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INDIAN Horticulture

November–December 2019

Global Potato Conclave 2020

Special on

Global Potato Conclave 2020

Global Potato Conclave 2020

The Indian Potato Association, Shimla in collaboration with Indian Council of Agricultural Research, New Delhi, and ICAR-Central Potato Research Institute, Shimla, is organizing the GPC 2020 during 28–31 January, 2020 at Mahatma Mandir, Gandhinagar, Gujarat, India. This mega event has three major components; (i) The Potato Conference, (ii) The AgriExpo and (iii) The Potato Field Day. GPC 2020 will provide an opportunity for researchers to present their work and share their knowledge with national and international scientists and academicians; to trade and industries to showcase their products/technologies/implements etc. and to the farming communities about the latest in potato technologies related to various components of potato value chain including seed, production technology, storage, marketing, value-addition etc.

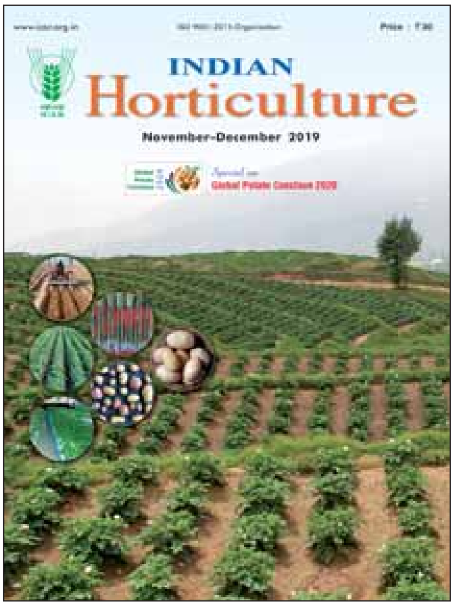




ICAR-Central Potato Research Institute

Shimla, India

Potato research in India formally began on 1st April, 1935 with the opening of three breeding and seed production stations at Shimla, Kufri and Bhowali, under the Imperial Agricultural Research Institute, New Delhi. In 1945, a scheme for the establishment of ICAR-Central Potato Research Institute was drawn up. The institute was established in August 1949 at Patna and subsequently, the headquarter of the institute was shifted to Shimla, Himachal Pradesh in 1956 in order to facilitate hybridization work and better maintenance of seed health. India emerged as the global leader in the area of sub-tropical potato production as a result of well-planned research effort that has been supported and strengthened during successive five year plans. Potato production jumped from mere 1.54 million tonnes from 0.23 million ha area in 1949-50 to 50 million tonnes from 1.96 million ha area during the triennial, thus making India the second largest potato producer in the world. ICAR-CPRI has developed and released more than 60 high yielding potato varieties possessing combination of important agronomic traits suitable for cultivation under diverse agro-climatic conditions. ICAR-CPRI varieties occupy more than 90% of total potato growing area of the country.



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Editorial Contact:

Telephone: 011-2584 1004, 2584 2828/612

Fax: 011-2584 1282

E-mail: indhort@icar.org.in

Business, Subscription and Advertisement Contact:

SK Joshi, Business Manager
Indian Council of Agricultural Research
Krishi Anusandhan Bhavan, Pusa
New Delhi 110 012

Telephone: 011-2584 3657
E-mail: bmicar@icar.org.in

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C O N T E N T S

Global Potato Conclave – 2020

POTATO, the wonder crop, emerged as the third most important food crop in terms of human consumption primarily because of its overwhelming popularity in two Asian giants, i.e. China and India who jointly contribute about 38% of total world production. In India, the potato sector witnessed rapid growth during last seven decades as a direct consequence of strong R&D support extended by ICAR-Central Potato Research Institute, Shimla. For example, total potato production in India increased from 34.7 million tonnes in the year 2008 when the second global potato conference was held in New Delhi, India to 53 million tonnes now; an increase of almost 53% in 10 years. Moreover, the sector is expected to grow at about 3% annual compounded growth rate in India by 2050. However, shifting economic status and aspiration of people of India as well as emerging global food market are casting inevitable influence on R&D orientation.

The changing global climate and agricultural landscape also necessitate continuous fine-tuning of ways and means to achieve desired quality and productivity in sustainable manner through eco-friendly and climate smart technologies.

It is therefore necessary to deliberate on the decadal achievements in potato sector and to set up a roadmap for forthcoming decade. In this direction, during last two decades two Global Potato Conferences were organized during 1999, and 2008. This year, 'The Global Potato Conclave' is being held during 28–31 January 2020, at Gandhinagar, Gujarat, India, to highlight achievements and opportunities in the area of potato research, trade and industry, and value chain management.

