0.18% in 1990-1991. This share remains more or less in this range for the subsequent years (Joshi et al., 2015). The return to investment in research and extension are almost equal but huge gap exists in investment in research and extension. Rate of return to agricultural R&D expenditure is quite high and investment reduces income inequality. Marginal rate of return to agricultural R&D expenditure in low-income states are as high as 9.9 compared to middle (4.4) and low-income states (3.2).

Third Party evaluation of Krishi Vigyan Kendras (KVKs) has been carried out by National Institute of Labour Economics Research and Development (NILERD), an autonomous institute under NITI Aayog 2015. The major observations and findings of this evaluation are as follows.

- It was observed that KVKs are playing proactive role in transferring new technology at field level with beneficial impacts.
- The KVKs have an edge in technology transfer over other service providers by virtue of having better technical expertise and demonstration abilities.
- About 40 percent farmers reported that they implemented the technology immediately after its dissemination by KVK and that 25 percent did so from the next agricultural season.
- On an average a KVK covers 43 villages and 4300 farmers per year. 80% of villages covered are 10 km away from KVK.
- 96% farmers' requests were attended by KVKs.
- 42% technologies adopted by farmers resulted in higher productivity, 33% resulted in high harvest income and 20% resulted in drudgery reduction.
- About 25% of persons trained started self-employment ventures.
- With the intervention by KVKs, about 80% of the farmers have modified their agricultural patterns which were related to diversification of crops and changes in cropping pattern, seed planting technique, use of fertilizers and pesticides, changes in machinery used and in water use pattern.

Besides, International Food Policy Research Institute (IFPRI) evaluated the KVKs in 2019. The major findings of Study on KVK by IFPRI are as follows:

- KVKs' efforts generated an additional net farm income of Rs. 5752 per hectare.

- Cost Benefit ratio is 1:11.78. Thus, the rate of return on expenditure on KVK is very high.
- One farmer trained by a KVK disseminates technology/knowledge to 30 fellow farmers.
- 3 FLDs can benefit 31 other farmers and 3 training beneficiaries can benefit 27 other farmers
- FLD and training primary beneficiaries have 51.8% and 21.3% higher adoption rates
- For FLDs, secondary and network beneficiaries have 12.6% and 11.5% higher adoption rates compared to non-beneficiaries, respectively.
- For training programs, network beneficiaries have 16.1% higher adoption rates compared to non-beneficiaries.

Major findings of study titled "Impact Evaluation of Central Sector Scheme (CSS) of Indian Council of Agricultural Research (ICAR) – Agricultural Extension Segment" conducted by Indian Society of Agribusiness Professionals, New Delhi during 2020 are given below.

- For training programs, network beneficiaries have 16.1% higher adoption rates compared to non-beneficiaries.
- On an average, KVK outreach found to be around 90-100 villages. With its strong ICT interventions, the outreach to villages increases to even 200 villages per KVK.
- There is increase in the outreach programs by KVKs from 2012-13 to 2019-20 in number of on farm trials by 51%, frontlines demos by 61%, farmers trained by 16% and extension personnel trained by 35%.

Over a period of time, the KVKs have emerged as an instrument of change in the technological adoptions across the production systems and largely impacting the farmers' income and profitability. KVKs have proved to be a major district level innovative institution catering the technological needs of the small and marginal farmers and of the progressive farmers to provide the technological options at the cutting-edge level. It has made very positive and visible impacts in the far flung, tribal, hilly and mountainous areas too.

The KVKs have worked in 112 Aspirational Districts in convergence mode with other departments. KVKs have played crucial role in providing extension services to farmers which has contributed in increased pulses production in the country. They promoted improved varieties of crops related to stress tolerant, drought tolerant and facilitated in identification of indigenous varieties practiced by the farmers. They have played an important role in promoting Climate Smart Villages and promoted ecosystem-based farm practices, like organic farming, IFS, crop residue management and bio-agents. KVK has trained farmers and extension functionaries on Skill enhancement and provided seed and planting materials.

The system so credibly established needs to be supported in terms of requisite manpower and financial provisions. Various Ministries and Development departments are proposing programmatic linkages with the KVK System for mutual advantages; these very moves indicate the strong urge to strengthen the KVK system further.

The ICT and Social Media applications are systematically promoted by the KVK system, as in the present and future, the role of social media would play an important role. This is crucial step towards promoting digital agriculture as well as achieving Sustainable Development Goals (SDGs) in a systematic manner. Various internet applications and media packages need to be developed. Linkages with the Common Service Centres are a welcome step in this direction.

There have been various initiatives taken up by KVKs for capacity building of women which includes Nutri-Sensitive Agricultural Resources & Innovations (NARI) project initiated in 2017-18 by KVKs to sensitize farm women and aanganwadi workers to combat malnutrition. Other than this, the women participation to the tune of 25-30 % is ensured in programmes conducted by KVKs. The KVKs are very much focused on the IFS approach and integrated delivery of the technology transfer. Therefore, the agriculture and allied sector FLDs and OFTs should be strengthened. Along with the strong backward technological linkages, there is an urgent need for looking into the income and business orientation to the activities.

The State and the Central development department have been looking at KVKs for scientific interventions. There should be adequate focus on developing such linkages without affecting the basic mandate of the KVK system evolved over a period of time. The recommendations of this study and of the previous studies synthesized indicate continuation and thereby strengthening the KVK system further.

8. Future roadmap

As ICAR shall be completing 100 years in 2029, KVK system 50 years in 2024, it is proposed for converting 50 years old KVKs into new institution of excellence named level- District-level Institute of Scientific Agriculture (DISA).

8.1. Skill development/capacity building

Commercial agriculture requires added extension services for which reorientation of existing extension system is required, including incorporating banking and financial institutions, cooperatives, etc. as extension platforms. ICT has taken over as a biggest medium to deliver farm advisory to farmers across the country. Human interface is required for interpretation, dissemination and delivery of ICT messages to client farmers for which extension workers need to be adept in handling of ICT tools. Market led extension should be given priority and farmers need to be taught to e-market their produce. Appropriate skill training of extension functionaries is needed and it is possible only through policy interventions. It is also suggested that regular positions should be filled by well qualified agricultural science graduates available across the country.

8.2. Creation of a national level farmers' database

The KVKs and other extension agencies send farm advisory through mobile messages and even through web portals. Most of such messages are sent in bulk to the farmers and are not farm specific and need based. In order to send farm specific messages extension workers should have access to the details of each farmer. The creation of a National Farmer Database of resource endowments, crops grown and operations, areas under cropping may immensely help in agricultural research and extension and providing farmer specific farm advisories. Although part of such data base is already available in PM Kisan, PMFBY and Agriculture Credit, and soil health card scheme. These are AADHAR seeded data. All these can be integrated to create the national level database.

8.3. Strengthening technology backstop ping backstopping institutions

Technology backstopping can be strengthened by establishing a four-way mode of communication, between labs, from land to lab and lab to land, and between farms. Every village can be facilitated by an Agri-Clinic and Abri-business Centre (ACABC) to offer the farmers doorstep service and also generate employment in the rural areas. The technical backstopping of the Farm Tele-Advisors needs strengthening and number of KCC can be increased. There is a growing market for agricultural journalists and broadcasters/telecasters having formal education in agricultural journalism and agricultural communication academic disciplines. Continuous capacity building of agricultural extension professionals in Agricultural Journalism deserves priority attention. Common Service Centres numbering 3.47 lakhs may be utilized to also serve as 'Extension Delivery Points'. KVKs need to be strengthened to focus on income enhancing technologies in PPP mode (value addition, post-harvest, agri-business enterprises).

8.4. Agri-preneurship and business incubation through skill development of rural youth

The ICAR schemes like ARYA and Student READY (Rural Entrepreneurship Awareness Development Yojana) and Govt. of India schemes like Skill India, Start-up India, Stand-up India, *Pradhan Mantri Kaushal Vikas Yojana* are also playing significant role in capacity building of farming community, especially the rural youth. If business motive can be effectively induced into this component, then successful agripreneurs can be developed in rural areas. Effective hand holding support and incubation should be provided to agri-startups which will attract youth towards agriculture and reduce their migration to urban areas.

8.5. Promotion of cooperatives and commodity clusters

Similar to AMUL and Mother Dairy models may be promoted in other agricultural products to take advantage of aggregation of resources. KVKs may help in capacity development of such groups in project management, fund and financing and agri-business and aggregation.

8.6. Farmers' Local and Indigenous Practices (FLIP)

Local and indigenous techniques along with the farmers' innovations need to be validated and replicated in the similar agro-climatic region. Frontline extension has a great role in up-scaling and outscaling of these technologies.

8.7. Promotion of indigenous breeds/organic farming/natural farming

The frontline extension to generate scientific evidences of natural farming and organic farming in different agro-climatic regions so that these technologies may help large scale awareness creation for viable and sustainable farm livelihoods. Improvements of desi breeds will be beneficial for farmers practicing natural farming. Building strong farmers institutions and farmer producer organizations will be beneficial for knowledge dissemination, credit, risk management and for marketing of produce of natural farming.

8.8. Farmer-led extension and group approach

The Indian extension system has been suffering from lack of adequate manpower that impacts its reach out to the farmers. The alternative is farmer to farmer extension. Group approach helps in faster and more effective dissemination of information. The Farmers' Interest Groups (FIGs), Cooperatives, Farmer Producers Companies, SHGs and various NGOs are now playing commendable roles in better farmers' participation in implementation of several extension activities. These groups are also mobilizing documentation and recognition of farmer-led innovations and for further upscaling. The recognitions to farmers innovations in the form of awards in various *Krishi melas* and other institutional arrangements have been made across the country.

8.9. ICT and social media application for enhanced outreach

Social media (WhatsApp, Face book, Twitter, Instagram, emails, blogs, App-based services, etc.) are powerful communication tools that enhance the beneficiary coverage in the shortest period of time which could be used effectively in networking farmers' and offering context-specific information. Farm-portals provide information on e-commerce, production/protection technologies, inputs/prices, e- advisories, etc.

9. Conclusion

One of the critical masses of the agricultural development is vibrant agricultural extension, particularly the frontline extension. This has been recognized by virtues of its contribution in many of the revolutions the agriculture experienced in the past 75 years. As we move along, the knowledge and skill-based agriculture shall be the new life mantra in the next decades and so. The public and private research and extension system need to rise to these expectations of the millions of farmers in the country and the region who are looking for more precise, efficient and productive technologies with a shorter gestation period matching to the local situations and the consumer preference. The relevance of agricultural extension system shall depend how quickly we can adapt to changing ecosystem of technology driven farming with much faster but dynamic man-machine interface. A robust and efficient extension system which is capable of meeting the evolving needs of farmers in the context of changing agricultural scenario is the need of the hour. Investment in extension system to create state of the art facilities for the analysis of farmers feedback and real-time response to their queries would serve to establish our credibility and growth in India. The scope of agricultural extension has expanded well-beyond its traditional role in pushing the frontiers of production and productivity in pursuit of the nation's food security. It is time to strengthen the structural framework of the extension system to fulfil its ever-widening scope.

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Poultry birds in Holy Cross KVK farm

Training program for farmers and farm women on cultivation of azolla for poultry feed

Exposure visit of paddy (MTU- 7029) seed production through SRI method , GVT- KVK, Godda

15
Chapter

International and National Collaborations in Agricultural Research and Development

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Summary

Collaborations in agricultural R&D during the last 75 years shaped the country's path for agricultural development and provided solutions to needs of the people and the planet. The initial collaborations with Ford Foundations and Rockefeller Foundations in the 1950s and 1960s helped introducing the dwarf varieties of wheat from Mexico and establishment of SAUs on the Land Grant Pattern of USA. On education, the Indo-US agreement on educational exchange, was signed on February 2, 1950 in New Delhi by Prime Minister of India and U.S. Ambassador that led to establishment of US Educational Foundation in India and the Fulbright Program in India. The national collaborations with SAUs which started with AICRP on Maize in 1957 unfolded the ICAR-SAUs partnership in subsequent decades to become one of the largest collaborative frameworks in agricultural research, education and extension globally. The international collaboration with Mexico/CIMMYT for exchange of dwarf wheat varieties/lines and ICAR-IRRI for dwarf rice varieties augmented the efforts under Green Revolution and made India food secure. ICAR-IRRI and ICAR-CIMMYT collaborations in rice and wheat later extended for development of varieties for water stressed conditions and rust resistance, respectively in India. The ICAR-ICRISAT collaborations starting with research on hybrid pigeonpea and later genomics and gene editing in pulses was also strategic. The ICAR-CGIAR collaborations expanded to strategic locations through the establishment of ICARDA's Food Legumes Research Platform (FLRP) in Madhya Pradesh and its satellite hubs in West Bengal and Rajasthan; CIMMYT's Borlaug Institute for South Asia (BISA) in 2014 at Ludhiana along with its field offices in MP and Bihar; and IRRI-South Asia Regional Centre at Varanasi in 2017. The collaborative research under network project NICRA for climate change and soils, water and plant nutrients, IFS, and agroforestry were strengthened over time. International and national collaborations in livestock and fisheries sector helped introduction of new breeds, and development of vaccines and diagnostics, quality standards, health, nutrition and hygiene standards and protocols. The collaborations in the farm machinery and power helped development of energy efficient farm implements. The bilateral cooperation in agricultural R&D extended to all continents touching to 65 nations in 2020-21. India as a founder member of SAARC, BRICS, BIMSTEC shaped regional cooperation in agricultural R&D with member Nations. The agreements between the Governments of India and

Israel led to establishment of high-tech farm demonstration unit at IARI in 1996 and later the Centre of Excellence (CoE) for Horticulture in the States under MIDH. The Hi-tech Centre and CoEs served as demonstration and training center for latest technologies for protected cultivation. More recently in 2021, BRICS-ARP for collaborations and exchange of information and ideas for research and innovations amongst BRICS countries was established and made operational in India. ICAR also established collaborates with UN Agencies like FAO, UNDP, UN-CAPSA and many organizations such as CABI, NACA, APAARI, APCAEM, ISTA and ISHS. These collaborations resulted 54 foreign aided projects on ground in 2019-20. India made an impressive foot print in its neighborhood through the establishment of ANASTU in Afghanistan, ACARE in Myanmar and Deemed University for Agricultural Education in Nepal. Besides, several initiatives and fellowships implemented in Africa. The ICAR-Industry collaborations that started in 1990s, have been extended for technology dissemination, upscaling and validation. The international collaboration and its implementation sharpened after 2014 with creation of International Relations (IR) Division in ICAR.

1. Introduction

In a man-machine-animal-plant-competing world, the sustainable development of agriculture & allied sectors took the central stage in all planned efforts for the progress in an agrarian economy like India. The agriculture and allied activities, otherwise also, was the major source for economic growth at the time of independence as evidenced by their lion's share in the Nation's GDP. Amongst the various subsectors of agriculture, cropping enjoyed the centrality immediately after the independence for ensuring the food security. Gradually, agriculture diversified towards allied activities for raw materials like textiles, dairying, logging, fishing, etc. Agriculture, in its entirety, have been pivotal for ensuring food security to all on a given geography and income for those who opt it as a primary occupation. As the population grew and income increased, the dietary intake and demand diversified and consumption also increased which has to be met through the finite land and water resources. The luxury of abundance of these resources started drying up and stresses to plant, animal and mankind started escalating due to their over exploitation. The agriculture research through well-orchestrated national and international collaborations helped the country's efforts to address the food security concerns, raising the income of the farmers and livelihood support to those who depend on the farms and farm related activities.

Pre-independence India experienced severe famines and stresses that continued after independence also. Immediately after independence, the agreements between India and Ford Foundation and Rockefeller foundation during 1951-1959 paved the way for many significant beginnings in Indian agriculture in subsequent decades (Table 1). These included community development programme (CDP), establishment of State Agricultural Universities (SAUs) and introduction of semi-dwarf Mexican wheat varieties. The hurtful memories of PL 480 after two successive severe droughts during 1964-66 still daunts many due to much undignified remarks of 'ship to mouth' to the country. The international collaborations and cooperation caused a turned around the entire scenario and helped achieving the successes in Indian Agriculture. The beginning of the international collaborations and joint research was strengthened through the MoUs with foreign countries, international organizations and foreign universities and institutes. The process of research collaborations was hastened post 1973 with the establishment of Department of Agricultural Research & Education (DARE) as a separate Department under the Ministry of Agriculture in the Government of India. The DARE was designated as the nodal department for all the international collaborations for research. The collaborations with National Agencies and organizations including industries were also sharpened between ICAR and the institutions, universities, and organizations working in the field of agriculture and allied sector.

Table 1. Milestones in international and national collaborations in agricultural research and development

Year	Milestone
1950	Establishment of US Educational Foundation in India to administer the Fulbright Program in India.
1951	Ford Foundation signed an agreement of US$ 1.2 million with GOI to train personnel for the CDP. Rockefeller Foundation committed to fund agricultural work in India and sent a team to India.
1952	U.S. Technical Cooperation Administration pledged $50 million to support the CDP and Rural Infrastructure in India. Rockefeller Foundation launched its collaborative India Agricultural Programme (IAP).
1956	Rockefeller Foundation granted US$ 1.38 million to help India develop the IARI and begin cereals improvement program.
1957	Douglas Ensminger of the Ford Foundation wrote a briefing paper to PM after his 3 months extensive travel of rural India. AICRP on Maize started in 1957 opening of the ICAR-SAUs partnership.
1959	Norman Borlaug visited India. Semi dwarf varieties of wheat came into the focus of researchers in India. Later, a Mexican wheat variety imported to India.
1964	Seed of two Mexican varieties (20 tons each) for demonstration at 1000 acres was requested from Dr. N.E. Borlaug.
1965	Demand for 200 tons of seed of Sonora 64 and 50 tons of Lerma Rajo 64A placed to Mexico for demonstration at 5000 farmers' fields. Rockefeller Foundation was requested to provide 5000 tons of Mexican wheat for planting in 1966 rabi season.
1966 -67	18,000 tons of wheat seeds shipped from Sonora, Mexico. Green Revolution varieties of wheat covered over 5 lakh ha in India.
1972	MoA with Ford Foundation for establishment of ICRISAT in India.
1973	DARE created in GOI and designated nodal department for international and national agricultural research matters.

Year	Milestone
1974	MoU with CIMMYT, Mexico and IRRI, Philippines for strengthening wheat and maize and rice research in India.
1991	ICPH 8, the world's first pigeonpea hybrid released jointly by ICAR and ICRISAT.
1996	India and Israel led to establishment of high-tech farm demonstration unit at IARI in 1996.
2011	BISA established at Ludhiana, India with collaboration of CIMMYT and its two R&D Centres in Bihar and Madhya Pradesh.
2016	Food Legume Research Platform of ICARDA started in Madhya Pradesh.
2017	IRRI South Asia Regional Centre established in Varanasi, Uttar Pradesh.
2021	BRICS-ARP launched for cooperation in Research & Innovations amongst BRICS countries.

2. Agri-R&D pre-independence and collaborations

The institutional mechanisms of agricultural development in India started as early as 1869, when Lord Mayo, Governor General in India proposed the Department of Agriculture in the Government of India with its counterparts in the provinces. Twenty years later in 1889, the Imperial Bacteriological laboratory was established in Pune which was later shifted to Mukteshwar in 1895 and subsequently development of its campus at Izatnagar, Bareilly in 1913. However, the first organized and geographically balanced initiative was introduced by Lord Curzon, in 1905 and the Imperial Agricultural Research Institute was established at Pusa, Bihar followed by 6 agricultural colleges in the different provinces, besides central institutions. In 1929, on the recommendations of Royal Commission on Agriculture, Imperial Council of Agricultural Research (ICAR) was set up under the Registration of Societies Act 1860. Few Commodity Committees were also existing at the time of establishment of the Imperial Council of Agricultural Research. These Committees used to provide advisory services to the government and on a limited scale taken up research on cotton, lac, jute, sugarcane, coconut, tobacco, oilseeds, arecanut, spices and cashewnut, etc. Majority of these activities were standalone and limited to a delineated geography with least domestic collaboration and almost absent international linkages.

3. Agri-R&D post-independence and collaborations

In 1951, the Ford Foundation, a US based NGO signed an agreement with Government of India for providing a support of US$ 1.2 million for the capacity development of Indian personnel in community development programme (Perkins 1990). In the similar vein, the Rockefeller Foundation also committed to fund agricultural work in India and sent a team to study the agricultural and community situation in India (Perkins 1997). In 1952, Rockefeller Foundation launched its collaborative India Agricultural Programme (IAP) and the Technical Cooperation Administration of US, a precursor of USDA assured for $50 million to support the community development programme (CDP) and rural infrastructure programmes. In order to study the Indian universities and reorganize them on Land Grant

Pattern of USA, an Indo-American team was constituted in 1955-56. In the same year, Rockefeller Foundation granted US$ 1.38 million to develop the IARI and initiate the cereals improvement programme (Gary 2002). Following the USDA's publication *India's Food Crisis and Steps to Meet It,* Norman Borlaug visited India in 1959 which was the beginning of new research for semi-dwarf wheat varieties in India. During 1964 to 1967, the concerted efforts of the policy planners and researchers in India helped augmenting the Mexican wheat varieties touching to its acreage to over 5 lakh ha in 1966-67 (Perkins 1990).

The research on cotton, oilseeds and millets were intensified with the implementation of the Project for Intensification of Regional Research on Cotton, Oilseeds and Millets (PIRRCOM) between 1954 to 1957. The first ever orchestrated institutional linkage and partnership between ICAR and SAUs that unfolded the successes in agriculture in subsequent decades was the establishment of AICRP on Maize in 1957. Based on the learnings of the AICRP on Maize, the AICRPs on important commodities, natural resources, inputs, farm machineries, livestock, social activities were started subsequently. ICAR-SAUs is the largest collaborative framework globally, in agricultural research education and extension. When population was low, single crop in a year with traditional varieties and practices was the rule rather than exception. The farmers used to grow traditional varieties of all crops. Post-World War II, the use of synthetic fertilizers became popular for increasing the productivity of foodgrains. India started looking for a plant type which should respond to heavy fertilizer usage. In 60s the rice varietal development got a shot in the arm with the help of International Rice Research Institute which helped in evolving dwarf high yielding varieties by using the gene from semi-dwarf Chinese varieties. The AICRP on Rice, launched in 1965, coordinated the interdisciplinary and inter-institutional research on rice domestically that helped improving the productivity, production and profitability of the farmers. The development of Taichung (Native)-I from the semi-dwarf mutant followed by the Padma and Jaya varieties were the initial but a major breakthrough. Subsequently, several semi-dwarf varieties of high yield potential were released. Similar efforts were also made in wheat. In 1963, Norman Ernest Borlaug's new semi-dwarf, disease-resistant varieties, revolutionized the spring wheat in Mexico. Dr. C. Subramaniam, the then Union Minister for Agriculture and Dr. M.S. Swaminathan, former Director General, ICAR along with team of scientists, after assessing the possibility of increasing the production of wheat through the use of Mexican wheat varieties, introduced 5 dwarf varieties, Lerma Rojo 64-A, Sonora 63, Sonora 64, Mayo 64 and S 227 along with about 200 other breeding lines in 1963. These varieties were stiffer and shorter and relatively photo-insensitive and capable of high yields at high doses of fertilizers, irrigation and other inputs. Subsequently, the collaboration with International Maize and Wheat Improvement Centre (CIMMYT), Mexico was established in 1973 signing the MoU between ICAR and CIMMYT. The success in other field and horticultural commodities also happened due to domestic and international collaborations particularly the SAUs and the Consultative Group of International Agricultural Research (CGIAR) institutions, respectively.

The field crops varieties much responsive to fertilizers and irrigations were vital revolutions in plant types but resulted into new challenges in soil and water management. The multiple cropping became the order of the day post Green Revolution which intensified the man and machine activities on land causing the soil and water issues along with the concerns of water stressed cropping in rain dependent agriculture. This led to the establishment of AICRP on Dryland Agriculture (AICRPDA) in 1987 with strengthened collaborations with SAUs. which provided scientific solutions for moisture conservation, crop production, selections of varieties, crops and cropping systems, crop substitution, alternate land use, etc. for almost all geographies in India. More value was added in these efforts with the establishment of AICRP on Agrometeorology in the subsequent years. The research on long-term fertilizer experimentation, soil test crop response, micronutrients, salt affected soils, rainwater management, integrated nutrient management, integrated farming systems, climate variability, and agro-forestry, etc. also touched new high with domestic and international collaborations during the last 75 years. The parallel efforts also continued for international and national collaborations in the livestock and fisheries sector which helped in developing new breeds, quality standards, strains and fingerlings, vaccines and diagnostics etc. The collaborations in research on farm implements and machinery proved promising in enhancing the use efficiency and reducing the cost of cultivations besides, reducing the drudgery in farm operations. The frontline extension system in India started with the first KVK established in Puducherry in 1974. At present each district in India has one KVK, many big districts are having 2 KVKs. Today, the National Agricultural Research System is a two-tier system, comprising of ICAR at National level, and State Agricultural Universities (SAUs) at state level.

In 2014, ICAR established International Relations (IR) Division to facilitate the initiatives of international cooperation and smoothen the functionalities between DARE and ICAR. The International Relations Division was mandated to have the global technology foresighting, enable the research collaboration to reach beyond borders and funding and facilitate SMD-Institute Interface with DARE.

India suffered the most devastating two consecutive drought during 1964 and 1965 and resorted to import wheat from USA under PL 480 on at relatively low prices and on rupee payment. However, the transaction with US landed into trouble due to India not supporting American bombings at Hanoi and Haiphong under Vietnam War. The ICAR entered into collaborations in research on rice and wheat that sowed the seed of food security in the country. During 1951-1971, when the country was likely to reap the benefits of technological advancement due to these research collaborations, more than 18.55 crore people added to our population making it 1.5 times (MoAFW 2019). Resounding confidence came from the fact that the growth in wheat availability outpaced the growth in population and that could happen due to concerted efforts of collaborative research of India with international organizations and domestic organizations and institutions (Fig. 1).

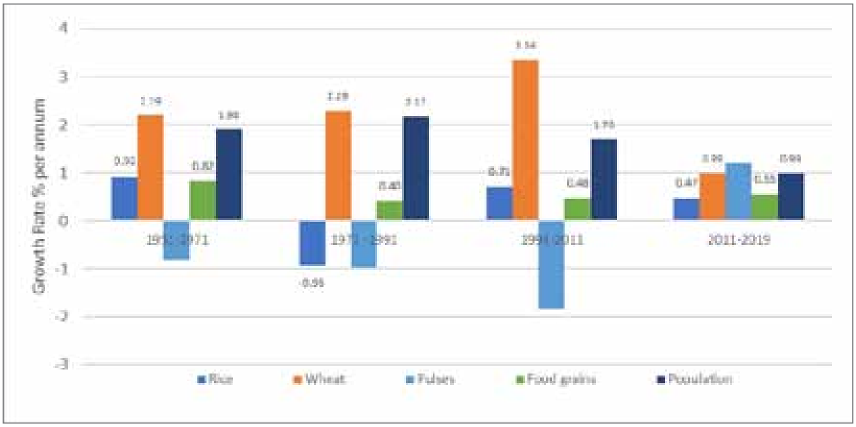

Fig. 1. Growth rate in population and food grain availability

3.1. Intensification and spread of international collaborations

The international cooperation in agriculture research and development has different dimensions and level of engagements. Under the bilateral cooperation arrangements between Government to Government, the Department of Agriculture Research and Education (DARE) or Department of Agriculture and Farmers Welfare (DAFW) represent the Government of India to sign the MoUs with the department handling agriculture R&D of the partnering country. The Figure 2 presents the spread and intensification of bilateral international cooperation in the field of agricultural R&D. Over a period, the cooperation has extended to all the continents, the most intensive being in Asia, Africa and Europe (MoEA 2021) (Fig. 2). During last decade the collaboration in fisheries got sharp focus with India entering into bilateral cooperation agreement with Norway (2010), Bangladesh (2011), Morocco (2014), Vietnam (2014) and Iceland (2019). The most significant bilateral agreement of India and Israel in the field of Hi-tech.

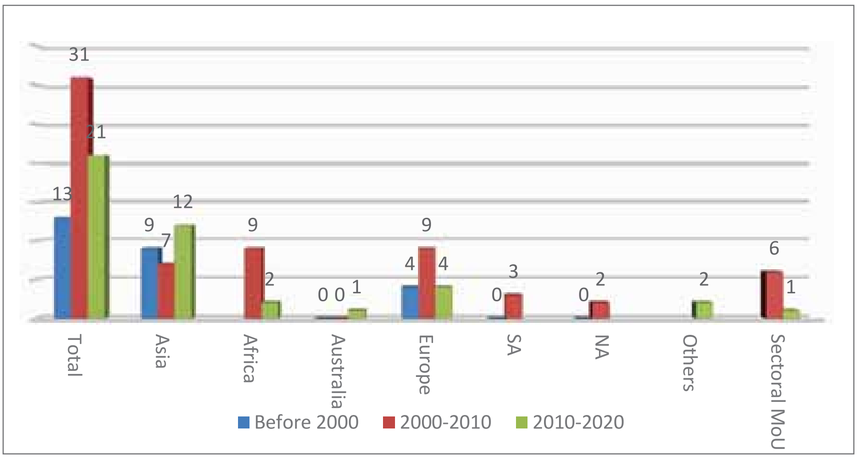

Fig. 2. Bilateral and multi-lateral memorandum of understandings (MoUs)

horticulture and protected cultivation dates back to 90s. In 1996, the much-celebrated Indo-Israel Centre for Protected Cultivation was established at IARI with ICAR-Israel joining hands for contributing to its development. Later, Centre of Excellence (CoE) for Horticulture were established in collaboration with Israel, Netherland and Germany under Mission for Integrated Development of Horticulture (MIDH). These CoE serve as demonstration and training centre for latest technologies and source of planting material for horticulture development. Israel and Netherlands provided technical support and training to the Indian participants/ technical personnel while financial support for establishing the COEs was provided by the Centre Government and States. The funding support of 8 million Euros are committed by GIZ under Indo-German collaboration. The land for CoEs is provided by the State Governments.

The cooperation was also established between ICAR and foreign Institutes/Universities. ICAR entered into MoUs/MoAs with Philippine Council for Agriculture and Resources Research, Philippines; Bangladesh Agricultural Research Council (BARC), National Institute for Agricultural Research (INRA), International Fertilizer Development center(IFDC), USA; International Centre for Genetic Engineering and Biotechnology (ICGEB), Italy; National Agriculture Research Institute, Lima, Peru; International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal; National Agricultural research organization (NARO), Uganda; Agricultural Research Centre, Egypt; Centre for International Research on Agricultural Development (CIRAD), France; Cornell University, USA; Chinese Academy of Agricultural Sciences (CAAS), China; University of Western Australia, Australia; National Institute of Research on Forestry, Agriculture and Livestock, Mexico; Fishing and Aquaculture Development Centre of ElSalvador, Michigan State University (MSU), USA; Ethiopian Institute of Agriculture Research (EIAR), Ethiopia; KazAgro lnnovations, Kazakhstan; University of Nebraska, USA; Purdue University, USA; Royal Botanic Gardens, United Kingdom; Dhofar University, Oman; University Queensland, Australia; OHIO State University (OSU), USA; University of Edinburgh Scotland, UK; ; Seychelles Agricultural Agency, (SAA) Seychelles; PNG University of Technology, Papua New Guinea; Brazilian Agricultural Research Corporation (EMBRAPA), Brazil; Belarusian State Agricultural Academy (BSAA), Belarus; University of Copenhagen (UCPH), Denmark; Rwanda Agriculture and Animal Resources Board (RAB); Agricultural Research Council, South Africa; Tajik Academy of Agricultural Sciences, Tajikistan; Western Sydney University, Australia; International Bamboo and Rattan Organization, P.R. China (INBAR); World Vegetable Centre (AVRDC), Taiwan; Hawassa University, Hawassa, Ethiopia; Heinrich Heine University (HHU), Germany; Donald Danforth Plant Science Center (DDPSC), USA; and Faculty and Graduate School of Agriculture, Kyoto University, Japan.

ICAR-SAUs collaboration also extended beyond AICRPs over time. Several ICAR Institutes inked MoUs with SAUs for collaborations in higher agricultural education. ICAR-IISWC with CCS University and SGRRU; ICAR-CICR with PDKV, Akola; ICAR-NIASM with MAU, Parbhani; ICAR-CIFE with CAU to facilitate collaboration in academic, research and training programmes. ICAR also signed MoUs with Ramakrishna Mission Vivekanand University, Kolkata and Amity University, UP for knowledge sharing, collaboration, cross learning, innovation and extension in agriculture.

The agricultural cooperation within the several multilateral frameworks such as SAARC (South Asian Association for Regional Cooperation), ASEAN (Association of Southeast Asian Nations), IBSA (India, Brazil and South Africa), BRICS (Brazil, Russia, India, China and South Africa) were also strengthened. The most intensive collaboration has been developed between ICAR/DARE and CGIAR Centres. Apart from CGIAR, the MoUs have also been entered with Centre for Agriculture & Biosciences International (CABI), Food and Agriculture Organization (FAO), Network of Aquaculture Centres in Asia-Pacific (NACA), Asia-Pacific Association of Agriculture Research Institutions (APAARI), Centre for Alleviation of Poverty through Sustainable Agriculture (UN-CAPSA), Asian and Pacific Centre for Agricultural Engineering and Machinery (APCAEM), International Seed Testing Association (ISTA), International Society for Horticulture Sciences (ISHS), etc.

ICAR has also established collaboration with FAO for setting up Indian Network of Fisheries and Animals for antimicrobial resistance (INFAAR) in 2017. ICAR- NIVEDI was given the responsibility for the overall technical and data management operations of the network with NBFGR for coordinating technical activities of laboratories from fishery sector.

The strong linkages with international research organizations and scientific institutions across the world also played positive role in eliminating the insecurity on food front from the country (ICAR 2017). These organizations/institutions helped through mutually agreed cooperation framework in finding the solutions against the challenges posed from climate change, insects-pests and virus infections in crops and livestock. Many has helped in creating the state-of-the-art facility for advance research in plant, livestock and fisheries. The recent advances in basmati rice, multiple disease resistance in wheat, tomato, rice, etc. along with genomics in pigeon pea, chickpea, rice, tomato, etc. are some examples to cite.

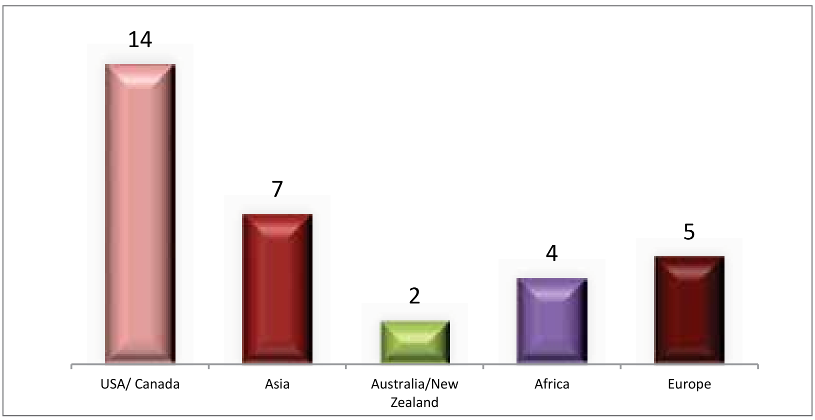

Fig. 3. MoUs of ICAR with other countries

While we began with the CGIAR institutes initially, our horizontal spread increased substantially in the next decades leading to deepening of global foot prints across continents (Fig. 3). Besides direct participation and MoUs, the ICAR/DARE also participates in the international cooperation framework signed by the Departments of (i) Agriculture & Farmers Welfare; (ii) Animal Husbandry & Dairying; (iii) Fisheries. Ministry of External Affairs and the Ministry of Commerce constituted Joint Working Groups (JWGs) and Joint Commissions which have agriculture research component. DARE/ICAR has been an active partner in several of the international collaboration signed by Ministry of Science and Technology DARE /ICAR also participate in such JWGs and JCs. The MoUs signed between DARE/ICAR and foreign countries/agencies promote research and education through human resources development, exchange of information, technology and germplasms, etc. During the last three years, a total of over 688 Scientists/science leaders were deputed abroad under these programmes.

3.2. Collaboration of ICAR with CGIAR

The DARE entered into a MoA with the Ford Foundation (on behalf of CGIAR) in 1973 and subsequently the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) was established at Hyderabad in India (Table 2). The collaborations with CIMMYT and IRRI was established in 1974 that gave a new boost to our research & development of wheat and rice in initial years of green revolution and to maize and rice-based systems in subsequent years. The work on potato improvement and protection was strengthened with the collaboration of CIP established in 1975. Gradually our collaborations expanded covering almost all the fields like crops, horticulture, animal sciences, fisheries, biodiversity, water, agroforestry and policy. Today ICAR has active MoUs with 12 out of 15 CGIAR Institutes that have helped bolstering our efforts for R&D on agriculture and food (Table 2). Along with ICRISAT, Government of India also enabled setting up of 11 regional offices and country offices out of 14 CGIAR Research Centers. Our contribution to CGIAR have been acknowledged as donor member of CGIAR System for decades. India is one amongst the many donor countries having voting rights in the CGIAR system Council. This is because our sizeable contribution through Window-I and Window III of the CGIAR System. The research collaboration involves enhanced cooperation in germplasm exchange and variety & technology development to achieve higher productivity and better-quality produce. Besides, the strategic areas such as utilization of rice fallows, watershed development, rainfed/dry land agriculture and water management and working together for doubling farmer's income. The ICAR-CGIAR collaborations with CIP for potato, ILRI for livestock, WorldfFish for fisheries, ICRAF for agroforestry, IWMI for water management has also strengthened over time. Over 1000 accessions of diversified potato supplied to India by CIP which helped developing 8 potato varieties by CPRI. Two processing varieties of potato developed using CIP accessions as male parents occupy over 100,000 ha area in India. These varieties fetch 20-25% higher price in wholesale over HYVs. Besides, training to the scientists on innovative technologies like aeroponic for seed production, marker assisted selection, GIS, crop modeling, TPS production technology, etc were provided at CIP, Lima.

ILRI implemented collaborative projects in the region including Cereal System Initiative South Asia (CSISA), Enhancing livelihoods through livestock knowledge systems (ELKS), Milk India Tanzania (MilkIT) Project, Farm Animal Genetics Resources (FAnGR), India Mozambique Goat (IMGoat) project, Climate Change, Agriculture and Food Security (CCAFS), etc. Presently ILRI-ICAR collaboration is driving research on assessment of economic impact of priority animal diseases and their control; genome wide association study in indigenous poultry breeds/varieties; methane emission and its mitigation and multi-dimensional improvement of food-feed crops including deconstructing ligno-cellulose biomass**.** The research priorities of ICAR-WorldFish collaborations have helped environment foot print analysis of carp and pangasius farming systems in India and yield gap analysis and on farm performance evaluation of genetically improved varieties e.g., Jayanti rohu and freshwater prawn; productivity enhancement from wetlands and flood plains and development of specific fish products for the pregnant women and children of 6-24 months age.

Table 2. MoA/MoU and work plan with CGIAR centres

Year	Name of the CGIAR centre
1974	International Maize and Wheat Improvement Centre (CIMMYT), Mexico.
1974	International Rice Research Institute (IRRI), Los Banos, Philippines.
1975	International Potato Centre (CIP), Lima, Peru.
1976	International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad, India.
1985	World Agro-Forestry Centre (ICRAF), Nairobi, Kenya.
1986	International Centre for Agricultural Research in the Dry Areas (ICARDA), Beirut, Lebanon.
1988	International Food Policy Research Institute (IFPRI), Washington, USA.
1996	World Fish Centre (WFC), Penang, Malaysia.
1996	Biodiversity International (BI), Rome, Italy.
1996	International Water Management Institute (IWMI), Colombo, Sri Lanka.
1998	International Centre for Tropical Agriculture (CIAT) Palmira, Colombia.
2004	International Livestock Research Institute (ILRI), Nairobi Kenya and Adis Ababa Ethiopia.

Currently, 112 research projects are under implementation in various ICAR Institutes with CGIAR Centres (Table 3).

Table 3. Research projects under operation with CGIAR centres

CGIAR centre	No. of projects	ICAR Institute	Commodities/Resources
International Maize and Wheat Improvement Centre (CIMMYT), Mexico	18	3	Maize, Wheat, NRM

CGIAR centre	No. of projects	ICAR Institute	Commodities/Resources
International Rice Research Institute (IRRI)	14	22	Rice, NRM
International Potato Centre (CIP)	1	2	Potato, Sweet potato,
International Research Centre for Semi-Arid Tropics (ICRISAT)	13	36	Chickpea, Pigeonpea, GN, Pearlmillet, Finger millet, Sorghum, NRM, ICT
World Agro-Forestry Centre (ICRAF)	20	11	AF Systems, Ecosystem services
International Centre for Agricultural Research in the Dry Areas (ICARDA)	5	10	Legumes, cereals, forage & fodder crops, NRM, crop-livestock systems
International Food Policy Research Institute (IFPRI)	5	5	Policy Research
World Fish Centre (WFC)	3	3	Fisheries and Aquaculture
Biodiversity International (BI)	9	14	Collection of germplasm, Distribution under SMTA
International Water Management Institute (IWMI)	9	6	Resource, Recovery & Reuse of water
International Centre for Tropical Agriculture (CIAT)	6	4	Tropical commodities
International Livestock Research Institute (ILRI)	9	12	Livestock and Poultry, Value chain, Health

This global partnership helped India to harness the potentials of global germplasm. The screening of global germplasm for disease resistance in field crops have helped in development of landmark varieties in rice, wheat, maize, millets, etc. that have revolutionized the agriculture in India. The recent achievements like Swarna sub-1 for flash floods situations and HD 6927 wheat with resistance to blast and rust are the testimony of the strong and fruitful cooperation with IRRI and CIMMYT (based on information from NBPGR and the CG Centres in India). The region-specific varieties like JG 11 and JG 14 in chickpea and ICPL197 in pigeon pea developed in collaboration of ICRISAT have also helped in enhancing the production of pulses in India. Similar achievements have been noticed in other field crops and natural resources as well. The IFPRI has been providing very useful policy insights and feedbacks through collaborative research with NIAP and other ICAR and SAUs on all important policies in agriculture. The collaboration with CGIAR has taken even deeper dive in India during last decade with its strengthening and expansion to subnational level. The establishment of ICARDA's Food Legumes Research Platform (FLRP) at Amlaha, Sehore, Madhya Pradesh with Satellite Hubs in West Bengal and Rajasthan for research and outreach in pulses and Borlaug Institute for South Asia (BISA) in 2014 at Ludhiana to strengthen the research on wheat and maize in India and south Asian region along with BISA's field offices in MP, Bihar and Telangana for location specific research and outreach is the welcome turn around. The IRRI-South Asia Regional Centre has been established at Varanasi for providing training and capacity development in seed sector in rice as well promoting new varieties in the eastern India. The collaborations with CGIAR centres enabled exchange of over 2 lakhs of germplasm for explorative and futuristic agricultural research (Fig. 4). In addition, as high as over 5 lakh samples are imported from the CGIAR nurseries for testing at different locations in India. The ICAR-CGIAR collaboration helped capacity development of about 39682 researchers and extension personnel and development of 969 crop varieties through the use of their germplasm or bred directly for India.

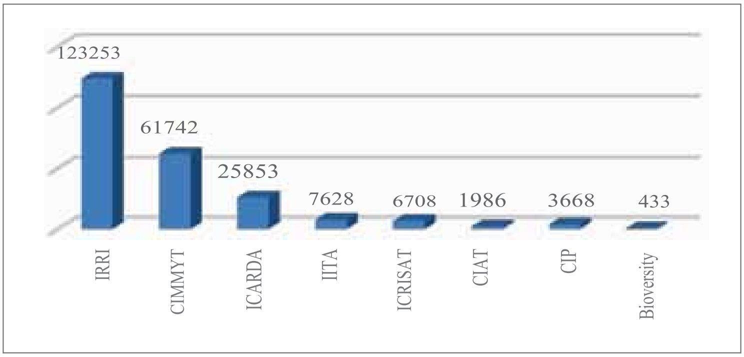

Fig. 4. Germplasm exchanged with the CGIAR centers

4. Multilateral and regional collaboration

4.1. South Asia Association for Regional Cooperation (SAARC)

ICAR/DARE is a permanent member of the Governing body of the SAARC's Agriculture Centre (SAC). Our cooperation in extending the expertise and capabilities has helped training of over 100 agricultural professionals and scientists of SAARC Member States so far. During last decade, training in the areas of soil health, climate smart agriculture, salt affected soil reclamation, agro-forestry, aquaculture, fish processing quality, herd health management of dairy buffalo, animal reproductive biotechnology and field epidemiology in veterinary science conducted. Indian Scientists have given their services at different capacities in R&D and management of SAC.