This mega event is having three equally important components; (i) The Potato Conference, (ii) The AgriExpo and (iii) The Potato Field Day. The GPC 2020 will provide an opportunity for researchers to present their work and share their knowledge with national and international scientists and academicians; to trade and industries to showcase their products/technologies/implements etc. and to the farming communities about the latest potato technologies related to various components of potato value chain including seed, production technology, storage, marketing, value-addition etc. It is expected that more than 5,000 farmers, representatives from trade and industries, researchers, officials from various government organizations, students etc. will be participating in this mega event.

I feel highly encouraged and motivated by the overwhelming response from potato growers, and the world leaders in potato research, technology, trade and the policy makers. I extend a warm invitation to one and all to participate in this global event and add value to the three dimensions of potato i.e. Farming, Health and Business. You can contribute as researcher through lead papers, oral/ poster presentation. If you deal with any aspect of trade in potato you can demonstrate/ display your products/ technologies. As industry you can showcase your tools/ implements/ any other relevant process or product. Field Day component of this conclave will provide a platform for live demonstrations of technologies/varieties/tools or implements etc. which is expected to be a very effective demonstration, meant for developers as well as the end-user. I do hope that your participation in the Conclave will help in devising a system-based roadmap for enhancing the role of potato in making our world a better one for all. Being at the venue of the Conclave will itself have the feel of our rich cultural heritage.

S K Chakrabarti
Director, ICAR-Central Potato Research Institute
Shimla 171 001 (Himachal Pradesh)

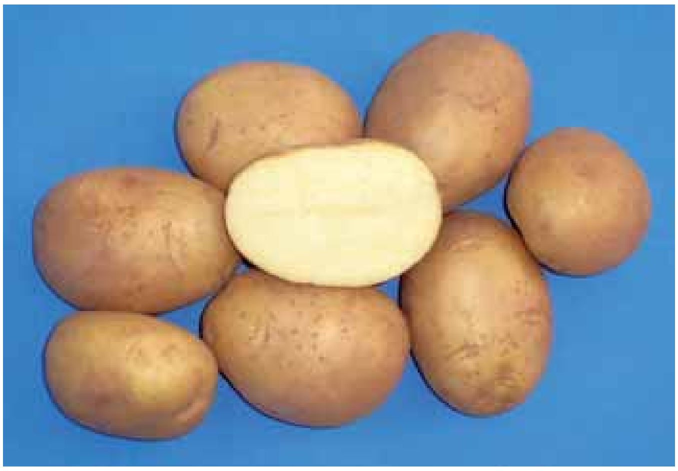
Anand K Singh, S K Chakrabarti
and T Janakiram

Potato research in India – achievements and the road ahead

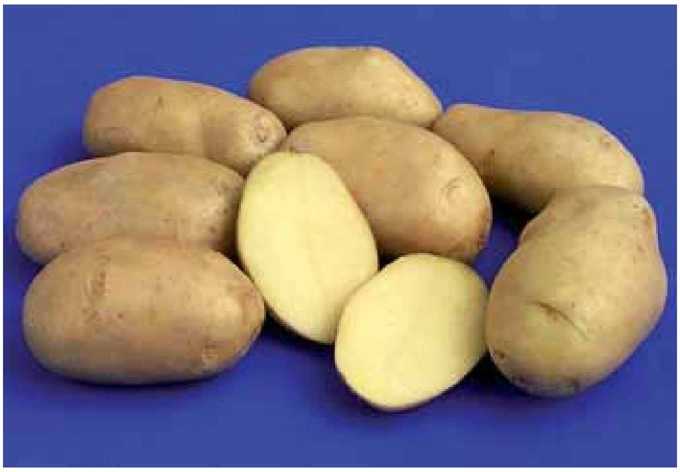
India will be the most populous country in the world by 2050 with about 1.67 billion population. Diversification and utilization of horticultural crops would be the most important strategy to ensure food and nutritional security of the burgeoning population. This highlights the importance of horticultural crops in Indian agriculture and future thrust on research and development of horticultural crops. Potato, in particular, has immense potential to achieve sustainable development goal.