During 2018-19, PhD scholarship in Agricultural Biotechnology has been instituted by the SAC to promote cooperation in agricultural education. IARI enrolled one student in the PhD program. Two more SAARC PhD Scholarship, one each in Animal Science at ICAR-IVRI and Fisheries at ICAR-CIFA were approved in 2020-21. ICAR has been conferred a certificate of appreciation on 20th August, 2018 in recognition of its commendable contribution in the agricultural growth in the SAARC region. ICAR experts provide their inputs in a number of sectoral and theme-based consultation held under the SAC including the SARC Agriculture Vision for 2030.

4.2. Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC)

Agriculture is one of the 14 areas adopted in charter of the BIMSTEC in 2007, Republic of Myanmar being the lead country for agriculture. Amongst the significant achievements in agriculture so far under BIMSTEC are one meeting of agriculture ministers on 12th July 2019, senior officers meeting on 11 July, 2019, 8 agricultural experts' meetings, workshops on good agricultural practices (GAP) and agricultural trade and investment have been held. In the 4th Expert Group on Agricultural Cooperation meeting held on 6-7 April, 2015 in Kathmandu, Nepal, India floated the concept notes on "South-South East Asian Diagnosis Network for Ensuring Bio-security and Bio-safety" covering the area of crop/animal/fisheries, and "Human Resources Development in Agriculture". Following the first BAMM, the International Seminar on Climate Smart Farming Systems was organised by ICAR on 11-13 December, 2019 in New Delhi for the benefit of the BIMSTEC countries in which 13 delegates from BIMSTEC nations participated. India presented its experiences, best practices for enabling climate resilience in the BIMSTEC countries and organised the field visits. During 2021, India organized the expert group meeting. The group identified 9 areas for enhancing the capacities by Indian expert institutions in agriculture & allied activities. Besides, 6 slots of scholarships one each for the 6 nations other than India was to be sponsored by India. The training and expert consultation was also planned on seed sector and transboundary diseases.

4.3. Association of South East Asian Nations (ASEAN)

India-ASEAN working relationships on agriculture and forestry stretched over 25 years since now. DARE is the nodal department for this relationship in agriculture. Several projects related to exchange of experts and farmers for training and capacity development in agriculture and agroforestry sectors have bene implemented under the cooperation. The projects for Higher Agricultural Education under ASEAN-India Fellowships, women empowerment through cooperatives, training on organic certification for fruits and vegetables. etc. The Medium-Term Plan of Action for ASEAN-India Cooperation in Agriculture and Forestry for 2021-2025 was adopted in the 6th ASEAN-India Ministerial Meeting on Agriculture held on 21st October 2020 virtually in New Delhi. The priority areas included scholarships, exchange visits for farmers, climate-smart agriculture, application of robotics and drones in agriculture production and electromagnetic waves in food processing, promotion of post-harvest technology for fruits and vegetables, and transboundary diseases and health management.

4.4. Agriculture cooperation of G-20 nations

Group of 20 major economies (G-20) offers unique opportunities to the Chief Scientists governing national level organizations to discuss and develop road map for science-led development processes. The process started in 2011. In 2016, India agreed to participate in the working group on Agriculture Technology Sharing (ATS), a group formed in the meeting. ICAR has been contributing in the global critical areas like climate change, food security, agri-food system, transboundary diseases and zoonosis, etc. In the 9th Meeting of Agricultural Chief Scientists (MACS) of G20 held at Al Khobar, Kingdom of Saudi Arabia on 17-19 February, 2020, India suggested the need of regional cooperation among G 20 nations in monitoring and forecasting transboundary insects/ pest's movement using spatial techniques & information technology, which was later adopted in final draft communique of MACS. During 2021, the 10th MACS was held virtually. India presented its initiatives on one health and climate resilient and resilient agri-food systems.

4.5. BRICS agricultural collaboration

Since its formulation in 2009, India has been actively engaged to give a shape to this multilateral organization. India organized BRICS expert consultation on climate smart agriculture in 2012 and proposed BRICS Agriculture Centre was by India. In 2013, India presented its experiences on climate smart technologies in the seminar on Climate Smart Agriculture organised by South Africa. In 2015, establishing a virtual Agricultural Research Platform (ARP) was agreed by the Expert Committee. The secretariat of BRICS-ARP was decided to be established at New Delhi under the governance of DARE. On 16th October, 2016, the Member Nations signed the MoU for establishment of BRICS-ARP. The ex-post-facto approval of the Cabinet of Government of India was given on 2nd August, 2017. The BRICS-ARP conceived to serve as global platform through science led agriculture for sustainable and resilient agri-food system addressing the hunger, malnutrition, poverty and inequality between farmers' and non-farmers' income. It shall facilitate enhancing agricultural trade, bio-security and climate resilient agriculture. India hosted BRICS Agriculture Expert and BRICS Agriculture Minister Meeting being the BRICS Chair for 2021. The BRICS-ARP with the domain name of http://barp.org was made operational on 27 August, 2021 with its announcement by the Hon'ble Agriculture Minister. The BRICS Agriculture Action Plan for 2021-24 focusing on agri value chains, agrobiodiversity for nutrition, climate change management for resilient agri-food systems, digital agricultural solutions, One Health approach and trade development was adopted under the BRICS with India's Chairmanship on 27 August, 2021.

5. India's foot-prints in neighborhood

5.1. Afghanistan

The Afghan National Agricultural Sciences and Technology University (ANASTU) in Kandahar is being established with the support of the Ministry of External Affairs (MEA), Government of India through a bilateral cooperation programme and ICAR has been providing all technical and institutional support to establish the University as well training the Afghan researchers and students. The MoU between ICAR and ANASTU was signed on April 21, 2016 to this effect. Under the Indian-Afghanistan Fellowship program, during 2016-2019, total 187 students were enrolled for UG, PG and Ph D courses (Table 5). The ICAR-IARI has been assisting the ANASTU in establishing the laboratories and devising the course curricula for Master's in Agriculture programme. The capacity building of the faculty of ANASTU in advanced research and technologies of agriculture has been put in place by ICAR.

Table 5. Enrollment in different levels at ANASTU during 2016-2019

Academic year	Total enrollments	Graduation	Post-graduation	PhD
2016-17	43	04	39	Nil
2017-18	88	04	80	04
2018-19	56	05	48	03
Total	**187**	**13**	**167**	**07**

5.2. Myanmar

Prof. MS Swaminathan led a team of experts to Myanmar on July 23-27, 2011 to explore and strengthen the India and Myanmar cooperation in agriculture. Subsequently, the Government of India and Myanmar, on May 28, 2012, signed the MoU for setting-up of Advanced Centre for Agricultural Research and Education (ACARE). DARE was made nodal department to establish ACARE through a MoA between MEA and DARE/ICAR signed on September 21, 2015. The Council provided support in developing the centre and the course curricula. ICAR organized training on molecular breeding of crops; post-harvest management and value addition, and agriculture knowledge management (AKM) and helped in revising the PG courses curriculum. Three new PG programmes in Agricultural extension Education; Molecular Biology & Biotechnology; and Food Engineering & Technology were started in 2017-18. Under IARI-ACARE programme, 4 Myanmar students joined M.Sc. programme in 2017-18 and 2 in 2018-19 in different disciplines at IARI. Under Participatory KM programme, 4 villages in the 30 kms radius of ACARE were adopted for demonstration of agri-techniques. Hon'ble President of India dedicated ACARE to the people of Myanmar in 2018.

5.3. Nepal

The India-Nepal cooperation has been growing stronger over time. The work plan for 2014-20 was adopted by JWG on Agricultural Working Group which *inter alia* focused on study visits and trainings, collaborative research; agri-business and capacity building through fellowships under Nepal-Aid Fund Scheme and opening of National Agricultural Universities, etc. Under Nepal-Aid Fund Scheme, 15 students completed their graduate/post-graduate courses from India by 2016-17 and another 18 were enrolled since 2017-18 for different courses in Agricultural Universities in India. India has proposed to provide technical assistance in establishing a Deemed University for Agricultural Education in Nepal on the patterns of the IARI.

5.4. Sri Lanka

ICAR-Sri Lanka Council for Agricultural Research and Policy (SLCARP) cooperation dates back to 1998. Both the countries enabled short-term training of scientists of Sri Lanka in India, M.Sc. and Ph.D. course in India, exchange of germplasm and technologies, and collaborative research projects. The IWMI headquartered in Sri Lanka has facilitates many water-specific projects in the South-Asia region including India.

5.5. South-South cooperation

The South-South Cooperation (SSC) is a parallel mechanism to support the sustained economic growth in emerging economies. In 2017, the India-UN Development Partnership Fund within the United Nations Fund for South-South Cooperation was established to support the initiative. In 2018, US$50 million Commonwealth window to catalyze the achievement of the SDGs in developing countries of the Commonwealth was announced. Since 2008, South-South Cooperation (SSC) got impetus with India-Africa Forum Summits happening. Under IAFS, the special agricultural scholarships for Masters and Ph.D. programmes are offered to African students. During 2010-2015, 195 students from 27 African countries were enrolled in PG and Ph.D. programme in 36 Indian Universities. The new proposals for establishing soil, water and tissue testing laboratories in Kenya, Burkina Faso, Tanzania and Tunisia and agricultural seed production-cum-demonstration centers in Rwanda and Togo and Farm Science Centres (KVK) in Liberia are discussed.

5.6. Asia-Pacific Association of Agriculture Research Institutions (APAARI)

ICAR is a founder member of APAARI since 1990 and contributes US$ 10,000 annually to APAARI. DG, ICAR Vice-chair of the Executive Council of APAARI since 2018. APAARI hosts 5-10 ICAR scientists every year for thematic trainings and consultative workshops.

5.6.1. Network of Aquaculture Centres in Asia-Pacific (NACA)

DARE is the founder member of NACA and donor since 1992. The ICAR-CIFA, Bhubaneswar is one of the regional lead centers of NACA. Under ICAR-NACA, production of improved spawn of rohu and catla and their dissemination amongst farmers, infrastructure development and training and exposure visits of ICAR fisheries scientists at international meeting and workshops have been accomplished. More recently on 26-27 February, 2019, ICAR-NBFGR, Lucknow organized regional consultation on ‘genetically responsible aquaculture: sustainability of genetically fit bloodstock and seed of certified origin in Asia aquaculture.’

5.6.2. Centre for Agriculture and Bioscience International (CABI)

DARE entered into a MoA with CABI on the 22nd September, 2017 to establish collaboration and partnership in information management, support to small farmers, pest management and sanitary and phyto-sanitary standards, capacity building of farmer and extension service, transfer of technology from India, and research and capacity building on microbial resources in agriculture and exchange of biocontrol agents. In 2018, the work plan to implement a strategic research program on microbial taxonomy, diagnostics, biocontrol and quarantine protocols was signed. ICAR-NBAIM (Mau, Uttar Pradesh) and ICAR-NBAIR (Bengaluru) are actively involved in these programs.

6. Foreign aided/collaborative research

Figure 5 depicts foreign-aided collaborative projects in different disciplines. Total 54 foreign aided projects in different sub sectors of agricultural R&D implemented since 2018-19 in ICAR. These projects are funded from UN Agencies FAO, UNDP); US Programme (USIEF, USAID) and international organization (CABI, AVRDC, DIFD, BMGF) and research organizations of developed countries (INRA, JIRCAS, BBRC, CSIRO). A few of the projects funded by foreign universities in Australia, United Kingdom, USA, Norway are also implemented. Under Indo-Swiss and Indo-UK collaboration 3 projects have been supported. The BMGF has supported the next-generation breeding, genotyping and digitization for improving the genetic gain in Indian staple crops. ICAR-CMFRI partnered with research institutes of India, UK, Kenya and Bangladesh and CG Centre, World Fish under Newton Fund Global Research Partnership in Aquaculture for evaluation of costs and benefits of prophylactic health products and novel alternatives on smallholder aquaculture farmers in Asia and Africa. ICAR-CIFT, Kochi collaborated with University of Edinburg; University of Bradford; University of Southampton; University of the Arts London; University of Edinburg under FAO-UK Sandpit project on Diagnostics for One Health and user driven solutions for AMR for assessment of food loss from selected gillnet and trammel.

ICAR also developed collaboration with Bill & Melinda Gates Foundation (BMGF). In 2018 BMGF-ICAR-NDRI joined hand to work together on molecular markers for improving reproduction of cattle and buffaloes 2018. In January, 2019 ICAR in collaboration with BMGF launched a mega project on 'application of next-generation breeding, genotyping and digitalization approaches for improving the genetic gain in Indian staple crops.

ICAR also partnered in the rice biotechnology project initiated with the support of Rockefeller Foundation after two years intensive survey and analysis during early 80s. The projects laid the scientific foundation for rice biotechnology as some of the early successes like the first DNA molecular marker map, regeneration and transformation, use of rice pest genomic information to unravel host-plant resistance and numerous other discoveries changed the breeding for biotic and abiotic stress resistance and tolerance and hybrid rice. These discoveries ultimately led to revelation of rice pivotal genomic position in evolution of cereal species. The programme linked the national rice biotechnology research efforts to advanced research institutes in US, Europe, Australia, Japan. About 400 rice scientists, primarily from Asia were trained under the programme during 17 years of its operation. The successful linkage of research in cutting edge biotechnology led to long-term collaborations like Asia Rice Biotechnology Network managed by IRRI.

India also joined the Borlaug Global Rust Initiative in 2009 for active, collaborative research for combating wheat rust involving CGIAR, BGRI, ACIAR and ICAR. ICAR and ACIAR initiated a strategic molecular wheat breeding project with shared research projects on Ug99, water use efficiency, water logging tolerance, quality improvement and bioinformatics.

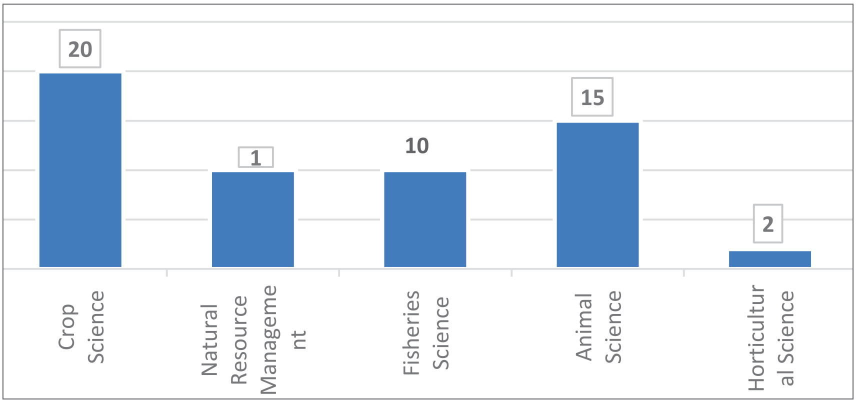

Fig. 5. Number of foreign-aided collaborative projects in different disciplines (2018-19)

7. International fellowships

ICAR has instituted Netaji Subhas International Fellowships under National Higher Agricultural Education Project (NHAEP) in 2017. The fellowship aims at human resource development in cutting edge technologies and showcasing strength of India's agricultural system abroad. The training of Indian researchers at global best laboratories and offer overseas candidates to the best of the ICAR-AU laboratories are provided to create pool of scientist-envoys for enhanced cooperation. Total 30 fellowships including Indian and foreign candidates for pursuing Ph.D. degree, are awarded annually.

8. Domestic collaborations

8.1. National level

ICAR-SAUs umbrella MoU for establishment of AICRP cooperating centres in SAUs and the establishment of KVKs dates back to 60s and 70s, respectively. Post-liberalization, ICAR institutes-industry collaborations for production of seed, contract research and commercialization of technologies were established. Furthering the collaborative research in agricultural sciences, technology dissemination and upscaling and validation of technologies, 20 umbrella MoUs were signed by DARE/ICAR since 2014. The MoUs with leading national R&D organization such as CSIR, ICMR, ICFRE, DBT and IMD were signed to strengthen the research. The farmer's outreach has been strengthened with the MoUs with NCDC, NGOs like Patanjali Bio Research Institute, ICICI Foundations and Indian Chamber of Food & Agriculture (ICFA), and financial institution-NABARD, etc. The convergence matrix has been adopted to upscale the best practices in one-district one-product initiatives through ICAR-MoFPI and water positive interventions under

MGNREGA and utilizing the social capital created under NRLMP with tripartite MoU between ICAR-MoRD and RCRC. ICAR has also diversified its wings to cooperate with State Agencies as well. MoU has been signed with Chhattisgarh Minor Forest Produce Cooperative Federation Pvt Ltd, Raipur to promote technologies of minor forest produce and develop the capacities of the producers. The MoU signed with Ministry of MSME in 2021 shall provide an opportunity for strengthening the working with Industries.

8.2. Sub-national and sectoral

ICAR Institutes entered into MoUs with State Governments, agricultural and technology universities/institutions, State Agricultural Management, Extension & Training Institutes (SAMETIs) and industries. Research-Industry collaboration got sharp focus in recent years. In sugarcane, collaborations with DCM Sriram Ltd since 2016-17 for doubling the income of farmers of Lakhimpur-Khiri district in Uttar Pradesh; contract research with Daurala Sugars in 2010 for commercialization of IISR technology; with M/s Fine Trap India Ltd in 2013 for the production of IISR combo traps for management of white grubs are noticeable one. The collaboration for breeder seed production of sugarcane was introduced with Bihar Government in 2013 which helped significant amount of breeder seed of sugarcane annually in the State under the supervision of IISR scientists.

The IPM demonstration in Basmati rice with the partnership of Dawat Foods Ltd. in 2012 over 20,000 acres covering 987 farmers, and with Ebro India Pvt Ltd in 2013 in 396 villages at 2462 farmers' fields of Pusa Basmati-1 on 38600 acres in 5 districts of Haryana and 2 districts of Punjab helped reducing use of tricyclazole drastically. The ICAR-IMD collaborations for installation of automatic weather station, exchange of data, online access to weather data for agro-advisories was initiated in April, 2018. The tripartite MoU between ICAR-CRIDA-DAFW in 2016 has helped developing districts contingency plans and their cyclical revisions for over 650 districts.

The public-private partnership (PPP) happened for production and promotion of improved varieties and hybrids of rice, wheat, cotton, maize, soybean, mustard, fruits and vegetable seeds, farm machineries and water conservation structures. PRH-10 was the first super fine grain aromatic rice hybrid licensed to 19 seed companies in 2008. The hybrid rice seed production and commercialization were licensed to 20 Seed industries for hybrid rice Rajalaxmi, CR Dhan 701, Hybrid Rice Ajay during 2013 to 2016 by NRRI, Cuttack. The Basmati variety PB 1509 was licensed to 13 Seed Companies in 2013. Variety PB 1718 has been licensed to 19 and PB 1728 has been licensed to 15 seed companies in 2018. Variety PB 1637 has been commercialized through 11 seed companies. This is an improvement of Pusa Basmati 1 with resistance to blast disease.

IARI entered into PPP mode for seed production and marketing of HD 3086. This variety was commercialized to 202 companies within two years. In case of HI-1563 wheat, 40 licenses were issued for seed production and marketing. HD 3226 commercialized in 2019 to seventy industry partners. The DBW187 was commercialized with 163 Seed Companies and DBW173 with 51 companies in 2017. Collaboration with ITC Ltd. for market assisted transfer of Rht gene revealed 6 wheat varieties HI 1544, HI 1605, HD 2987, HI 1621, MP 3288 and HI 1620 as the most suitable with superior yield potential and on par in quality parameters with C 306 based on trials at 20 centres across India where ITC manufacturing units are functioning.

The collaborations for development of ginning machines were established between CIRCOT and M/s. Forech Mining & Constructions International New Delhi in 2017. In 2018, ICAR-IIWM, Bhubaneswar and Indian Rubber Manufacturers Research Association (IRMRA) established collaboration for promotion of rubber check dams. In 2018, IARI and Ajay Bio tech (India) Ltd. entered into MoU for dissemination of entomopathogenic nematode in tea garden in West Bengal and Assam. A product 'Bio-fighter' was launched by the company in July 2019 which is effective against tea semi-looper, armyworms, cutworms, white grubs and termites. Since, 2014 onwards, ICAR has inked umbrella MoUs with leading national organization for promotion of research in cutting edge areas, scaling up the outreach and forging the convergence. The important are given below.

8.2.1. R&D, Exchange of germplasm, GM technology

Agricultural education (AMITY University 2014), trans-disciplinary research in basic, clinical, pharmacological, pharmaceutical and social sciences (Institute of Transdisciplinary Health Science & Technology, 2015), zoonotic diseases, AMR (ICMR 2016), ICT research, and IT based societal development (IIT, Delhi, 2018), Post-harvest management and energy efficiency in agricultural operations (Bureau of Energy Efficiency 2018), agro-forestry (ICFRE, 2018), agri-foods, medicinal and aromatic plants (CSIR 2019), agricultural biotechnology, release of GM crops, regulatory aspects transgenic crops (DBT 2019 and SABC, 2022), research, outreach, multiplication testing, exchange of germplasm(PBRI, Haridwar 2020)

8.2.2. Outreach programmes

The important outreach programmes initiated in the country includes promotion of grassroots innovations in the selected products (National Innovation Foundation, Ahmedabad, 2015); capacity building and extension consultancy (MANAGE 2019); climate resilient technology-promotion and upscaling (NABARD 2019); advocacy, capacity building services to ICAR (ASCI, Hyderabad, 2020); training and capacity building of farmers (ICICI Foundation, Mumbai, 2020); training and capacity building of farmers' cooperatives (NCDC, New Delhi, 2020); testing and validation, awareness campaigns, field demonstrations(IFFCO, 2020); linking of KVKs with rural CSCs to enhance KVKs reach (Common Service Centers, 2019); establishment of District Agro-Met Units in KVKs (IMD 2018); outreach programmes, exchange of information (ICFA, New Delhi 2021).

8.2.3. Convergence of Resources

Capacity development and need-based research have been initiated for one-district one-product initiatives under PMFME (MoFPI 2020), technology dissemination, livelihood support, skilling, and mobilization and communication in 100 districts (ICAR-MoRD-Rapid Rural Community Response MoU, 2020), R&D on non-wood forest produce and Chhattisgarh Minor Forest Produce Cooperative Federation Ltd. (2021) by ICAR institutes.

9. Conclusion

The Agri R&D during past 75 years has been marked with well-orchestrated national and international collaborations helping India achieving food security, enhancing the income of the farmers and livelihood of farm workers and those earning wages in agri-related activities. International collaborations started immediately after independence and broadened their scope and space over time that helped through the revolutions and transformations. As the luxury of plentifulness of natural resources is drying up and the problem of plenty of output is escalating, collaborations with international organizations through a foresighting mechanism shall be the core activity to innovate in the science based agricultural research in the future. The institutional mechanism started in 1973 with the establishment of DARE has also sharpened with the establishment of International Relations (IR) division in ICAR in 2014 and similar setup in the Department of Agriculture & Farmers Welfare to facilitate the initiatives of international cooperation and smoothen the functionalities between DARE and ICAR. The escalating biotic stresses of transboundary nature require much concerted efforts on agri R&D for sustainable and resilient agri-food systems. The future of agricultural R&D collaboration should aim building relationships with Centers of Excellence in public and private sector in India and overseas focusing on innovations in digital agriculture, precision farming, climate change management, secondary agriculture, etc. The mechanisms for public-private partnerships and CSR funding should targeted for augmenting the financing for the implementation of the mutually beneficially projects. The global technology foresignting should be strengthened to establish the research collaboration to reach beyond borders and to accomplish the development of agricultural research in India and facilitate other countries as well.

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16
Chapter

Investment, Policy and Entrepreneurial Ecosystem for Agricultural Development

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Summary

The chapter discusses the development of agriculture in the post-independent India. It traces the agricultural growth trajectory during different phases of technology adoption, spread, stagnation, and revival. The expansion of diversified farming and a gradual shift towards a commercial agriculture in the nation is illustrated. The role of investment in sustaining technology-led growth, supportive institutional mechanisms, emergence and development of entrepreneurial ecosystem, their establishments and governance changes are highlighted. The policy supports of the public and private institutions in reshaping and reforming the agriculture sector during the development process is portrayed. It summarizes the importance of technology commercialization, the role of intellectual property rights, the need for public-private partnerships, the role of institutional arrangements such as agri-startups and FPOs, and necessary support through higher research allocations for agriculture growth and sustainability.

1. Introduction

Agriculture bears the prime responsibility of ensuring food and nutritional security in India. The share of agriculture in national output has declined from 53% in 1950-51 to 18% in 2019-20. It still provides livelihood to about half of the workforce. Literature suggests growth in agriculture has strong poverty-reducing impacts in India (Ravallion and Datt 1996; Thirtle et al. 2003), but the farmers earn relatively less income than the non-farm workers (Chand et al. 2017). Improving the income of the agricultural households, therefore, becomes a critical factor for reducing poverty and inequality in the country. Agriculture itself has transformed significantly after the independence and has transformed India as well from a food-deficit economy to a food surplus and net-exporting country. Early developments were initiated in Indian agriculture through the science-led onset of the green revolution during the 1960s, which was adequately supported by favorable public policies (Table 1). After achieving self-sufficiency in food grains, the sector is now on the path of commercialization. The recent development agenda has shifted from production enhancing strategies to income improvement strategies for farmers' welfare. This paper analyzes the growth trajectory of Indian agriculture and dissects the transition from subsistence farming towards the commercialized enterprise. In this milieu, the role and contributions of investment and policy change in agricultural development have been discussed. The paper is divided into three sections. The first section discusses trends and patterns in agricultural growth, public investment, diversification, and commercialization. Section two presents the price policies, market reforms, institutional development, and governance supports for agriculture. The third section discusses the role of property rights and partnerships in agricultural development in the country. New era of agricultural transformation led by promotion of FPOs and agri-startups has been discussed in the fourth section.

Table 1. Milestones in investment and policy for agricultural development in independent India

Year	Milestone
1965	Commission for Agricultural Costs & Prices (CACP) and Food Corporation of India (FCI) were established for price support and procurement operations.
1966	Seeds Act enacted to provide for regulating the quality of certain seeds for sale, and for matters connected therewith.
1966-67	Minimum Support Price (MSP) system started for wheat. The other commodities were gradually covered since then.
1969	14 major commercial private banks were nationalized. 6 other banks were then nationalized in 1980.
1970	Patents Act was passed to regulate the laws related to patenting. Successive amendments were made in 1999, 2002, 2005, 2017, and 2020.
1974	Priority Sector Lending rates were announced to the commercial banks, covering agriculture and other weaker section.
1976	Regional Rural Banks (RRBs) were set up for expanding credit to agriculture and other rural activities.
1982	National Bank for Agriculture and Rural Development (NABARD) was established. It's the apex body for RRBs and Cooperative Banks.
1985	Fertilizer Control Order (FCO) was issued under the Essential Commodities Act, 1955.
1985	Comprehensive Crop Insurance Scheme (CCIS) was introduced to provide farmers the financial support in the event of crop failure due to natural calamities.
1987	National Water Policy (1987) stated the concept of Participatory Irrigation Water Management and stressed its necessity.
1998	Kisan Credit Card (KCC) scheme was introduced to offer credit to the farmers to meet their farm expenses.
2001	The Protection of Plant Variety and Farmers Right Act (PPVFR Act) was enacted to provide for the establishment of an effective system for the protection of plant varieties, the rights of farmers and plant breeders, and to encourage the development and cultivation of new varieties of plants.

Year	Milestone
2005-06	National Horticulture Mission was launched by Government of India to promote horticulture sector by diversification of agriculture.
2006-07	Interest subvention scheme came into force from Kharif 2006-07 to provide short-term credit to farmers at a subsidized interest rate. The subvention rate was 2% in Kharif 2006-07 to the commercial, cooperative, and regional rural banks for the short-term production credit. The subvention was extended from crop growing farmers to animal and fish growers since 2018-19.
2015	Soil Health Card Scheme was launched by Government of India, under which soil samples were collected from farmers' fields and soil health cards were issued to the farmers which carry crop-wise recommendations of nutrients. It helped in improvement in crop productivity through judicious use of inputs.
2016	e-NAM (Electronic National Agriculture Market) scheme was introduced to integrate existing markets to *one nation one market* for agricultural commodities. By May 2020, 1000 APMC mandis were integrated with e-NAM platform. In 2016 Startup India Programme was also launched and it was envisaged that new age entrepreneurs will bring in effective technologies to value chains.
2018	PM-KISAN Scheme became operational from December 1, 2018. Income support of Rs. 6,000/- per year is extended in three equal instalments to all land-holding farmer families.
2019	A new Ministry of Fisheries, Animal Husbandry and Dairying (MoFAH&D) was formed.
2020	Three acts viz., a) Farmers' Produce Trade and Commerce (Promotion and Facilitation) Act, 2020; b) Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Act, 2020; and c) Essential Commodities (Amendment) Act (ECA), 2020 were enacted to reform the agriculture sector. However, due to continuous protests by some section of the farmers, these Acts were later repealed in the year 2021.
2020	Agriculture Infrastructure Fund, a medium - long term debt financing facility was announced for investment in viable projects for post-harvest management infrastructure and community farming assets.

2. Agricultural growth and public investment

2.1. Growth-trajectory of agriculture and non-agriculture sectors in India

The performance of agriculture depends on a variety of technological, institutional, and policy interventions. The effects of such changes are aptly captured by the growth in gross value added (GVA). The growth trajectory is examined here by estimating the decadal trend-growth rate in GVA. The trend growth rates are estimated for the 10 years starting from the decade 1951-52 to 1960-61 and extended to the latest decade covering the period 2010-11 to 2019-20. Further, the growth in agriculture has been compared with the non-agriculture sector to gauge the relative performance. The estimated growth rates for the decadal periods ending with 1960-61 to 2019-20 are presented in Fig. 1.

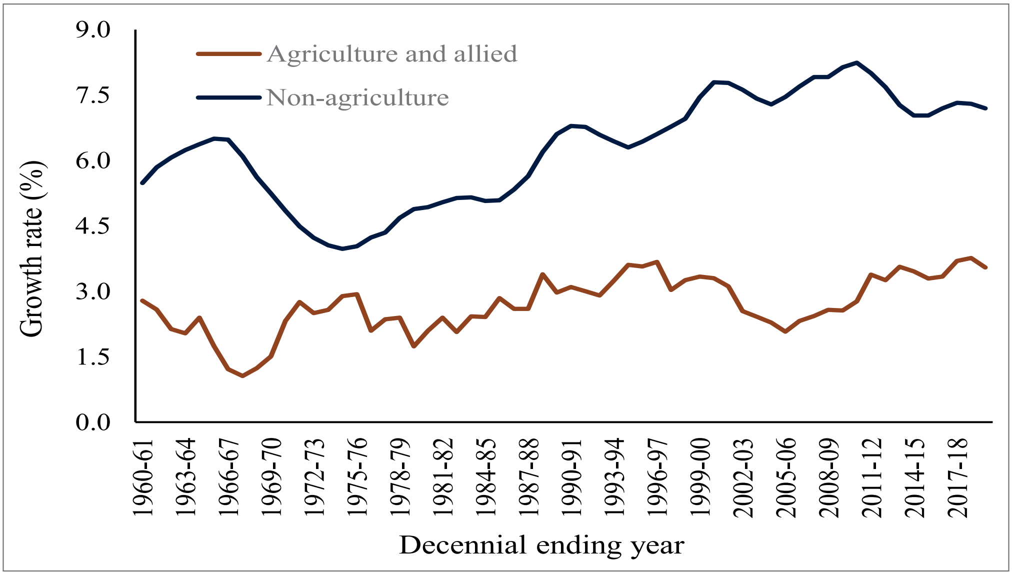

Fig. 1. Trend in decennial growth rate of agriculture and non-agriculture sectors in India

Source: Estimates based on MoSPI data (2020)

Between 1950-51 and 2019-20, the GVA (at 2011-12 prices) from agriculture and allied sectors has increased 6.7 times at an average annual growth rate of 2.7%. The growth, however, has not been uniform throughout the period. The decadal growth rate was 2.8% in agriculture during 1950-51 to 1960-61, which decelerated to 1.1% till the year 1967-68. Following the expansion of green revolution technologies across the states, agricultural growth accelerated significantly and reached about 3% by the year 1975-76. After a few years of deceleration, the growth sustained at above 2% during the 1980s and early 1990s. The growth, however, could not be sustained longer and witnessed a decade of deceleration during the mid-1990s to mid-2000s. This deceleration has coincided with the introduction of globalization and liberalization policies the country adopted in the early 1990s. The general neglect of agriculture has been put forth for this deceleration, which coincided with limited benefits from the terms of trade. The revival began in the mid-2000s, since when both the terms of trade and agricultural expenditures began to improve. The pace of acceleration has been much faster than that was observed during the 1980s. Agricultural productivity has risen faster, notably among the low-productivity states since the mid-2000s. Growth has turned more inclusive in agriculture since then, establishing convergence in agricultural productivity (Balaji and Pal 2014). It is to be noted that growth in the agriculture sector lagged far behind the non-agriculture during the entire period. Consequently, the share of agriculture in national output (GVA) has declined over time. There is a trend reversal in recent years, with agriculture growing faster. Further, the growth during the past three years is at the historically highest level since the independence on account of concerted efforts towards technological interventions and policy reforms.

2.2. Agricultural growth at the disaggregated level

Agriculture and allied sectors comprise crops, livestock, fisheries and aquaculture, and forestry and logging sub-sectors. Growth has varied significantly across the sub-sectors (Table 2). The overall growth was at the historically highest level during the recent decade (2011-12 to 2019-20). The sub-sectors such as crops and livestock grew at the same pace during the first five decades since the year 1950-51. Since 2001-02, the livestock sector is growing at a significantly higher rate as compared to the crop sub-sector. The growth of the crop sub-sector is decelerating in recent years. Fisheries and aquaculture have also registered significant growth in their output. These two sectors – both livestock and fisheries have helped to sustain higher growth in agriculture over decades.

Table 2. Decade-wise growth (%) in agriculture and allied sectors in India

Period	Crops	Livestock	Fisheries & aquaculture	Forestry & logging	Agriculture and allied
1950-51 to 1960-61	3.0	3.0	5.6	0.5	2.8
1960-61 to 1970-71	1.9	1.8	3.9	3.2	2.0
1970-71 to 1980-81	2.1	2.0	2.7	-1.0	1.8
1980-81 to 1990-91	3.2	3.3	5.8	0.0	3.1
1990-91 to 2001-02	3.2	3.2	5.1	1.2	3.2
2001-02 to 2011-12	2.7	4.5	3.8	-0.6	2.7
2011-12 to 2019-20	1.5	7.5	8.6	3.5	3.5

Source: Estimates based on data from MOSPI (2020)

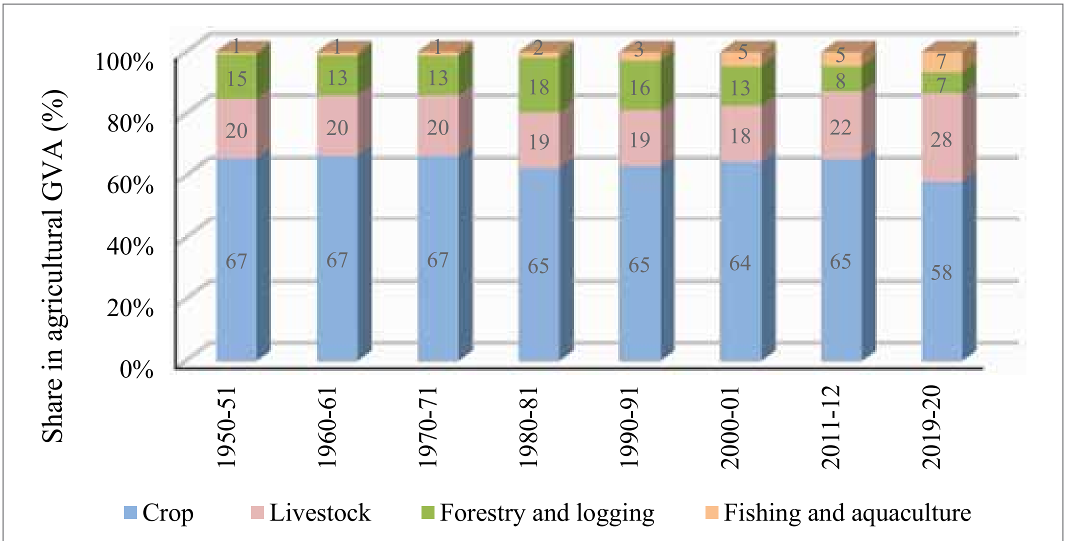

Fig. 2. Changing composition agricultural output in India

Source: Estimates based on MOSPI (2020) data

Diversification has been the prime factor behind growth acceleration and convergence. A general shift from crops towards livestock and fisheries sectors is obvious across states (Pal et al. 2020), driven by the demand arising from higher growth in industrial and service sectors observed above and subsequent rise in income per capita. This has made agriculture more diversified and market-driven, where markets offer higher prices to the farmers. The rising diversification is evident from the declining share of crop sub-sector in agricultural output, from 67% in 1950-51 to 58% in 2019-20 (Fig. 2). On the other hand, the share of livestock and fisheries sub-sector is rising over time. As the crop sub-sector remains a predominant constituent of agricultural output, there exists huge potential for diversification towards other sub-sectors.

2.3. Commercialization of Indian agriculture

The onset of the green revolution during the 1960s initiated agricultural intensification using modern inputs i.e., high yielding varieties, chemical fertilizers, pesticides, etc. Subsequently, the level of input use has increased considerably and Indian farmers are steadily shifting from using home grown farm inputs to off-farm inputs. The evidences from both factor and product markets indicate that Indian agriculture is gradually transitioning towards commercialization, with the rising dependence on the market for input needs and output disposal (Table 3).

Table 3. Indicators of commercialization of Indian agriculture

Indicator	TE 1987-88	TE 1997-98	TE 2007-08	TE 2017-18
Factor Side				
Certified seeds (lakh quintal)	56	74	154	335
NPK (kg ha^{-1} GCA)	49	78	111	127
Irrigation coverage (%)	32	39	45	48
Electricity use (kwh ha^{-1})	168	460	506	947
Labour use (hours ha^{-1})	674	663	673	566
Product side				
Marketed surplus ratio# (%)	-	-	68	78#
Share of export in agricultural output (%)	3.3	5.8	6.9	7.8
Share of area of non-food grains in GCA (%)	31	33	35	37*
Value share of non-food grains in crop output (%)	58	60	64	66

**Triennium ending (TE) 2016-17; # TE 2015-16*

 # Value of output sold to the value of output produced in % terms averaged over crops namely rice, wheat, maize, jowar, bajra, barley, ragi, arhar, gram, urad, moong, and lentil.

The product side change is indicated through increasing marketed surplus and agricultural exports, and a diversification towards non-food grains crops. For instance, the farmers disposed of about 78% of the products they raised to the market in the Triennium ending (TE) 2017-18, which was 68% just a decade before. The share of exports has also risen from 3.3% in TE 1987-88 to 7.8% in TE 2017-18. Higher area allocations have supported these responses to the markets. To date, around two-thirds of the total crop sector output is contributed by non-food crops such as cotton for which domestic and trade values are substantial. On the factor side, rising commercialization is reflected from the increasing use of quality seeds and fertilizer consumption, improvement in irrigation coverage and electricity use, and reduction in labor use due to rising farm mechanization and other developmental factors. Pesticide use is also witnessing notable transition despite the presence of regulatory issues (Subash et al. 2017).

2.4. Public expenditure in agriculture and rural development

A gradual rise in the public sector expenditures in agriculture and rural development have helped for the transition. The public expenditure (at 2011-12 prices) has increased gradually from 1991 to 2005 but has risen more rapidly afterwards (Fig. 3). It was less than a lakh crore in the early 1990s but stands at around four lakh crores at present, rising around 4 times within a short span. Even in a relative term, measured as a share to total expenditures incurred by the public sector, the share of agriculture, including rural development, has begun to rise in recent years as a shift in the earlier trend. The growth in expenditure has risen in agriculture from 3.4% in the 1990s to more than 14% in the 2010s, and in irrigation expenditure, these shares have been 3.9% and 11.5%, respectively. The expenditures on development like roads and infrastructure have also risen substantially in the rural regions, helping for higher agricultural growth and sustainability.

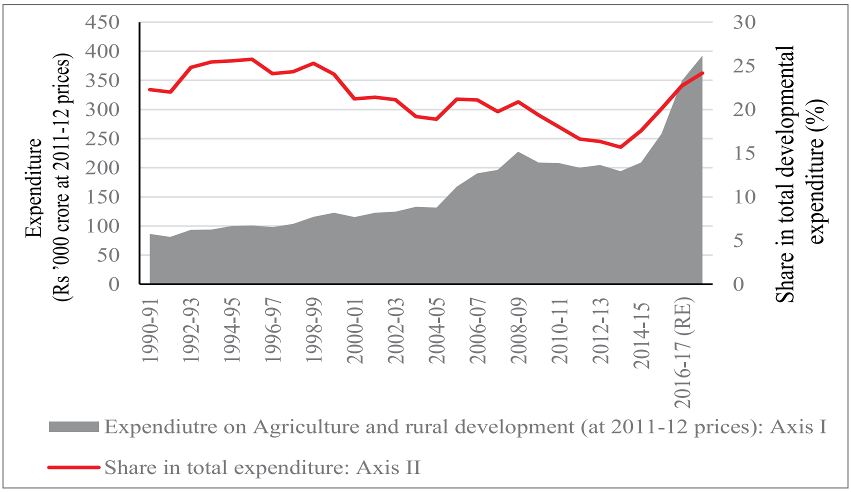

Fig. 3. Trends in public expenditure in agriculture and rural development and its share in total developmental expenditure

Source: Estimates based on MOSPI (2020) data

2.5. Impact on food production

The immediate impact of scientific developments and investment is reflected through the increase in food production to fulfill rising demand. The estimates show that growth in food production (at the aggregate level[1]) in the country has remained higher than the growth in the population. Consequently, the per capita food production in the country has increased from just 0.94 kg/day in 1950-51 to 2.65 kg/day in 2019-20 (Fig. 4). Notwithstanding, during the recent years (2001-02 to 2019-20), growth in population has decelerated which has further provided a fillip to the growth in per capita food production in India. The present level of food production is sufficient to sustain food security in the country (NITI Aayog 2018). The production growth is primarily led by improvement in productivity. Chand and Srivastava (2018) have decomposed growth in production of crop groups into area effects, yield effects, and interaction effects of area and yield during 2004-05 to 2014-15, and found that 92%, 76%, and 67% of the growth in production of cereals, pulses and oilseeds were attributed to increase in yield. Thus, an increase in yield has emerged as a major contributor to food production in the country.