POTATO (*Solanum tuberosum* ssp. *tuberosum*) is not a native crop of this sub-continent. This New World crop was originally domesticated about 8,000 years ago by communities of hunters and gatherers in the Andes mountain range of South America, on the border between Bolivia and Peru. It was discovered and taken out of South America by the Spanish conquistadores who invaded Peru between 1532 and 1572 and caused the mass massacare of at least half of her population. After its first introduction to Spain's Canary Islands in 1565, potato quickly spread to the whole of European continent within a span of 40 years and reached England by 1597. Though potato was not readily accepted as a food by common Europeans, it became a favourite food of the sailors who took potato tubers for consumption on ocean voyages specifically to avoid scurvy since the tubers were a rich souce of vitamin C. That was the time when Europe's "Age of Exploration" had begun and many sea voyages were undertaken by Portugal, Spain, and England. Potato was carried as a preferred food in many of those journeys. Most likely, potato reached the Indian southern coast as food aboard Portuguese ship during later part of 16th century. The first written mention of potato in India occurs in Edward Terry's account of a lavish banquet hosted by Abdul Hassan Asaf Khan (elder brother of Nur Jahan and father of Mumtaz Mahal) who was the Governor of Punjab under the Mughal Emperor Jehangir, in honour of the British Ambassador Sir Thomas Roe in 1615 at Ajmer. In the beginning, the orthodox Brahmins objected to its use because it was not mentioned in the Hindu Puranas as an article of food. The prejudice, however, vanished gradually and it was accepted as a primary vegetable supplement largely because of its mild flavour. Potato cultivation in the country during next 300 years remained, at the best, restricted and the entire Indian

Potato tubers

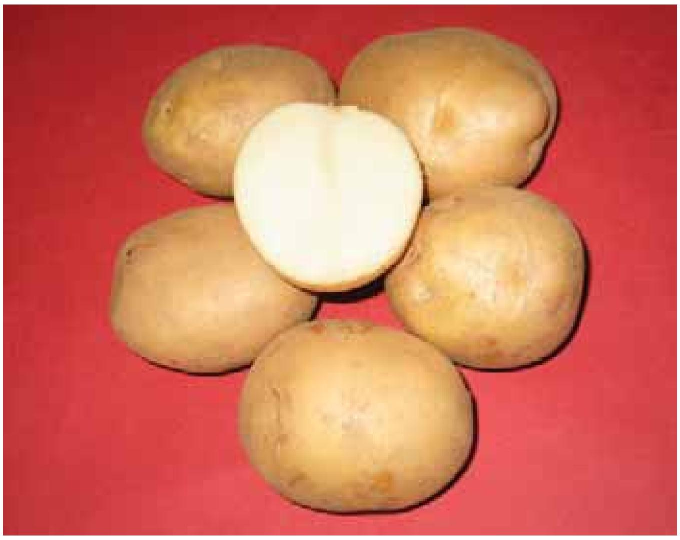


Kufri Chipsona 1



Kufri Surya

subcontinent contributed less than 1% of world's potato area and production by 1941. This was primarily due to non-availability of locally adapted varieties and technologies for growing potato under sub-tropical climatic condition. To take care of those problems, an organized research programme on potato was initiated in April 1935 with the opening of three breeding and seed production stations at Shimla, Kufri and Bhowali (Kumaon hills), under the Indian (Imperial) Agricultural Research Institute, New Delhi. In 1945, a scheme for the establishment of Central Potato Research Institute was drawn up under the guidance of the then Agriculture Advisor to the Government of India, Sir Herbert Stewart and Sir Pheroz M. Kharegat, Secretary, Ministry of Agriculture. Dr B. P. Pal, Dr S. Ramanujam, Dr. Pushkarnath, and Dr R. S. Vasudeva participated in the formulation of the scheme and in establishment of the institute. Dr S. Ramanujam, who was then working as Second Economic Botanist at IARI, was appointed as an Officer on Special Duty for implementing the scheme in 1946. The institute was established in August 1949 at Patna and started functioning from an old single-storey, barrack-type building provided by the Government of Bihar. The headquarter was shifted to Shimla, Himachal Pradesh in 1956 in order to facilitate hybridization work and better maintenance of seed health. Presently, the institute has 7 regional research stations in different potato growing areas of the country. These are located in Kufri-Fagu (HP), Modipuram (UP), Jalandhar (Punjab), Gwalior (MP), Patna (Bihar), Shillong (Meghalaya), and Ootacamund (Tamil Nadu). The institute played a key role in popularizing potato cultivation and utilization under sub-tropical agro-ecosystem. The major research outputs of the institute are breeding of 61 improved varieties, seed plot technique, national potato seed production programme and scheduling zone-wise agro-techniques. The major outcome of the scheme is 32.68 fold increase in production, 9.35 fold increase in area and 3.54 fold increase in yield during last seven decades. The area, yield and production in 1949-50 (the year of establishment of ICAR-CPRI) was 0.23 million ha, 6.59 t/ha and 1.54 million tonnes, respectively. As per 3rd Advance Estimate of DAC&FW, India produced 53.03 million tonnes of potato from 2.16 million ha area with an average yield of 24.55 t/ha last year (2018-19). As a consequence, India emerged as the second largest potato producer in the world after China. Some of the key technologies developed by the institute are briefly described below. ICAR-CPRI has been adequately recognised by the nation on several occasions for this stupendous contribution.