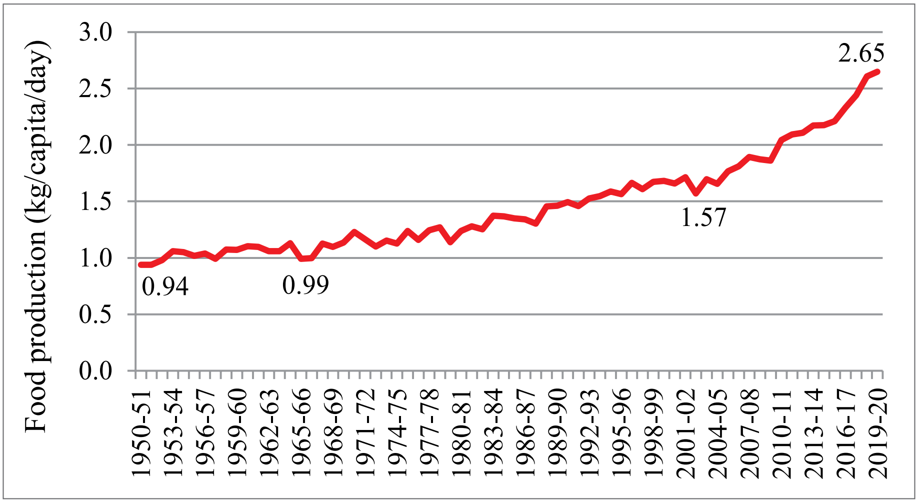

Fig. 4. Trend in per capita food production in India

Source: Data from Agricultural Statistics at a Glance (various issues) and MOSPI (2020)

3. Institutional development and governance

3.1. Credit demands, informal finance, and the rise of formal financial institutions

Credit institutions and their supportive policies over years have played a pivotal role in the present state of developments in agriculture. Credit inadequacy in the farm sector has long been felt, even before the introduction of the green revolution in the country - and several

[1]*Foodgrains, edible oil, sugar, fruits & vegetables, spices, milk, eggs, meat and fish, aggregated using foodgrain equivalent unit prices as weight.*

interventions have been made to address the demand. The Cooperative Societies Act passed in 1904 and subsequent reforms through the Maclagan Committee on Cooperation in 1915; the examination of rural credit program by the Royal Commission on Agriculture in 1926-27; Sir Malcolm Darling's report on cooperative credit to the Government of India in 1935 are the examples. Even then, almost entire credit requirements of the farmers were observed to be financed by the money lenders, and the formal agencies like cooperatives had a minor role. In the year 1951, the money lenders financed around 70% of the cultivators' credit requirements (Table 4). Not more than 3.3% of the farmers accessed their credit needs through the cooperatives. The access to finance through the commercial banks was still worse, less than a percent.

The practice of capital and input-intensive agriculture since the adoption of green revolution technologies in the mid-1960s and the technology spillover to the rest of the regions accelerated the need for further finance for agriculture. In the year 1974, following the concept of 'priority sector lending' that comprised agriculture, the commercial banks were advised to raise the share of these sectors in their aggregate advances to the level of 33.33% by March 1979. Further efforts were done by attaching each district with a commercial Lead Bank. The Regional Rural Banks (RRBs) were set up following the recommendations of the Narasimham Committee in 1976. In the year 1982, the National Bank for Agriculture and Rural Development (NABARD) was established. The NABARD undertook the agricultural credit-related functions of the Reserve Bank of India and refinancing functions of the Agricultural Refinance and Development Corporation.

Table 4. Source of finance of farm households over years (%, 1951-2019)

Source/Institution	1951	1971	1991	2019
A. Non-Institutional	92.7	68.3	30.6	30.4
1. Money Lenders	69.7	36.1	17.5	20.5
2. Others	23.0	32.2	13.1	9.9
B. Institutional	7.3	31.7	66.3	69.6
1. Commercial Banks	0.9	2.4	35.2	44.5
2. Others	6.4	29.3	31.1	25.1

Source: Mohan (2004), MoSPI (2021)

Table 5. Share of formal credit institutions in agricultural credit outstanding (All-India, %)

Year	Co-operatives	SCBs	RRBs	All
1983-84	49.8	45.8	4.4	100.0
1989-90	38.2	55.2	6.6	100.0
1999-00	51.5	41.1	7.4	100.0
2009-10	14.2	74.8	11.0	100.0
2019-20	13.3	71.9	14.8	100.0

Source: Estimates based on RBI (2021)

These efforts resulted in increased credit flow in agriculture in the coming years. Notably, the access to finance from the commercial banks rose dramatically, from less than a percent in 1951 to more than 35% in 1991. This has enhanced further to 44.5% in the year 2019, due to both the expansion of commercial banks in the rural regions and the Government's supportive policies towards the farm sector. The composition of credit has also undergone major changes (Table 5). The higher access of finance of farmers from the commercial banks was also complemented with an increased rate of credit delivery over the years. Rather, the role of cooperatives in credit delivery has declined since the RRBs came into operation. From around 50% in the year 1983-84, the share of cooperatives in the total agricultural credit outstanding has declined to just above 13% in 2019-20. On the other side, the share of RRBs has risen from 4.4% to 14.8% during this period, surpassing the credit outstanding of cooperatives. When measured in terms of growth, while the cooperative sectors' credit outstanding grew annually at the rate of 10.7%, it was 18% in the commercial banks and 19.5% in the RRBs during 1991-2020.

3.2. Subsidies, income transfers and public investment

Public institutions both at the centre and states have cushioned throughout the time the risks the farmers faced in agriculture and their efforts to minimize the costs of inputs used in agriculture for higher profit realizations. Subsidies and waivers have been the prime instruments. The centre incurred the subsidy expenses amounting to more than Rs. 81 thousand crores (comprising urea and nutrient-based subsidies) in the year 2019-20 to offer fertilizers at affordable prices (Table 6). The expense was just Rs. 60 crores in 1976-77. It rose to about Rs. 4.4 thousand crores in 1990-91; to Rs. 13.8 thousand crores in 2000-01; and to 62.3 thousand crores in 2010-11. Similarly, to facilitate higher credit flow, institutional finance is being offered for years at lower interest rates. The Government introduced a subvention rate of 2% in Kharif 2006-07 to the commercial, cooperative, and regional rural banks for the short-term production credit. It introduced an additional 1% in 2009-10, which was hiked to 2% in 2010-11 and 3% in 2011-12. The subvention was extended from crop growing farmers to animal and fish growers since 2018-19. Costs of such inventions have generally been higher. In the year 2019-20, the Government incurred a credit subsidy of more than Rs. 16 thousand crores at this end.

Table 6. Selected financial expenditures of the Government (Rs. crores, 2019-20)

Year	Fertilizer Subsidy	Direct Income Transfer (PM-KISAN)	Gross Capital Formation (GCF) in Agriculture*	Loan Waivers
2014-15	71,076	-	47,319	60,000
2015-16	72,415	-	56,167	6,100
2016-17	66,313	-	66,895	6,041
2017-18	66,468	-	66,916**	88,791
2018-19	70,605	-	79,611**	54,600#
2019-20	81,124	48,714	76,141**	-
2020-21	1,27,921	60,990	-	-

*Note: *Public sector GCF; **Revised Estimates; #till December 2018.*
Source: MoAFW (2021), MoF (2016-21), Narayanan and Mehrotra (2019).

The other institutional intervention to support farmers to meet out their farm expenses has been the approach of direct income transfer. On 24th February 2019, the union Government launched the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) scheme. An amount of Rs. 6,000 is transferred in three installments in a year directly into the farmers' bank accounts since then. The present statistics show more than 11 crore farmers are benefitting through this scheme, which translates into an expense of Rs. 66 thousand crores to the Government. To note, the rise in subsidy burden over years has not been at the cost of a decline in public sector capital in agriculture. The public sector Gross Capital Formation (GCF) in agriculture, which reflects the investment made in agriculture, was about Rs. 35.7 thousand crores in the year 2011-12. This rose to Rs. 56.2 thousand crores in 2015-16 and to Rs. 76.1 thousand crores in 2019-20. Thus, the centre has extended huge financial support to the welfare of the farmers.

Among the states, loan waivers had been the major welfare intervention other than offering electricity at subsidized rates for agricultural purposes. The burden of such waivers on the states' exchequer had generally been high. Sometimes, the aggregate of waivers in a few states has surpassed the centre's expenditures on fertilizer subsidies for the entire nation i.e., in the year 2017-18. One shall note that other than these seasonal/irregular waivers in states, the centre spends regularly on credit subsidies as noted earlier. Estimates show that they have risen from around Rs. 2,000 crores in 2009-10 to around Rs. 6,000 crores in 2013-14, and to more than Rs. 12,000 crores in 2015-16. With the expanding credit requirements over years and with the Government's financial inclusion initiatives, the credit subsidies shall rise further in the coming years.

3.3. Price policies, market reforms, governance and innovations

The governance support has evolved parallelly with the developments in agriculture. The acceleration in productivity with the onset of green revolution has brought a transformation in Indian agriculture. Institutions namely the Commission for Agricultural Costs & Prices (CACP) and the Food Corporation of India (FCI) were established in 1965 to assist the farmers with price support operations on one side and ensure the productivity gains reaching the consuming sector through the Public Distribution System (PDS) on the other side. The former institution was mandated to recommend the Government the Minimum Support Prices (MSP) at which the latter institution was obliged to procure food commodities to distribute to the public. The support price act as a safety net to the farmers, notably when the market fails to guarantee reasonable prices to the commodities. At present, the MSP is announced for 14 kharif crops and 10 rabi crops.

Further, the Fair and Remunerative Price (FRP) is announced for sugarcane to guarantee the price to the sugar growers and for the smooth operation of sugar industries. Unlike MSP, the FRP is paid by the sugar industries. These procurement mechanisms ensure the nation's capability to maintain adequate buffer stock for national food security and act as a tool for domestic price stability. In recent years, concerted efforts have been made for farmers' welfare by scaling-up public procurements. In the Kharif Marketing Season

(KMS) 2020-21, about 60 million tons (Mt) of rice was procured from the farmers, which was just 32 Mt in KMS 2014-15. Similarly, more than 39 Mt of wheat was procured in the Rabi Marketing Season (RMS) 2020-21, and it was around 28 Mt in RMS 2014-15. The procurement of these two commodities itself has benefitted more than 1.3 crore farmers and more than 43 lakh farmers in the kharif and rabi marketing seasons, respectively in 2020-21.

The recent agricultural ecosystem has encouraged innovations in agricultural practices. In the policy domain, the idea of higher production and productivity has reshaped into higher income and price realizations at the market. The Government aims to double the farmers' income, double the agricultural exports, connect the traditional agricultural marketing system electronically through the approaches like e-National Agricultural Market (e-NAM), handhold the farmers to cope-up with rising prices and climatic risks through a series of insurance programs that are improved upon over time, encourage soil conservation and organic farming practices among the farmers are a few examples. More appreciable was the introduction of farm laws i.e., a) The Farmers' Produce Trade and Commerce (Promotion and Facilitation) Act (2020); b) Farmers (Empowerment and Protection) Agreement of Price Assurance and Farm Services Act (2020); and c) amendments in the Essential Commodities (Amendment) Act. The first two acts provided a mechanism to the farmers to carry out their farm businesses outside the APMCs and allow them to enter into contracts, thus encouraging free-market operations. The last Act allowed trade in food grains, pulses, edible oils, and onion (except in times of crisis), which were not permitted earlier. These reforms were aimed to promote competitiveness among farmers, thus promoting domestic and international trade. While the recent repeal of these laws sets the agendas back towards maintaining protectionist forms, one shall hope for alternate mechanisms that promote the intensions of free trade.

No wonder the concept of governance is gradually transforming into e-governance. Other than connecting agricultural markets electronically, one shall cite the efforts taken to connect the farmers in the financial inclusion process as a major move. Since its inception (1998), around 19 crore Kisan Credit Cards have been issued so far (till 2019-20), attracting farmers to the formal financial institutions. The introduction of the direct benefit transfer approach in the fertilizer industry, direct income transfers to the farmers through PM-KISAN, and digitalization of rural land records are the other major initiatives at this front. The gradual emergence of the private sector in the agro-advisory services in recent years marks an improvement in information governance for the welfare of the farmers. The entry of Amazon Retail in India to offer agronomy services, the collaboration of the Indian Council of Agricultural Research (ICAR) with the Digital India Corporation (DIC) for extending tele-advisory services, the joint efforts of Microsoft and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for sowing advisories, and the partnership of the Ministry of Agriculture & Farmers Welfare (MoAFW) with private companies to take forward the digital agriculture are few among several signs of transition.

4. Property rights, partnerships, and donors

As a result of the World Trade Organisation Trade-Related Intellectual Property Rights (TRIPS) agreement in 1995, India opted for *a sui generies* system for the protection of plant varieties through the Protection of Plant Varieties & Farmers Right Act in 2001. Over the years, there had been an increase in the total number of varieties registered under this act. The data on varieties filed under PPVFR Act for the period 2009-2021 (Table 7) shows that out of all varieties registered, around 39.78% of the varieties were registered by farmers, 21.14% were from ICAR, 29.61% from the private organizations, and 8.61% from the State Agricultural Universities (SAUs).

Table 7. Varieties registered under PPVFRA Act (2009 to 2021)

Sector	Number of varieties*	Percentage
Private	1410	29.61
ICAR	1006	21.14
SAU	410	8.61
Farmer	1894	39.78
Others	41	0.86
All	4761	100.00

*Note: *Includes Essentially Derived Varieties, Extant varieties, Farmers varieties, and new varieties.*

Source: PPVFRA (2018) (https://www.plantauthority.gov.in/)

Intellectual Property Rights in the post-independence in India started with the Patents Act 1970. To comply with the TRIPS agreement, the Patent Act was amended in 2007 to accommodate chemicals. The number of patents filed in India has increased gradually, as a result of successive amendments made in the Indian Patent Act in 1999, 2002, and 2005. But both in absolute and relative terms, India lags behind several countries. It currently ranks 14th in the total global patent filing in the agriculture and allied sector. The monetary value out of the patent system is paid limited attention, and patents are used as a protection mechanism rather. Preservation of innovations and preventing competitors from claiming priority over the invention has become the key focus.

4.1. Commercialization of technology

For a responsive agricultural research system, committed support of the Government is a necessary factor (Pal 2017). Technologies produced by the public R&D institutions are commercialized to various private and public companies. The Indian Council of Agricultural Research (ICAR) commercializes its technologies through the institutional mechanism developed under the IP and technology commercialization policy in 2006. Since 1991, the ICAR has commercialized several technologies. These technologies are disseminated through the State Department of Agriculture, State Agricultural Universities, National Seed Corporation, and other public entities. After the year 2007, the number of technologies commercialized has increased significantly. This increased from 29 in 2007 to 575 in 2021 (Fig. 5). The Business Planning and Development units established under National Agricultural Innovation Project (NAIP) and later Institute Technology Management Units and Agrinnovate India Ltd. have helped in stimulating the commercialization process.

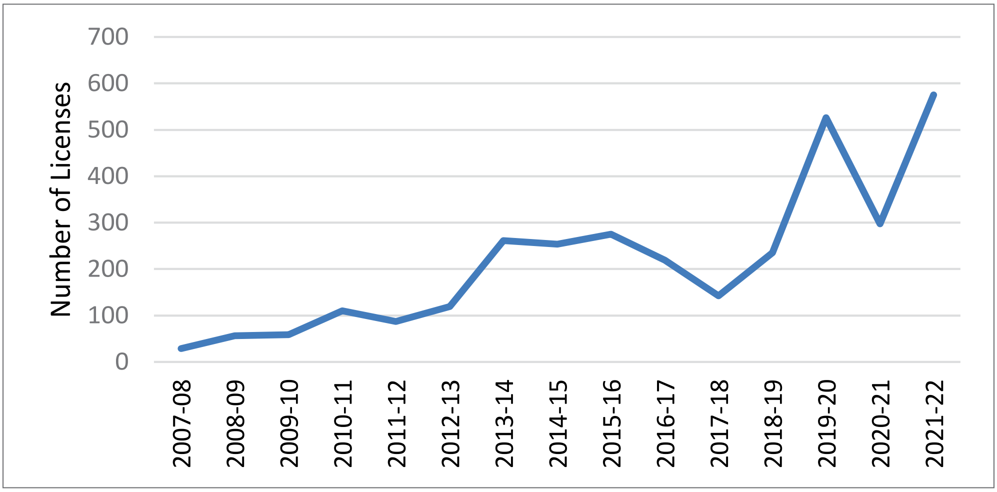

Fig. 5. Trend in commercialization of technologies by the ICAR (1991-2017)

5. Development of entrepreneurial ecosystem: Agri-Start-ups and Farmer Producer Organizations

Innovation in the technology development process for helping the agri-food system in addressing grand challenges is critical to fulfil the challenges pertaining to Sustainable Development Goals (SDGs). Until mid-nineties, the role of public funded research institutions in innovation management in India were significantly higher. Later, with opening of the economy, private sector led innovation played a major role in growth of economy. The rise of new generation entrepreneurs or startups, since last decade, led by innovative ideas to solve the problems along with ethical business practices are playing in profound ways. These startups have emerged in almost every sphere of life, agriculture, healthcare, biotech, engineering, fintech, transport, environmental services, clean energy, logistic, IT services, marketplace, etc. The cumulative effect has pushed the rank of India in Global Innovation Index 2021 to 46th position. India ranked 2nd among the 34 lower middle-income group economies.

The term startup denotes the early stage of an enterprise with science-based innovations having potential to scale up. As per the Government of India gazette notification 2019, an entity incorporated or registered in India not prior to 10 years with an annual turnover not exceeding Rs. 100 crores in any preceding financial year, working towards innovation, development or improvement of new products or processes or services or it is a scalable business model with a high potential of employment generation or wealth creation shall be considered as a Startup. Agriculture and allied sector have been witnessing emergence of several startups, commonly termed as "Agri-startups". These agri-startups develop products/ services to bring efficiency in the value chain at different stages, like infrastructure (storage & warehousing), farm automation (digital farming, advisory services), precision agriculture, upstream startups (input delivery and advisory), downstream startups (market linkages for output), fintech (agri-finance and insurance), agri-biotech (new inputs, post-harvest methods), etc. Many of these startups are using new generation IT tools like, artificial intelligence (AI), Internet of Things (IoT), imaging & sensors, remote sensing, drone, data analytics, blockchain technology, etc. in agriculture and allied sector for improving yield, efficiency, and profitability.

On the other hand, the Primary Agricultural Cooperative Society (PACS) is one of the oldest forms of farmers' organizations in India. Additionally, there have been many other forms of producer organizations catering to specific or multiple function(s) such as self-help groups (SHGs), Federation of SHGs, Common Interest Groups (CIGs), Joint Liability Groups (JLGs), and Farmers Clubs. In common parlance, all these may be termed as Farmers Producers Organizations (FPOs). Moreover, co-operatives in agriculture sector could not make profound impact in improving the livelihood and income of the farmers across the country, as it has done in some sectors like dairy, sugar or fertilizer production. Growing agrarian crisis over the years and simultaneously healthy growth of private sectors led to beginning of new thinking of bringing best attributes of both the sectors, the co-operatives and the corporates together. In the year 2000, the concept of producer companies was recommended by a committee chaired by Prof. Y.K. Alagh. In 2002, the Companies Act of 1956 was amended and new section 'Part IXA' was inserted for 'Producer Companies', a new form of corporate entity (GoI 2002).

These companies were designed on 'mutual assistance principles' and 'patronage' basis, to bring together desirable aspects of the cooperative and corporate sectors for the benefit of primary producers, especially small and marginal farmers (Alagh 2019; GoI 2000). Though, the act was extended beyond agriculture and farming, and non-farming sectors like rural artisans were also included in its ambit. In order to promote the mobilization of farmers and form the FPOs under new framework as a Producer Company, Small Farmers Agribusiness Consortium (SFAC) under Ministry of Agriculture, Government of India was designated as nodal agency. Such FPO is specifically called as Farmers Producers Company (FPC). Currently, FPOs are registered as different legal entities. Most of the FPOs are registered under Companies Act or State Co-operative Society Act, while some are also registered as Mutually Aided Cooperative Society (MACS) or Trust or Section 8 company. Although, several supporting government schemes for FPOs are valid only for those FPOs which are registered either under Companies Act or under Co-operative Society Act.

5.1. Ecosystems for Agri-Startups

Agri-startups are new business entities, which need support for its growth and sustainability. The appropriate ecosystem needed in the economy comprises of enabling policies, easy funding support at early stage, incubation facilities, and mentors. Startups usually fail due to lack of technical support to validate innovation, financial support at early stage, scaleup and low market acceptability of products and services. "Startup India Action Plan" was launched in January 2016 by the Government of India which paved the way for the introduction of a number of policy initiatives aiming at building a strong ecosystem for nurturing innovation and startups (GoI 2016). This has led to a tremendous surge in incorporation of new companies with innovative ideas in almost every sector including agriculture. The technology-led startups alias tech-startups are also growing in big number.

The incubators and accelerators play a major role in nurturing these entrepreneurs/ startups. The incubators are mostly technology backed, where the innovations are validated and improved, if needed, bring the technology to market acceptability stage. Besides, these incubators also provide business, technical, financial, legal & IPR, and networking services to the startups/entrepreneurs to sustain and grow their business. These help in mustering support services for start-ups, finding funding agencies such as angel investors, venture capitalists, and better networking opportunities for locating good markets. This support system is also relevant to the agri-startups.

Presently, there are about 890 incubators in India. Out of these, about 80 incubators are agriculture specific, while about 300 incubators are working in multiple sectors including agriculture. There are 50 incubators across different ICAR institutes, which facilitate the business environment to the agri-entrepreneurs. Besides, there are 29 incubators supported by Ministry of Agriculture & Farmers' Welfare in ICAR institutions, IIMs and State Agricultural Universities (SAUs). NABARD has also created 5 Agri-Business Incubators. These incubators work in different domain knowledge, like animal science, crop science, agricultural engineering, agricultural education, horticulture, fisheries, and natural resource management.

The NIDHI[2] Incubation Programme of Department of Science and Technology supports startups by its more than 150 Technology Business Incubators (TBIs) through Seed Support System (SSS) and Accelerator programmes with these TBIs. Similarly, Department of Biotechnology through its company Biotechnology Industry Research Assistance Council (BIRAC) has promoted incubators called *Bionest*, through different supporting programmes like BIRAC Ignition Grant (BIG), Small Business Innovation Research Initiative (SBIRI), etc. NITI Aayog is also supporting incubation centers under Atal Innovation Mission.

2 Department of Science and Technology (DST) under Government of India through its National Science and Technology Entrepreneurs Development Board (NSTEDB) initiated Technology Business Incubator (TBI) programme in the year 2000 to incubate and handhold startups in India. The programme was later rechristened as National Initiative for Developing and Harnessing Innovations (NIDHI) Incubation Programme in 2016.

These programmes are sector agnostic. These incubator centres are established at public as well as private academic and research institutions.

In agriculture sector, ICAR initiated entrepreneurship development programme in 2012 by establishing 10 Business Planning and Development (BPD) units (5 in ICAR institutes and 5 in state agricultural universities). This was followed by 12 more such units in 2013. The primary objective of these BPDs was to focus on transfer of technology to commercial ventures so that the developed technology reaches targeted stakeholders. Later under XII Plan, the project on 'National Agriculture Innovation Fund (NAIF)' addressed issues towards innovation and incubation by supporting Agri-Business Incubation (ABI) Centres. This initiative was more focused on start-up entrepreneurship. Presently ICAR has 50 ABIs. Together 977 entrepreneurs and startups were enrolled in these ABIs during 2014-21 against only 611 entrepreneurs enrollment in 2008-2014. Success rate was very high in current period, due to very conducive policies like startup India, Mudra Loan and other programme were launched. These incubates created job opportunities for more than 20,000 people. To develop the ecosystem culture, ICAR institutes also conduct entrepreneurship development programmes.

The Council also organized a two days Agri-Startup and Entrepreneurship Conclave for Unleashing potential in agriculture for young agripreneures (UPAYA) on the World Food Day during 16-17 October, 2018 as ecosystem building exercise. About 700 participants attended the Conclave which includes 104 ICAR (ABI-Network) nurtured agri-startups / entrepreneurs /licensees from different corners of the country. It had provided a unique platform for bringing together agri-professional, business experts, researchers and Farm Producers Organizations (FPO) in a face-to-face mode, same time country's finest mentors, angel investors, and venture capitalists were also interacted in different technical domains.

Later, Ministry of Agriculture & Farmers' Welfare, Government of India also launched RKVY- RAFTAR[3] scheme to promote agripreneurship and agribusiness by providing financial support through existing incubator centres in the country. The canvas of agribusiness incubation initiatives is wide and diverse with players from ICAR Research institutes, SAUs, IITs, IIMs, other engineering/ management colleges, NGOs, and other corporate entities.

5.2. Role of policy in the startup ecosystem

Journey of a startup starts from scouting an innovative idea to solve some major problems and then takes the startups to different stages of growth. Fig. 6 describes the stages of growth and the possible funding sources, which incubators help to bring on to the table for the discussion. Though, the success of any startup depends on large external factors such as change in policy, demand, demography and choices of customer.

3 The Rashtriya Krishi Vikas Yojna- Remunerative Approaches for Agriculture and Allied Sector Rejuvenation (RKVY-RAFTAAR) Agripreneurship is a scheme of the Ministry of Agriculture and Farmers' Welfare (MoA&FW), Govt. of India aimed at strengthening infrastructure in agriculture and allied sector in order to promote agripreneurship and agribusiness by providing financial support and nurturing the incubation ecosystem.

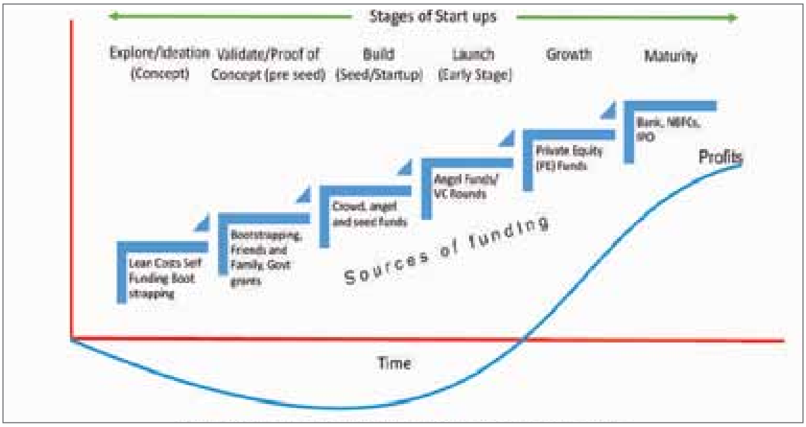

Fig. 6. Lifecycle of a typical startup and possible sources of funding

In order to reduce the effect of risk from the equation of startup, Government of India launched Start-up India Policy in the year 2016. With the new policy in vogue, a) startups are allowed to self-certify compliance for Labour Laws and Environmental Laws through a simple online procedure; b) fast-tracking of startup's patent applications with panel of facilitators are done to assist in filing of IP applications at rebate; c) eligible startups can be exempted from paying income tax for 3 consecutive financial years out of their first ten years since incorporation; d) Exemption under Section 56(2)(VIIB) of Income Tax Act; e) If company is not able to sustain, can wind up company with easy norms; and f) Startups have opportunity to list their products on Government e-Marketplace (GeM), with exemption from prior experience/turnover and EMD exemption. Besides these start-ups can avail seed funds from incubators (Seed Support from Department of Science and Technology, Department of Biotechnology), Startup India Seed Fund and RAFTAR scheme of Government of India.

5.3. Bringing capital for agri-startups

Startups in agri-sector have many avenues to raise the initial capital besides bootstrapping and lending from family & friends. As discussed earlier, all the incubators support the agri-startups in initial stages incubating with them under different seed support schemes. The CIIE – the incubator of IIM Ahmedabad started seed funding in startups. Later, many other agri-startups raised seed fund from different incubators. Among ICAR's incubators, a-IDEA of NAARM has been the pioneer as it invested in 12 agri-startups as a seed investment. It becomes easier for these agri-startups to raise funding from VCs and other investors later, if they get early investment from the incubators. Apart from this, there are several individual angel investors who look for scalable ideas to invest in at early stage in expectation of early scale up. Similarly, there are many venture capitals (VCs) firms like Omnivore Partners, Aavishkaar, Indian Agriculture Network (IAN), Accel, Ankur Capital, Kalari, Social Alpha, accel, and Beenext, which are invest in good startups at early stage in agriculture and allied sector. Recently, some global funds such as Blume, Nexus, Sequoia, Tiger Global and RTP also taking interests in the sector. Overall, India's agritech start-ups have been growing at 45% YoY. The start-ups have raised more than US$ 313 million investment. As per the NASSCOM report in 2020, this sector is expected to entice more than US$ 500 million in the next few years.

5.4. Agri-startups scenario in India

Startups come with innovative ideas to fill the gaps in the agri- and food value chains. Farmers in developing countries face multiple risks on several fronts and these startups endeavor to address them using new generation IT tools such as internet of things (IoT), big data analytics, blockchain technology and so on. The three broad categories of startup innovations identified are: pre-production startups which are engaged in advisory, crop planning, soil testing, input supplies including financing; production stage startups which include advisory in agronomy, plant protection inputs, irrigation scheduling and execution, etc., and post-production stage startups which include quality analysis, processing, storage, warehousing and market linkages. In India, there are 55390 DPIIT recognized startups registered with Startup India Initiative of Government of India. Out of these, there are 2421 and 2405 registered startups in agriculture and food & beverage sector, respectively. Most of these start-ups have come up since 2016.

Pre-production agri-startups: The availability and quality of inputs and proper advisory to the farmers is a serious problem affecting productivity and profitability of farmers. Several agri-startups have been offering solutions to optimise the use and enable delivery of assured quality inputs to farmers along with proper advisory. *Agrostar* is the largest startup in input supply to farmers and is expected to be unicorn soon. It has mobilised US$ 47 million in funding. It has been serving farmers in Gujarat, Maharashtra and Rajasthan with 400,000 active users and one million downloads of its app. *EM3* operates on FaaS (Farming as a Service) platform that enables technology to reach the farmer in an efficient and affordable manner through a network of farm centres (*Samadhan Kendras*). These centres are equipped to handle a comprehensive suite of basic and precision farm operations throughout the entire crop production cycle. At *Krishitantra*, another startup accelerated at a-IDEA, NAARM is serving farmers with deep insights and advanced levels of understanding regarding the health of their soil. The automation finesse and engineering proficiency contrive the world's best and affordable soil health testing solution. *Handa Biotech* uses aeroponic technology for better potato seed production. In aqua sector, Eruvaka and *Krimanshi* deal with sustainable feed solutions, while *Eruvaka* has developed AI based on-farm diagnostic equipment during production process.

Agri-startups facilitating production process: Farming in the Indian context is becoming difficult for lack of suitable equipment especially for small farmers, enormous drudgery in identifying biotic and abiotic stress and its management besides lack of financial services. Agri-startups have been finding these gaps and operating efficient services across the length and breadth of the country. Some of them focus on accurate and timely assessment of soil moisture and developing data-driven controlled irrigation models. *CropIn* provides complete digitization of farms bringing automation in agriculture using SaaS (Software as a System) based cloud software helping the farmers in complete operational control and decision making about agriculture solutions. *Bharat Rohan* a drone operating company analyse field wise biotic and abiotic stress, advises famers and also supplies inputs to overcome it. Bangalore-based *FlyBird* installs censors in the soil to detect moisture content and controls irrigation at a low cost. *Kisan Raja* with its innovative device allows farmers to remotely control the agricultural motor using their mobile or landline and used by 34200 farmers in India. *Gen Agritech* uses bio-based formulations for soil treatment and repellents against wild boar, blue bull and birds. *Codagu AgriTech* uses bio-capsule technology for delivering bio control agents, and plant growth promoters to the farmers in efficient way. There are others like *Intech Harness* that provides solutions for water pump controller. Similarly, *Sense-It-Out*, *KamlKisan*, *Agrirain*, *Manna Irrigation, Sickle innovations*, *Distinct Horizon*, *TractorJunction*, *Khetibadi* and *J Farm service* are some of other agri-startups in mechanisation services. *Samunnati*, *Whrrl* and *PayAgri* provides financial services to the farmers through farmers' collectives like FPOs, SGHs, JLGs, etc.

Agri-startups for post-production process: Post-production process includes harvesting, drying, grading, quality checks, packing, value addition and marketing. It is imperative to reduce the chain of intermediaries between the farmer-producer and consumer to better benefits the farmer. A large number of agri-startups focus on innovations for linking the farmers in far-flung areas with the buyers of their produce. The important players among them include- *BigBasket, DeHaat, Ninjacart, WayCool, ZopNow, ShopKirana, Jumbotail, DeHaat, AgriBazaar, Bijak,* and *MilkBasket*. The first four of these start-ups are involved in direct procurement from farmers and selling to other supermarket chains and other downstream actors. In animal sector, *Licious, FreshtoHome,* and *TenderCut* procure live animals directly from farmers and supplies the meat products to the consumers at doorstep. Multispectral and hyperspectral image analysis are being used for quality check by *AgNEXT, IntelloLab,* and *AgriX*. *Delmos* tests milk adulteration using strip-based technology. Dairy sector has few startups like *Stellaps*, *Country Delight*, *Prompt AMCS*, *Meri Dairy* and *Farmery* which are looking after complete value chain that includes pre-production, production and post production aspects

5.5. Growth and spread of FPOs in India

Initially, the Small Farmers Agri-Business Consortium (SFAC), a Society under Department of Agriculture and Co-operation (DAC) was designated as nodal agency to act as a single window for technical support, training needs, research and knowledge management and to create linkages to investments, technology and market (DAC 2013). All other central agencies like NCDC (National Cooperative Development Corporation), NAFED, Food Corporation of India (FCI) were encouraged to include FPOs in their activities. Similarly, NABARD and other financial institutions were also roped in to facilitate the availability of short- and medium-term credit for the FPOs. For this, "Equity Grant and Credit Guarantee Fund Scheme" was initiated to provide a grant up to 10.0 lakhs to double the member equity of the FPOs and also seek collateral-free loans up to Rs. 1.00 crore from the banks.

In 2013, 'FPO Formation Guidelines' were issued by Government of India and next year (2014) was declared as "*Year of Farmer Producer Organizations (FPOs)*" by the Ministry of Agriculture, Government of India with special package allocation of Rs. 200 crores to NABARD[4] as PRODUCE Fund to promote FPOs. Apart from this, the national policy also laid the framework for mobilization of FPOs with a dedicated source of funding from the *Rashtriya Krishi Vikas Yojana* (RKVY).

These concerted efforts created huge awareness among the farmers and other stakeholders, due to which formation and registration of FPOs got significant boost across the country. As on 31st Mar 2021, there are 9500+ FPOs registered under Companies Act, which are called as Farmers Producers Companies (FPCs). These FPOs are registered with the Ministry of Company Affairs (MCA), Government of India and their names end with "Producer Company Limited". These FPCs might have been formed with the support of NABARD, SFAC, private companies, NGOs, state departments or even private individuals. From the figure below, it can be observed that more than 98% of these FPCs have been formed after the year 2015. Apart from this, there are about 1500 FPOs registered under State Co-operative Society Act/Mutually Aided Cooperative Society/Trust, etc. Therefore, we can say that there are almost 10,000 FPOs registered as different legal entity existing in the country. These FPOs are distributed across all the states, though with varying density.

Within the category of FPOs, the FPCs have an advantage over co-operatives in the light of their democratic and producer-member based operation and management. In a farmer producer company, unlike in a private limited company, each member has only one vote irrespective of the number of shares held. Only primary producers can become shareholders of any FPC. Each FPC is governed by Board of Directors (BoDs) selected out of the shareholder-members. Though, the BoDs may also have outside experts as independent directors, without having any voting rights. The FPC may have hired staffs including Manager/CEO to run the business operations smoothly. Thus, FPOs/ FPCs are member owned and self-managed organizations and hence, involvement of the farmer members since the beginning is essential. The basic principles behind a FPC are voluntary and open membership, democratic farmer member control, autonomy, and co-operation amongst farmers.

5.6. FPOs leveraging multi-pronged benefits to the smallholder farmers

Overcoming the constraints imposed by the small size of their individual farms, FPO members are able to leverage collective strength and bargaining power to access financial and non-financial inputs, services and appropriate technologies, reduce transaction costs, tap high value markets and enter into partnerships with private entities on more equitable terms. FPOs offer the farmers advantages that come from higher scales of operation at various stages of the agricultural value chain system- from pre-production stage of quality

[4] *National Bank for Agriculture and Rural Development (NABARD) is an apex financing agency for the institutions providing investment and production credit for promoting the various developmental activities in rural areas. It is under the jurisdiction of Ministry of Finance , Government of India. The bank has been entrusted with matters concerning policy, planning, and operations in the field of credit for agriculture and other economic activities in rural areas in India.*

input purchase to collectivization of outputs, value addition, storage and transportation, marketing. In the process, the FPOs earn from a range of activities and services. Depending upon the commodities produced by the farmer-members, the FPOs can earn revenue/ profit by bulk buying and selling of seeds, fertilizers, pesticides and facilitating in custom hiring services of farm implements. They also earn income by way of providing primary processing (cleaning and grading) and/or value addition and levying auction fee from buyers for selling the produce.

5.7. Government policies promoting FPO ecosystem

Myriad of constraints faced by the smallholder farmers in India stimulated the government to create enabling environment for the FPOs. The FPOs can enhance rural development, poverty reduction, productivity gains and food security through their role in facilitating effective and efficient smallholder participation in agricultural value chain. Major problems for these FPOs are to raise funds for the working capital and creating minimum basic infrastructure, business acumen among the management team, lack of understanding of markets for different produce, etc. Therefore, the government in recent years have initiated several schemes to address these issues of the FPOs.

1. Equity Grant Scheme of SFAC: Under the scheme, eligible FPOs (whose paid up capital is less than Rs. 30 lakh) receive a grant equivalent to their equity contribution of their shareholder members in the FPO subject to a maximum of Rs. 10.00 lakh per FPO in two tranches. This helps in enhancing viability and sustainability of the nascent FPOs.

2. Credit Guarantee Fund Scheme of SFAC: Under this scheme, SFAC provides credit guarantee cover to the eligible lending institutions (banks), to give collateral free credit to the eligible FPOs up to Rs. 100 lakhs. Maximum guarantee cover is restricted up to 85% of the amount.

3. Venture Capital Assistance of SFAC: *The SFAC provides financial support in* the form of a soft loan for the qualifying projects of the eligible FPOs. The venture capital assistance helps FPOs to make investment in setting up agribusiness project. The cost of proposed agribusiness project would have to be between Rs. 15 lakh and Rs. 500 lakhs. The SFAC also helps in developing the detailed project report (DPR) with the help of empaneled consultant.

4. Financing Schemes of NABARD: NABARD through its subsidiary NABKISAN Finance Limited provides credit assistance to the FPOs at various stages of their life. Loan products are customized to meet the requirement of FPOs without collateral/guarantee cover. The items eligible for assistance broadly include capital cost such as cost of building, machinery and equipment for processing, specially designed vehicles for transportation, etc. and/or working capital requirements for input supply, procurement, collective marketing, and other recurring costs connected with the project.

5. Agriculture Infrastructure Fund under Central Sector Schemes: In the year 2020, the Government of India has set up Agriculture Infrastructure Fund (AIF) worth Rs. 1 lakh crores for creating farm-gate infrastructure. The FPOs can get the medium to long-term debt financing with interest subvention under this fund for investment in viable project relating to postharvest management infrastructure like processing, ripening chambers, assaying, sorting & grading facility, modern packaging, storage & warehousing, etc. The scheme is operational from 2020-21 to 2029-30. The credit guarantee coverage is available for the FPOs for a loan up to Rs. 200 lakhs.

6. PM *Matsya Sampada Yojana* under Central Sector Schemes: As a part of *Atmanirbhar Bharat* package, the Government of India launched the *PM Matsya Smapada Yojana* in the year 2020 for next 5 years for supporting fish farmers and fish FPOs. Under this, credit guarantee assistance is provided to fish growers for modernizing and strengthening of fish value chain.

7. Central Sector Scheme on "Formation and Promotion of 10,000 New FPOs: This is so far the largest focused scheme from Government of India to promote new 10,000 FPOs in India with initial financial and managerial support. The scheme is targeted for five-year period of 2019-20 till 2023-24, with adequate handholding support to the FPOs for five years till 2027-28. It envisages to form and promote at least 15% of the targeted 10,000 FPOs in aspirational districts with at least one FPO in each block of these districts in the country. For this, SFAC, NCDC (National Cooperative Development Corporation) and NABARD have been identified as Implementing Agencies (IAs). Thus, the FPOs under the scheme can be formed either under Companies Act or under States' Co-operative Societies Act. The IAs will engage specialized Cluster Based Business Organizations (CBBOs) who have prior experience of farmer mobilization, marketing of agricultural products, MIS (Management Information System) implementation and overall business development of farmer organizations. Under this scheme, the FPOs get funding support for first 3 years. Besides, it can avail Equity Guarantee of up to Rs. 15.0 lakhs and Credit Guarantee up to Rs. 2.0 crore of project loan per FPO through the IAs. Capacity building and skill development of CEOs/Board of Directors, Accountant and other stakeholders are made through different national/regional training institutions in India.

In addition, all the development schemes in agricultural and allied sectors currently being implemented by Central and/or all the state governments in the country encourage the FPOs to be the beneficiaries of the programmes/schemes. It has been observed that the FPOs perform better when its management systems, governance and capital structure are strong. Other factors like market and financial accessibility, farmer-members engagement plan, infrastructure development, better than existing market pricing mechanism, etc. should also be strengthened to scale up the business of the FPOs for its long-term growth and viability.

5.8. Success stories of FPOs

Undoubtedly, there are several challenges in the way of FPOs in India, such as weak sense of ownership among producer-shareholders, inadequate funding support, poor management skills, weak governance, lack of business understanding, etc. (Prasad and Prateek 2019; Govil et al. 2020), the collectivization of activities through FPO would spur vertical business integration. This would increasingly be serving the twin purpose of profit making and welfare of its shareholders and local communities. It could prove an effective anti-poverty approach propelling rural entrepreneurship and youth employment in India.

The FPOs are benefitting the smallholder farmers in various ways. Average family income of FPO-member-farmers has significantly increased, FPOs provided easy access to farm inputs as well as linkages with the financial institutions in West Bengal (Das and Mandal 2021). Similarly, *Bhose Agro Producer Company* in Solapur district of Maharashtra with over 500 members has been exporting chillies and earning annual turnover of about Rs. 1.50 cr. Other FPOs, namely *Narmadanchal Producer Company* in Sehore district of Madhya Pradesh, established in 2013, has increased its annual turnover to Rs. 2 crores in first 3 years. It has undertaken agri-input trading and commodity trading businesses. The FPO got funding support from NABKISAN. Similarly, *Narsingh FPCL,* established in 2006 in Madhya Pradesh is actively involved in agri-input trading, seed production, trade of agricultural produce. It has set up its own seed processing infrastructure. With its about 2000 farmer-shareholders, the turnover of the company has reached to Rs. 9.79 crores in FY 2015-16. Thus, there are several success stories of FPOs in different parts of the country. It is noteworthy is illustrate the success story of two FPOs, which has established complete value chain and works in federation mode.

i) Sahyadri Farmers Producers Company Ltd. (SFPC): SFPC is one of the most successful FPOs in India. It was incorporated in December 2010. Now, it is working as federation of about 12 FPCs in Maharashtra state. The SFPC has 726 individual shareholders and all the FPCs under it are also the shareholders. The company is thus connected with more than 6000 farmers growing different horticultural crops, mainly fruits like grapes, tomato, banana, pomegranate, guava, vegetables, floriculture, etc. The company now operates in business-to-business (B2B) as well as serving directly to customers (D2C) through its own retail stores in the state. In the year 2019, the company became India's largest grape exporter. The SFPC provides technology and services to the producer FPCs' members improving crop productivity and quality. It also helped in optimization of cost of production. The value addition and marketing of the produce are taken care by the umbrella company viz. SFPC. The company has introduced the technology not only for the business operations, but also digitized the fields of its member-farmers to monitor and control the traceability of the produce. In the year 2020, the SFPC achieved revenue of Rs. 465 crores and net profit of Rs. 19 crores. The current paid-up capital of the company is Rs. 55.67 crores, and authorized capital of Rs. 70 crores (2020). The SFPC has raised most of the funds (as debt) from the banks for its operation and expansion. The company has created state-of-the-art infrastructure facilities for value addition, processing, cold storage as well as training centre near Nasik. The company is targeting to significantly improve the livelihood of more than 10,000 farmers of state in next 5 years.

ii) Sahaja Aharam Farmers Producers Company Ltd (SAFPC): SAFPC is also a federation of 23 organic farmer producer organization in Andhra Pradesh, Maharashtra and Telangana states, which owns end-to-end supply chain from seed to final products. The SAFPC, headquartered at Hyderabad was incorporated under Companies Act in November 2014. It is working with 10,000 fully organic farmers. The company has authorized capital of Rs. 25 lakhs and paid-up capital of Rs. 17.5 lakhs. It received credit funding of Rs. 80 lakhs from NABKISAN Finance Ltd in two tranches. The company procures crop produce from certified organic farmers, process at its own food-hubs, sells to other businesses or through its own exclusive retail stores as certified products under NPOP/USDA standards. More than 100 SKUs (stock keeping units) of products, including cereals, millets, edible oils, sweeteners, spices, processed foods (ready-to-eat and ready-to-cook), health foods, fresh fruits & vegetables, etc. are also available on e-commerce platform. The SAFPC provides the technical knowhow, seeds and conducts capacity building programmes for the farmer-members on continuous basis. By shortening supply chain, the SAFPC ensures about 50% higher price to the producer-farmers.

5.9. Synergising the agri-startups with FPOs for *Atmanirbhar Bharat*

India can't become *Atmanirbhar* unless the income and livelihood of its food producers are ensured. Currently, the income from farming is abysmally low, merely Rs. 816 per capita per month. The farm income can be increased by either reducing cost of crop/ animal production, or by increasing per unit productivity by adopting modern production technologies and improved resources use efficiency or by creating and capturing value from the agricultural value chain. It may happen alone or in combination of these factors. For these to happen, innovators and producers need to come together. Therefore, strong synergy between agri-startups and FPOs (Farmer Produce Organisations) are imminent. It offers win-win opportunities for both the entities. On one side, farmer-members get access to modern technologies, products and services offered by innovative agri-startups at their doorsteps, on the other hand, agri-startups get access to huge market of farmers and their produce for their business activities. Such collaboration would reduce the transaction costs for both the entities and help the farmers in realising better income from farming. The FPOs by design carry out aggregation of demand for farm inputs as well as farm produce and link farmers to markets. They need support in the form of financing, advisory, quality inputs, farm record maintenance, capacity building, warehousing, primary processing, etc. The agri-startups in India are trying very hard to achieve a sizeable scale. The majority of these startups are fund-starved to spend on customer acquisition on their own. Majority of them are revenue positive yet not profit earning. We are already seeing many startups orienting their business models to cater to the needs of FPOs. FPOs get the most innovative technology and services for their farmers at low cost creating value for technology. Thus, handshake between farmers' organization and agri-startups/entrepreneurs, like startup-

FPO immersion programme of a-IDEA will create unique win-win collaborative business models, and FPOs have a huge role to play in making this happen.

6. Conclusion

Scientific advancements are reshaping Indian agriculture rapidly. The achievement of cereal self-sufficiency is gradually shifting towards other commodities such as pulses. On the production side, market and price-responsive commodities like milk, meat, fish, fruits, vegetables, and other cash crops are increasingly being grown, and income and profits are replacing supply augmenting strategies. A pattern of diversified agriculture is clearly visible. Simultaneously, business ecosystem is gradually expanding and supportive mechanisms for agri-preneurship/startups such as technology business incubators and financial infrastructure is concentrating. At this front, technologies and policies ensuring sustainability need continuous efforts – ranging from sustainability in resource use, environmental impacts, risk-handling, information and business ecosystem development. Upscaling expenses for research and development (R&D) and research prioritization would be the key to meeting them. On the other side, encouraging and incentivizing private sector participation, notably in commercialization of agricultural technologies, developing agri-preneurship through start-ups, and supporting innovative organizations like FPOs would help to balance the agricultural ecosystem in the coming years.

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Prime Minister Shri Atal Bihari Vajpayee speaking at the 85th session of Indian Science Congress at IARI, New Delhi

17
Chapter

Leadership in Agricultural Research in Independent India

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Summary

National Agricultural Research, Education and Extension System (NARES) evolved over years with the significant contribution of its visionary leaders. Today, NARES is confronted with reducing resources and scientific manpower and localization, impacting the national character of the organization and a scenario demanding solutions for complex problems. Such situation demands for strong and visionary leadership to effect the change both 'structural and cyclical' to make the organization relevant to the emerging challenges and contextual to the geo-political ecosystem. The journey of last 90 years of NARES has been full of reforms and innovations, the bulk of them happening post-independence. The Indianization of Imperial Council of Agricultural Research in 1929 was the first and foremost important reform that put the very basic foundation of the diversified organization in the form of Indian Council of Agricultural Research we have today. Since 1929, ICAR was subjected to periodical reviews and emerged stronger after every review due to the vision and stewardship provided by its leaders from time to time. Following the recommendations of Gajendragadkar Committee in 1972, DARE was created in 1973 to provide linkage with Government and line departments. The institutional mechanism of inter-institutional linkages was established following the creation of subject matter divisions after the recommendations of GVK Rao Committee, 1988; functional autonomy to the scientists following the Johl Committee's recommendations in 1995; ICAR-industry interface and scientist-entrepreneur tie-up after Mashelkar Committee's recommendations in 2005. Restructuring of ASRB, reforms in AICRPs, cadre review, and accreditations of SAUs were implemented after Peer Review Committee in 2017. The one of its kind reforms of allowing foreign germplasms in the breeding programme changed the face of the Indian agriculture post-independence and forever due to visionary political-scientific leadership in 60s. The establishment of Agricultural Scientists' Recruitment Board (ASRB) in 1973, Krishi Vigyan Kendra (KVK) in 1974 and Agricultural Research Service (ARS) in 1975, and Agrinnovate India Ltd. (AgIn) in 2011 for commercialization of ICAR technologies were the landmark structural reforms. Parallelly, the leadership in ICAR helped country to move on the path of revolutions through green, white, yellow, blue and more recently pulses, sugar and gene revolution. ICAR actively engaged itself in the policy formulation and implementation such as Specifications and Standards for Biofertilizers and Micro-

inoculants under Fertilizer Control Order, 1985; Comprehensive Marine Fisheries Policy, 2004; Seed Bill, 2004; Coastal Aquaculture Authority Act, 2005; Nutrient-based Subsidy for Fertilizers, 2010; National Agroforestry Policy, 2014; National Policy on Marine Fisheries, 2017; National Mariculture Policy, 2019; Inland Fisheries and Aquaculture Policy, 2019; National Policy for Fisheries, 2020; and Pesticide Management Bill, 2020, regulations on germplasm and biodiversity, quarantine, climate change mitigation and adaptation and more recently on genomics and gene editing. ICAR had the benefit of scientific leaders all along the various stages of its transformational journey, which is set to remain as an ever-evolving continuum.

1. Introduction

The transformational narration of Indian Agriculture post-independence will be incomplete without the mention of the phenomenal transformation and the pivotal role played by organizational leadership of Indian Council of Agricultural Research (ICAR) in shaping the National Agricultural Research, Extension and Education System (NARES). *Azadi Ka Amrut Mahotsav* is an opportune time to salute the great leaders who removed the cutting blade of hunger and poverty from $1/6^{th}$ of the humanity on the Globe.

Indian agriculture continues to battle the formidable challenges of meeting food and nutritional requirements of increasing population from depleting and deteriorating land, water and other resources that are under acute pressure due to overuse, misuse and abuse. However, unlike in its formative years after independence, the country now effectively deals with current challenges including the unforeseen ones like the COVID-19 pandemic. Several attributions can be made to this phenomenal journey of farm sector *viz.,* political will, science and technology, human resources, investments, infrastructure, and the resolute and resilient farming community. The organizational leadership played the catalytic role in this spectacular makeover.

The mid-60s witnessed one of its momentous milestones - the green revolution, a classic case of synergy of the political, scientific and bureaucratic leaders that boosted the farm production using science and technology. The structural reforms to accommodate diversified views and resources like SAUs, ARS, DARE, foreign breeding materials in the mid-60s and 70s led to strengthening of ICAR and NARES. The white revolution owing to 'cooperative farming' and cross-bred breeds was another landmark blend of science and development ushering into rapid transformation in production and supply chain management of milk. The institution of Agricultural Research Service (ARS) in 1975 and National Academy of Agricultural Research Management (NAARM), initially called Central Staff College for Agriculture in 1976, were significant reforms in the domain of human resource development. Several other institutions of excellence were established and few institutions under the State Governments were brought under ICAR for more autonomy and location-specific countrywide research. Subsequent decades saw diversification for natural resource management, farm power and energy, high value cropping, allied sectors along with farmers' outreach, policy, HRD and research governance.

Agricultural research in India is designed to provide affordable technologies to farmers, and farm products to consumers by sustainable growth in agricultural productivity. The research leader has to mobilize adequate resources from the Government sources as well as from unconventional sources, of the respective times to keep this growth engine moving. The visionary leaders of ICAR have piloted the agricultural research in different phases, matching to the needs of changing times. The milestones of organizational leadership in the transformational journey of agricultural research are presented in Table 1.

Table 1. Milestones in the Transformational Journey of Agricultural Research in India

Year	Milestone
1929	Establishment of Imperial Council of Agricultural Research (1929), now Indian Council Agricultural Research.
1957	The concept of the All-India Co-ordinated Research Project (AICRP) introduced, and the first AICRP on maize started.
1960	The first State Agricultural University (SAU) at the Pantnagar established on the pattern of the Land Grant Colleges of USA.
1963	Council's rules and bylaws; reconstitution of the Governing Body; Administrative control of all research institutes and Commodity research institutes by the Council.
1965	Appointment of a Scientist as Director-General and Vice-President of the Council.
1965	Green Revolution initiated.
1966	Various agricultural research institutes under the Ministry of Agriculture, placed under the purview of the ICAR.
1969	Sugarcane Breeding Institute got affiliated to Indian Council of Agricultural Research.
1973	Creation of Department of Agricultural Research and Education (DARE). Director-General, ICAR, given the status of Secretary, DARE, and Chairman of the Governing Body of the ICAR. Establishment of Agricultural Scientists Recruitment Board (ASRB).
1974	First Krishi Vigyan Kendra established at Puducherry.
1975	Initiation of Agricultural Research Service (ARS) and recruitment of the scientists by Agricultural Scientists' Recruitment Board (ASRB).
1976	Establishment of the National Academy of Agricultural Research Management (NAARM).
1979	Launch of Lab-to-Land Programme and the National Agricultural Research Project (NARP).
1984	A separate Division of the Agricultural Extension, headed by the Deputy Director-General (DDG), created in the ICAR.
1987	Separate Divisions for Horticulture and Fisheries, headed by DDGs, carved out of the Crop Science and Animal Science Divisions, respectively.
1988	GVK Rao Committee, constituted to review infrastructure, personnel policies and functional role of the ICAR, submitted its report. Agricultural Engineering Division, headed by a DDG, carved out from the Natural Resource Management Division.

Year	Milestone
1990	Establishment of the National Academy of Agricultural Sciences (NAAS).
1995	Launched World Bank funded Agricultural Human Resource Development (AHRD) project.
1998	Launching of World Bank funded National Agriculture Technology Project (NATP).
2005	Implementation of the National Agricultural Innovation Project and the National Fund for Basic and Strategic Research.
2011	Establishment of Agri-innovate India Ltd. (AgIn) Company.

https://icar.org.in/files/vision-2020.pdf

2. Science Leadership: An Overview

Agriculture as a sector is probably the oldest one to have research as its core segment, though 'informally' practiced by farmers and other biologists in its formative stages. However, as human beings started practicing growing crops and rearing animals, research also started to see improvement. Starting in the mid-19th century, organized agricultural research was taking place in institutions such as the Agricultural Chemistry Association of Scotland, the Agricultural Experiment Station, Saxony, and the Land Grant Colleges in the United States (Loebenstein and Thottappilly, 2001). Around the same time, Imperial Council of Agricultural Research (1929) was established in Delhi, India, which is known today as Indian Council of Agricultural Research (ICAR). Currently several organizations and institutions are engaged in agricultural research. Most of the nations have National Agricultural Research System (NARS) consisting of national research institutions, universities, independent research organizations, the private sector, and international research centers.

Science leadership needs to resolve many potential areas of disconnect within research, spatial or cultural/social disconnect. The time lags between conducting research and actual utilization of research outputs and outcomes for solving problems could lead to many potential disconnects. More concerning is the disconnect between basic and applied research, often compounded by institutional or geographic distance.

Scientific organizations like ICAR engage in basic agricultural research for knowledge discovery for its prospective application to solve real-time problems. Research organizations have in the past had relative freedom to do this although at present with financial constraints it is progressively more difficult in some subjects to access the resources to continue basic research. In agriculture, basic research is an important starting point for much applied research, which is concerned with specific and defined problems rather than fundamental issues. The uniqueness of the leadership requirement in ICAR is that it is required to guide or lead the diversity of organizations and institutions performing research along this upstream, fundamental research to downstream, more applied research continuum (and often performing a development/extension function as well) to ensure minimum duplication and maximum synergy in a global environment. The system in the past was greatly benefitted by outstanding visionary leaders that enabled a diverse and dynamic system to contribute immensely to food secure nation.

3. Role of Leadership in Driving the Agricultural Research System with Changing Needs

Following the recommendations Joint Indo-American Teams of 1954 and 1959 and Agricultural Research Review Team, the Government of India in 1963 approved the reorganization of the ICAR. The revision of the Council's rules and by-laws were effected leading to structural changes such as reconstitution of the Governing Body; administrative control of all research institutes and commodity research institutes; and appointment of a Scientist as Director General and Vice-President of the Council. Dr. B.P. Pal, thus appointed as the first Director General of ICAR in May 1965.

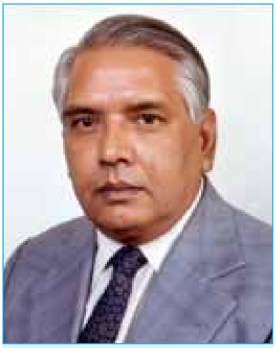
Benjamin Peary Pal (1965-72)

Prior to this, to achieve food security necessitated single agency administration and monitoring of various institutions established for that purpose. The first AICRP for maize was initiated in 1957 as a result of the Ministry of Food and Agriculture, GOI signing an agreement with the Rockefeller Foundation in 1956. The success of the coordinated maize project in India proved to be a watershed moment in agricultural research planning. By 1965, ICAR decided to initiate coordinated projects on other crops as well as in other areas of research, such as animal husbandry, natural resource management, and so on. Currently, 60 coordinated projects on various subjects are in operation. India pursued an agricultural development strategy that prioritized self-sufficiency in staple foods such as wheat and rice. Several other agrarian reforms such as the Integrated Production Program in the 1950s were crucial initiatives.

Mrs. Indira Gandhi, the then Prime Minister of India sowed the seeds of the Green Revolution with capable leadership of C Subramaniam, the then Agriculture Minister suitably advised by the visionary scientists Dr. M.S. Swaminathan following the successes of dwarf Mexican varieties developed by Dr. Norman E. Borlaug. The seeds of high yielding dwarf wheat varieties were allowed to be imported and demonstrated at farmers' fields with irrigation as well as external inputs such as chemical fertilizer and pesticides. The rest is the history. It aided India's transition from a massive food importer reliant on aid to a food exporter. The Green Revolution increased crop yields in India significantly and saved a large number of people from starvation or malnutrition.

Dr. Monkombu Sambasivan Swaminathan (1972-79)

Dr. M.S. Swaminathan served as Director General (DG) of the Council during 1972-79. He introduced sea changes in the agricultural research system in India. The Department of Agricultural Research and Education (DARE) was created in 1973; first Krishi Vigyan Kendra (KVK) established in 1974; Agricultural Research Service (ARS) initiated for scientific recruitments through Agricultural Scientists' Recruitment Board (ASRB) in 1975. Along with structural changes and reforms, the programmatic interventions such as Lab-to-Land and National Agricultural Research Project (NARP) were also launched. With immense contribution made to the agriculture sector in India, he has been decorated with many coveted international and national recognitions and popularly regarded as the father of Indian Green Revolution. This was the period when ICAR-CGIAR relationship started establishing which later ushered into significant outcomes. The ICRISAT was established in India through Dr Swaminathan's initiatives.



Dr. Om Prakash Gautam (1979-85)

Dr. Om Prakash Gautam, served the Council as Director General during1979-1985. He had been instrumental in revitalizing the Indian Agricultural Education System and making the Agricultural Universities as Centers of Excellence.

Dr. Narinder Singh Randhawa (1985-92)

It was during the leadership of Dr N.S. Randhawa, Phase II of the National Agricultural Research Project was implemented with an expanded mandate covering new areas of research such as irrigated farming, horticulture and commercial field crops, agro-forestry and animal nutrition besides development of programs for field testing and refining research results. He was also instrumental in recommending the Rural Work Experience (RAWE) program for imparting practical oriented education module for agriculture degree program.

Dr. Mangina Venkateswara Rao (1986-1989)

While cereals production has increased substantially after 1965, the oilseed production remained low. In 1986, the Government launched Technology Mission on Oilseeds (TMO) and Dr. M.V. Rao, Former Special DG, ICAR led the Mission with effective coordination among various Ministries, Departments, and Organizations such as ICAR and SAUs. The resultant was significant turnaround in oilseed production from 10.83 million tons in 1985-86 to 24.75 million tons in 1998-99. India achieved near-self-sufficiency in edible oils, popularly called Yellow Revolution (1986-1990). The subject matter divisions were established in ICAR during this period in response to the recommendations of the GVK Rao Committee in 1988, to foster inter-institutional collaboration.

Dr. Virender Lal Chopra (1992-94)

Leadership of Dr. V.L. Chopra as DG, ICAR was vital in giving right direction to ICAR for developing and promoting Horticulture technologies. Horticulture sector has seen a sharp growth for more than a decade.

Dr. Rajendra Singh Paroda (1994-2001)

Dr. R.S. Paroda revamped India's National Agricultural Research System while serving as Director General of the ICAR and Secretary of Department of Agricultural Research and Education (DARE), Government of India from 1994 to 2001. Under his stewardship, more than 20 new institutes in crops, horticulture, livestock, natural resources management, fisheries, agricultural engineering, and social science were established. The World Bank's National Agriculture Technology Project (NATP), which focused to reorient agricultural research, education, and extension systems to meet new challenges, was another pivotal development initiated during his tenure. Scientists were granted functional autonomy in 1995, following the Johl Committee's recommendations. He was instrumental in launching the Agricultural Human Resource Development (AHRD) Project in 1995 with financial assistance from the World Bank, which revolutionized agricultural education in the country. The world's largest and most advanced national gene bank was established in 1996, now housing over 400,000 crop germplasm accessions. His contribution in founding APAARI and establishing ICAR close working relationships with CGIAR is commendable.

Dr. Panjab Singh (2001-02)

As Secretary, DARE and DG, ICAR, Dr. Panjab Singh's significant contributions include strengthening laws to protect the country's valuable bio-resources from bio-piracy and translation of innovative technologies on the farmers' fields so as to ensure their better adoption and building collaborations among scientific institutions.

Dr. Mangala Rai (2003-09)

The National Agricultural Innovation Project (NAIP) was the next step toward achieving excellence in science, utilizing science for society and commerce, and enhancing rural livelihood security through the integration of technology and agricultural economy orientations. Under the leadership of Dr. Mangala Rai, Director General of ICAR during 2003-2009, public organizations collaborated with farmers' groups, the private sector, and other stakeholders to accelerate and sustain the transformation of Indian agriculture in support of poverty alleviation and income generation. The ICAR-industry collaboration and scientist-entrepreneur collaboration were implemented through the National Agricultural Innovation Project and the National Fund for Basic, Strategic and Frontier Application Research in Agriculture (NFBSFARA), renamed later as National Agricultural Science Fund (NASF) following the recommendations of Mashelkar Committee in 2005. He is also credited for establishing many new institutions, viz., ICAR-National Institute of Abiotic Stress Management (NIASM) ICAR-National Institute of Biotic Stress Management (NIBSM); Seed Science (ICAR- Indian Institute of Seed Science); ICAR-National Institute for Agriculturally Important Microorganisms (ICAR-NIAIM); ICAR-Indian Institute of Agriculture Biotechnology (ICAR-IIAB); & ICAR-Indian Institute of Vegetable Research were also established.


Dr. Subanna Ayyappan (2010-2016)

Dr. S. Ayyappan was the Secretary, DARE, and Director General of ICAR, during 2010-2016. He is credited with bringing Indian fisheries to a level of excellence in basic science and fish commercialization that is unparalleled anywhere in the world. His contributions to the organization, with foresight, innovation and partnerships, both at national and global levels were commendable. Under his leadership, the technological advancements in fisheries and aquaculture led to significant increase in the production and productivity. A new era of establishing Indian Agricultural Research Institute (IARI) like institutions was planned for the eastern States of Jharkhand and Assam to bring green revolution in eastern India. This period also saw upgradations of many ICAR directorates and NRCs into full-fledged institutions with inclusivity. Borlaug' Institute for South Asia got established in India with its research centers in Madhya Pradesh and Bihar.


Dr. Trilochan Mohapatra (2016-2022)

The Council under the current leadership of Dr. Trilochan Mohapatra as Secretary, DARE and DG, ICAR has taken a laser-sharp focus on driving Indian agriculture to meet ever-increasing challenges by leveraging the most recent advances in science and technology, such as digital technologies and smart farming, as well as the most recent biotechnological advances such as CRISPAR, among others. Thus, with strong science leadership, the council has been proactively transforming itself to the nation's ever-changing needs and evolved into the World's largest agricultural research and education system. ICAR-Mahatma Gandhi Integrated Farming Research Institute, Motihari, IARI, Jharkhand Campus, Assam Campus; International Centre for Foot and Mouth Disease, Mukteshwar were established under his leadership. He also started implementation of National Education Policy (NEP 2020) in the NARES system.

His pioneer reformist agenda is noteworthy too. In accordance to the recommendations on structural reforms by the Peer Review Committee, 2017 chaired by Dr. T. Ramasami, Former Secretary, DST, Government of India, the reorganization of the ASRB, right sizing of AICRPs, cadre review of ICAR were effectively implemented. The revision of ICAR's guidelines on Regulations for Intellectual Property Management and Technology Transfer/Commercialization and accreditation of SAUs for standards in higher agricultural education were implemented. He also led the mainstreaming of CSR funding to ICAR research & extension with ICAR putting its CSR Guidelines in 2021. The ICAR got noticed as a clear voice and organization in CGIAR reform process into One CGIAR; and many global platforms and organizations. The international relations expanded with explicit workplans and deliverables. ICARDA's FLRP in Madhya Pradesh and IRRI's South Asia Regional Centre at Varanasi were established during his able leadership. ICAR also made an impressive footprint in its neighborhood through the establishment of ACARE in Myanmar, ANASTU in Afghanistan and Deemed University for Agricultural Education in Nepal. Besides, fellowships for higher agricultural education to students from African countries and others implemented.

Besides these great doyens in Indian agriculture, there were many other leaders who did yeomen service to Indian agriculture. To mention a few are, Dr. A.B. Joshi; Dr. N.G.P. Rao, Dr. D.R. Bhumla, Dr. Ananta Rao who provided unmatched leadership in various ways that paved the way for ICAR's early recognition.

3.1. Impacts of Revolutions in Indian Agriculture

The Green Revolution facilitated institutional and social changes in rural areas and provided opportunities for self-sustaining economic growth, reduced poverty, averting hunger for millions of people, reduction in import of food grains, and industrial growth (Pinsterp and Anderson 1985). A significant contribution of green revolution is the change in the attitudes of farmers, enhancing the status of agriculture from a low-level subsistence activity to a commercial one. This contributed to the transformation of the state from food import into self-sufficiency and food export country.

The White Revolution in India was successful in transforming the country from a milk deficient nation to a world leader in milk production. It helped dairy-farming become India's largest self-sustaining industry and also, India's largest rural employment provider. India achieved near-self-sufficiency in edible oils from the yellow revolution and there was significant turnaround in oilseed production from 10.83 million tons in 1985-86 to 38.50 million tons in 2021-22. The Blue Revolution, with its multi-dimensional activities, focuses mainly on increasing fisheries production and productivity from aquaculture and fisheries resources: inland, fresh water and marine. Average milk, egg, fruit, vegetable, meat consumption improved over the decades leading to diversified food systems, nutrition security with increased life expectancy.

Other revolutions in the country were the outcomes of the technologies introduced and policies framed and implemented with strong backup from leadership and institutional strength of ICAR. The ICAR technologies contributed in sustaining the benefits of these revolutions, despite depleting and deteriorating natural resources (Soil, water, biodiversity, climate), as well as escalating stresses such as diseases, insect pests, droughts, and floods.

4. Milestones in Leadership

The ICAR laid significant focus on research, technology, education, innovation, etc., in different phases of its transition and all such developments were possible or successful essentially because of the major policies and cross-sectoral initiatives, organizational innovations piloted by the Director Generals of ICAR, in the respective time periods, ably supported by various eminent researchers and research leaders. The salient milestones, significant game-changing events, transformational reforms, etc. grouped based on the functional domains or intended purposes are presented in following para.

4.1. Enabling Research Partnerships, Consultancy, Resource Mobilization

ICAR revisited its resource mobilization strategy in 1997 by providing for engagement of researchers with external sponsoring bodies and corporate/private firms. The Rules and Guidelines on "Training, Consultancy, Contract Research and Contract Service in ICAR System" were formulated in 1997. Researchers were encouraged to participate in collaborative work with external agencies. These guidelines were in operation from April 1, 1997.

Later in 2014, these guidelines were updated as 'ICAR Rules and Guidelines for Professional Service Functions (PSF)' which are very futuristic and enabling to achieve the core objectives of the arrangement and operating even today. The seamless operation of the large number of externally funded projects, national and international consultancy services, sponsored projects currently under various institutions across the subject matter divisions, could be attributed to these initiatives from the ICAR.

4.2. Strengthening Research Outputs (Publications, Patents, Technologies)

ICAR has its Guidelines for Intellectual Property Management and Technology and a decentralized three-tier IP management mechanism is institutionalized in ICAR on October 2, 2006 under the guidance of Dr. Mangala Rai, the then DG, ICAR. It led to increased IPR-filing and establishment of business planning and development (BPD) units. These Units provide incubation facilities, research and business services and mentorship on marketing, technical, legal and financial matters, the encouraging lessons of which lead to 'National Agriculture Innovation Fund' which among others also included the much demanded initiatives of Attracting and Retaining Youth in Agriculture (ARYA).

The Agri-Startups associated with ICAR institutions through technology transfer or business incubation are helped through NAIF and IP&TM Units of ICAR institutions and documented the success stories of 100 such entrepreneurs partnering with ICAR under the able guidance of Dr. T. Mohapatra, Secretary, DARE and DG, ICAR (Srinivas et al. 2018). Number of Technology Business Incubation (TBI) centres were expanded towards overall entrepreneurship development in agriculture and food systems in the country.

4.3. Strengthening Research Spatial Networks & Outreach

4.3.1. Krishi Vigyan Kendra (KVKs) – Farm Science Centers

The idea of farm science center was conceived by Dr. M.S. Swaminathan the then DG, ICAR after the recommendation of the Education Commission (1964-66). Later discussion by the Planning Commission and Inter-Ministerial Committee, and recommendations of Dr. Mohan Singh Mehta committee in 1973 consolidated this idea and the first KVK, on a pilot basis, was established in 1974 at Pondicherry. In 1976-77, 18 more KVKs were approved for establishment with 100% central assistance. With the growing demand, the Government approved setting up of at least one KVK in each district, 731 KVKs are functioning in India under the administrative control of SAUs, ICAR institute, NGOs State Government and other educational institutions.

4.3.2. All India Coordinated Research Projects (AICRPs)

Starting in 1957 the AICRPs has become a unique conglomeration of central research institutes, agricultural universities and state departments of agriculture. The first AICRP on Maize was set up in 1957. Today, 60 AICRPs are functioning for multidisciplinary and multi-location research Dr. B.P. Pal, former DG, ICAR was the architect of All India Coordinated Research Projects (AICRPs) which helped to develop new varieties, hybrids, cropping and farming systems, machineries, vaccines, nutrition protocols of livestock and climate resilient models, biofortified varieties, high protein maize, etc. in India. This has cemented complimentary ICAR-SAUs structural networking. These projects have become a model for many developing countries with federal structure for organizing the agricultural research.

4.3.3. Farmer FIRST (Farm, Innovations, Resources, Science and Technology)

The Farmer FIRST (Farm, Innovations, Resources, Science and Technology), under the guidance of DG, ICAR Dr. T. Mohapatra, initiated during October, 2016, aims at enriching farmers–scientist interface, technology assemblage, application and feedback, partnership and institutional building and content mobilization. The farmers FIRST project has a network of 93 ICAR institutes, 20 State Agricultural Universities, Central Agricultural University and eight Krishi Vigyan Kendra with the process and methodological support, database creation and regular assessment and impact evaluation.

4.4. Institutionalizing Think Tank For Independent Policy Advocacy

4.4.1. National Academy of Agricultural Sciences

The National Academy of Agricultural Sciences (NAAS), established in 1990, is the brainchild of late Dr. B.P. Pal, noted Indian agricultural scientist. The Academy proved as a think tank and provided evidence-based scientific inputs for policy options for agriculture. The Academy inducts 34 Fellowships every year amongst Indians and 2 Foreign Fellows. The young talent (<40 years), are recognized as Associates of the Academy. NAAS has contributed Policy/Strategy Papers on topical issues and emerging challenges in Indian Agriculture. The Academy had developed a scorecard for rating the SAUs.

4.5. Strengthening Agricultural Higher Education

4.5.1. Central Universities/Deemed University

While States established SAUs since 1960 onwards, the CAUs were established with a national character, agenda and mission. The first CAU established in Imphal in 1992 with a strategic vision of providing support those NE States devoid of SAUs and their integration with National System. Later two more CAUs at Bundelkhand Region of UP and Samastipur, Bihar were established.

ICAR has 4 deemed universities (DUs) i.e., IARI, NDRI, IVRI and CIFE catering to multi-disciplinary research, education and extension for par excellence. The DUs are also established signifying the status of autonomy granted by the Department of Higher Education on the advice of the UGC, under Section 3 of UGC Act, 1956.

The ICAR system comprises of Deemed to be universities (04), Central Agricultural Universities (03), State Agricultural Universities (74) and Central Universities with Agriculture Faculty (04).

4.5.2. Education Quality-Accreditation

The National Agricultural Education Accreditation Board in its new form, is responsible for accreditation higher agricultural education institutions for ensuring quality in the era of ever-increasing agricultural universities and colleges in the country. Overall mission is to transform agriculture education with high quality and stay relevant to meet the current requirements and emerging challenges. Very important milestone in ensuring the quality of agricultural education was the creation of the Accreditation Board in 1996 by the Indian Council of Agricultural Research with a mandate of accrediting higher education institutions and programs in different branches of agriculture and allied sciences. In 2017, Accreditation Board has been rechristened as the National Agricultural Education Accreditation Board (NAEAB) with four Regional Centers at IARI, CRIJAF, CIFE, and IIHR.

4.5.3. Deans' Committees to Regulate Agricultural Higher Education

The Deans' Committees are constituted for improvement of quality agricultural education. The VI Deans Committee has been constituted to revise the curriculum in the context of National Education Policy, 2021. The first Dean's committee of 1965 gave guidelines for UG and PG education in Agriculture and Allied Sciences. The subsequent Dean's Committees in 1977, 1995, 2005 and 2013 reviewed the Course Curricula periodically and made recommendations for revisions to include the emerging aspects of globalization, National Economic policies, open market and GATT, skills for entrepreneurship, and re-structuring of UG program, scoring/grading in accreditation.

4.5.4. Rural Agriculture Work Experience Program (RAWEP) and Student READY Programs

The Rural Agricultural Work Experience Program (RAWEP), an innovative academic program was designed and initiated by Sri. J. Raghotham Reddy in 1980-8, the then VC of Andhra Pradesh Agricultural University. to enable the final year B.Sc. (Ag) students to work with and live among the farmers in rural areas for one semester. This popular academic program formed a model for adoption by several other Agricultural Universities in India (Borthakur and Bortamuly, 2013). Later, the Randhawa Committee (1992) recommended the Rural Agriculture Work Experience (RAWE) program for imparting quality, practical and production-oriented education for agriculture degree program. The program continued till 2015.

A new programme 'Student READY' (Rural and Entrepreneurship Awareness Development Yojana) was launched on 25th July, 2015 to reorient graduates of Agriculture and allied subjects for higher employability and greater entrepreneurship. Reorientation to agriculture education system in India is moving towards entrepreneurship, quality food, consumer preferences, natural farming, secondary agriculture, skilling, export orientation and reduction of food losses in India.

4.6. Institutionalization of World Bank-Aided Programmes

To augment funds and financing for agricultural research & education, several World Bank aided programs were implemented under the aegis of ICAR. The National Agricultural Research Project (NARP) was one such program of the World Bank, launched in 1979, aimed at conducting need-based, location-specific and production-oriented research with a mission-oriented problem-solving approach. The thrust of NARP was to strengthen the regional research capabilities of the State Agricultural Universities (SAUs) as an important means of finding solutions to the location specific problems in different agro-climatic zones (Raman and Balaguru 1988) The Agricultural Human Resource Development (AHRD) project, with World Bank Support, launched in 1995, aimed at enabling the institutions in building excellence in specific strategic areas in education and research, promoting holistic higher agricultural education by blending knowledge, skill and attitude through Experiential Learning Units, infrastructural development, gender mainstreaming and capacity building and Institutional reforms (ICAR 2014-15).

The National Agricultural Technology Project (NATP) project was initiated with the financial assistance of World Bank and piloted by ICAR in 1998. The NATP aimed at testing the new approaches to technology transfer, new organizational arrangements, and operational procedures. The goals included decentralize decision making to the district level; increase farmer input into program planning and resource allocation especially at the block level and increase program coordination and integration. The major outcome is the institutionalization of Priority Setting Monitoring & Evaluation (PME) system for its institutes.

The National Agricultural Innovation Project (NAIP) was launched in 2006 with the objective of accelerating the sustainable transformation of Indian agriculture in support of poverty alleviation and income generation by collaborative development and application of agricultural innovations by the public organizations in partnership with farmers' groups, private sector and other stakeholders.

At present the National Agricultural Higher Education Project (NAHEP) is implemented since 2017 with the aim to develop resources and mechanism for supporting infrastructure, faculty and student advancement, and providing means for better governance and management of agricultural universities in the areas of higher education.

4.7. Organizational Reforms

4.7.1. Initiation of Agricultural Research Service

The journey of ICAR since 1929 has been evolutionary with periodic reforms. The effectiveness of the organization largely depends upon the quality and quantum of work done by the Scientists which required attracting talents into agricultural research with pan-India personnel policies. With this broad objective, the Union Cabinet approved the Agricultural Research Service on October 1, 1975.

Dr. M.S. Swaminathan, the then DG, ICAR spearheaded in formation of Agricultural Research Services (ARS) a pan India research service for the entry level scientists. The main objective of the service was to generate a scientific culture and opportunity for continuous professional growth and lifelong specialization without any constraint and to promote individual and collective initiative for improving the productivity of research and application of knowledge in matters relating to all aspects of agriculture. Since the introduction of ARS, the Council has been giving continuous thought to the question of matching its personnel policies with the basic objectives of the organization and the requirements of its research programs. In order to bring reforms in the ARS, a Committee under the chairmanship of Dr. R.S. Paroda, former Director General, ICAR was constituted in 2010. The Committee suggested a slew of measures including the merger of the disciplines, creation of new disciplines, broad changes in the qualifications, besides the involvement of NAARM in HRD for the improvement in the system.

The subject matter divisions were created in ICAR on the recommendations GVK Rao Committee, 1988 to have inter-institutional linkages. The functional autonomy was provided to the scientists following the Johl Committee's recommendations in 1995. Mashelkar Committee, 2005 recommendations for ICAR -Industry interface and Scientist-Entrepreneur tie-up were operationalized through National Agricultural Innovation Project and National Fund for Basic & Strategic Research. Taking leads from the recent review of ICAR by the Peer Review Committee chaired by Dr. T. Ramasami, Former Secretary, DST, the restructuring of ASRB, reforms in All India Coordinated Research Projects (AICRPs), Cadre Review of ICAR, revision in ICAR Guidelines for Intellectual Property Management and Technology Transfer/Commercialization and accreditations of SAUs for standards in higher agricultural education were implemented. Some of the other recommendations are also under active consideration.

4.7.2. Establishment of NAARM

The National Academy of Agricultural Research Management (NAARM) was established under ICAR at Hyderabad, in September 1976 to impart Foundation Training to the new entrants of the ARS. In 1979, it acquired its present name with expanded mandate to enhance the performance and effectiveness of the NARES through capacity building, research, in agricultural research and education management.

ICAR operated a National Training Centre (NTC) for a period of two years at IARI, New Delhi to improve the quality of planning, formulation, evaluation and management of agriculture and allied projects. Later, National Commission on Agriculture (NCA) suggested the establishment of an All-India Institute of Agricultural Administration and Management for training the agricultural scientists in the principles of scientific research management. ICAR appointed a high-power Working Group to provide guidelines for formulating concrete proposals for organizing a Central Staff College for Agriculture and a Sub-Committee of experts appointed in 1975 to support the Working Group to formulate a scheme on initiating the work of the Central Staff College. Subsequently, the Central Staff College for Agriculture (CSCA) was established in August 1976 in the campus of the A.P. Agricultural University. The CSCA started functioning from September 1, 1976 for imparting Foundation Course Training to entry level scientists recruited through ARS examination 1976. The CSCA was renamed as the National Academy of Agricultural Research Management (NAARM) in 1979.

Since then, the Academy has continuously reviewed and organized its programs and activities in accordance with the changing needs of the NARES; such as digital education systems, agri-startups, farmer producing organizations (FPO) etc. The Academy added a new dimension of PG Diploma in Agricultural Management and Technology Management in 2009 to develop a new generation of leaders in agricultural development towards agriculture transformation to agri business management. Academy with renewed mandate of think-tank research policy institute contributing various research policy covering different subsectors of agriculture during the past 5 years (Srinivasarao et al. 2021).

4.7.3. Functional Aspects of DARE

The Indian Council of Agricultural Research is an autonomous organization under the Department of Agricultural Research and Education (DARE), Ministry of Agriculture & Farmers Welfare, Government of India. It was established on 16 July, 1929 as a registered society under the Societies Registration Act, 1860 in pursuance of the recommendations of the Royal Commission on Agriculture, 1926. The Union Minister of Agriculture & Farmers Welfare is the ex-officio President of the ICAR Society, Minister of Fisheries, Animal Husbandry & Dairying the Senior Vice President and Minister of State for Agriculture

& Farmers Welfare is the Vice President. The Director-General, ICAR is the Principal Executive Officer of the Council.

The General Body of the ICAR Society is the supreme authority of the ICAR, and the Minister for Agriculture & Farmers Welfare, Government of India, heads it. Other members of GB include Ministers of Fisheries, Animal Husbandry & Dairying, Minister of State for Agriculture & Farmers Welfare and the Senior Officers of the various state governments, Members of Parliament, industry, education institutes, scientific organization and farmers. The Governing Body, headed by the Director-General, is the chief executive and decision-making authority of the ICAR and assisted by the Standing Finance Committee, National Agricultural Education Accreditation Board, Regional Committee, Policy and Planning Committee, several Scientific Panels, and Publications Committee. In the scientific matters, the 8 Deputy Director Generals assist the Director General (https://icar.org.in/content/administration).

4.7.4. Agri-Innovate: A Commercial Wing of ICAR

Agri-innovate India Ltd. (AgIn) was incorporated on October 19, 2011 as 'for profit' company of DARE under the Companies Act, 1956Stimulating and fostering innovations in agriculture and building 'a world of Innovative public private partnerships' are twin goals of Agri-Innovate and serve as an interface between ICAR and various stakeholders of agricultural sectors including farmers; public & private sector; R&D organizations etc. The company also promote sustainable technologies from the NARES for the overall development of agribusiness sector.

4.7.5. Independent Recruitment Agency (ASRB)

Agricultural Scientists Recruitment Board (ASRB) was established during the year 1973 based on the recommendations of the Gajendragadkar Committee. Major activities of ASRB are the recruitment of entry level scientists through Agriculture Research Services (ARS) and recruitment to posts in the combined cadres of Administrative Officers/Finance & Accounts Officers and Research Management Positions for ICAR apart from advising the Council on personnel matters, including promotion; disciplinary matters, etc. The ASRB was delinked from ICAR during 2018 and currently it works under DARE, Ministry of Agriculture & Farmers' Welfare, Government of India.

4.7.6. Brand ICAR

ICAR started reaching the common man through brand ICAR initiative by media management, in order to showcase its stupendous efforts and contribution. The branding attributes give the product disposition and voice position the attention of stakeholders' mind, and give them the feel-good experience whenever they come in contact with the brand ICAR. The common guidelines for promoting, Brand ICAR' has been formulated for implementation by all the ICAR institutes uniformly. Communication nodes like visiting cards, ID cards, letter heads, email signatures, etc. have been identified as effective at individual level, while websites, media activities, products developed, print and social media presence, etc. have been identified as effective at institute and organization level. Besides aforementioned means, third party involving instruments like technology licenses, incubates, start-ups, etc. help enhance the brand of the ICAR.

5. Leadership Development: Focus and Strategies

The development of leadership has become essential for the NARES due to dynamic challenges, expectations from society and stakeholders, and enhanced research competition from the private sector across the globe. In the present context, there is a serious concern for effective leadership at different levels of hierarchy.

5.1. Strategy for Leadership Development

The Council's vision for transforming the employees of ICAR by developing a strategic human resource management system has led to the formulation of *ICAR HRM Policy: Training and Capacity Building*, taking a cue from National Training Policy 2012. The policy has been implemented successfully through imparting competency-based training for all cadres viz. scientific, technical, administrative (including finance and accounts), stenographer services and skilled supporting staffs based on Training Need Assessment (TNA)). The Council is committed to methodically implementing the Policy throughout all staff cadres in the NARES. Realizing the need for the development of leaders across the NARES ICAR initiated capacity building through a three-pronged approach by organizing a pre RMP training called Management Development Programs; Executive Development Programs for newly recruited RMPs and Senior EDP for experienced leaders of the Council which is fortified with international exposure.

5.2. Institutional Mechanism

A Training Board, chaired by the ICAR's DG, has been established to provide overall guidance for the execution of the HRM Policy. Other members of the board include Secretary, ICAR; three DDGs on rotation of three years; Director, NAARM, Joint Secretary (Training), DoPT and ADG (HRM) as Member Secretary. The HRM Unit of ICAR is the nodal agency for the coordination and implementation of this policy.

An exclusive HRM Unit was created at the Council and HRD cell at the institute level and a dedicated team of HRD Nodal Officers have been put in place for capacity building activities. Training Management Information System (TMIS) is also in place. There are 40 Centers for Advanced Faculty Training operational under the Education Division of ICAR for enhancing the capabilities of teachers, researchers, and extension specialists in educational innovations, modern teaching and research methodologies, as well as serving as a repository of ideas and information in relevant disciplines. Apart from the agricultural research service scientists of ICAR, NAARM is also actively engaged in nurturing academic leadership for Professors and University Officers of State Agricultural Universities.

6. Conclusion

The leadership vision requires a balancing approach to eliminate the professional and personal biases from the system and make the organization contextually relevant at a given period and point of time. The agricultural research management and governance involves many decisions that have scientific, social and political consequences, which pose unique challenges to the leadership. Every country has established agricultural research priorities based on many complex factors that must be considered when decisions are made on the choice of research problems to be investigated. Resources must be shared among projects that often compete for the limited funding available that supports the total research enterprise. Wishes by stakeholders have to be considered as well as the aspirations of the individual researcher. In addition, a system of incentives for the researcher (and his technicians) to promote first class research within the mandate of the institute will promote their output. Advancement based on merit and achievements is a necessity also in government institutes not to be bound by regular civil service regulations. These have to be handled by independent promotion committees, including scientists from other institutions, to prevent favoritism. Agricultural R&D policies and management particularly need be dictated and conducted by scientists who are familiar with the biotic, abiotic, and socio-economicconstraints of crop production in developing countries. Historical and political issues or lobbying from pressure groups should not interfere with the mission ofproducing more and healthier food for the poor, rural, and urban sectors of the world in a sustainable way.

These challenges coupled with growing expectations from the stakeholders and society at large and increasing competition (within the system as well as outside – regional and global), and relentless technology boom necessitate newer forms of leadership as well as organization and management (O&M) reforms to ensure that our NARES continues to remain relevant and effective in dealing with such dynamic ecosystem. ICAR in its long journey so far has seen many challenges and ably addressed them and met the expectations to a large extent by forward-looking and yet realistic measures the contemporary organizational leadership. However, it has to evolve a more dynamic human resource management strategy for effective utilization of the critical scientific mass for targeted outcomes, more specific to R4D.

With the growing challenges in the spheres of science & technology, fund & financing, policy & governance and an ever-dynamic societal ecosystem, where the farming community is increasingly becoming aspirational – the professional competence matrix required for leading an organization of the size of ICAR is set to turn more complex. However, given the talent pool the system has cultivated by attracting and retaining best talents in the organization gives adequate assurance that the organizational leadership is set to remain as an ever-evolving constant for the effectiveness of ICAR and NARES.

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