Kufri Chipsona 3

Achievements of potato research

- Development of 61 high yielding indigenous varieties

Earthing up

Spraying

Digging

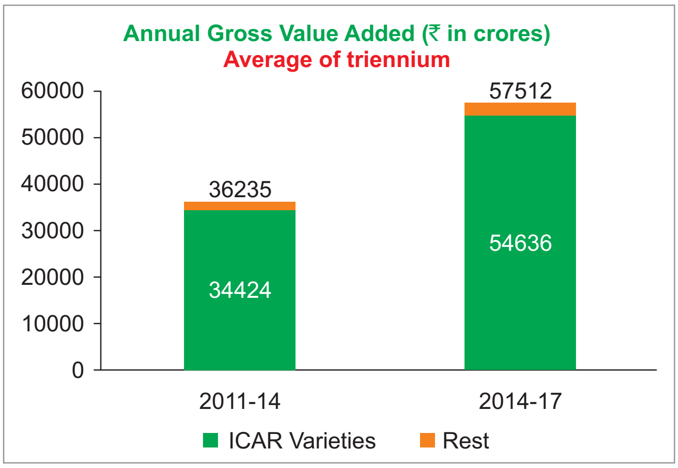
including 6 processing varieties and 1 heat-tolerant variety suitable for growing under different agro-climatic conditions.

- The Institute partnered with the Potato Genome Sequencing Consortium and deciphered the potato genome, which led to progress in functional genomics activities.
- The “Seed Plot Technique” made it possible to carry out disease free seed production in the plains and established a national disease-free seed production programme for hills and plains, utilizing the low aphid periods identified in the plains.
- The “Breeder’s Seed Production Programme” with annual production of about 3,000 tonnes of Breeder’s seed has ensured availability of quality planting material.
- Standardization of tissue culture techniques for micro-propagation, *in vitro* microtuber production and rapid multiplication.
- Development and commercialization of aeroponics based seed production technique.
- Development of “Package of Practices” for cultivation of ware and seed potato in different agro-climatic conditions.
- Identification of profitable potato-based cropping systems in different agro-climates, including inter-cropping of the potato with sugarcane, wheat and several crops.
- Development of agricultural implements for mechanizing potato cultivation, including an oscillating tray type potato grader, fertilizer applicator-cum-line marker, potato culti-ridger, soil crust brakers, granular insecticide applicator, two/four row automatic potato planter, and potato digger.
- Development of integrated package of practices for management of late blight, bacterial wilt, viruses, and soil and tuber-borne diseases.
- Development of Late blight forecasting model (Indo-blight cast) and Methodology for acreage and production estimation of potato using remote sensing, GIS and crop modelling.
- Development of sensitive virus detection techniques and DBT Accredited lab for testing of virus freedom.
- Development of techniques for storage of table and processing potatoes at elevated temperature and on-farm storage structures.
- Technologies and technical support to industry for value addition including chips, french fries and other processed products.

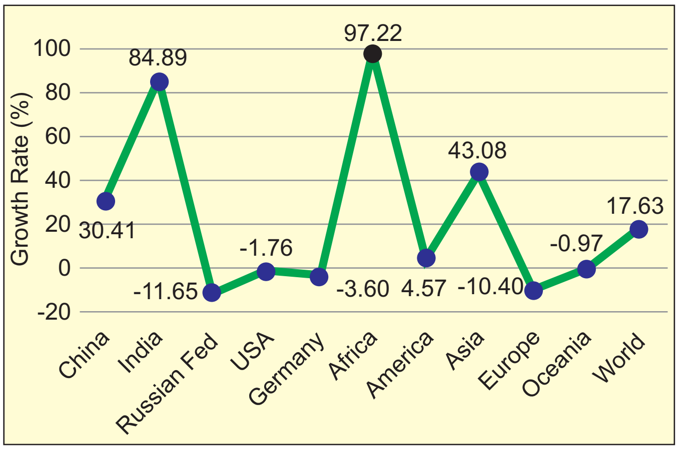
Contribution to agricultural economy

Agriculture, including allied activities, contributed 13.9% of the GDP at constant prices (2004-05) in 2013-14 while this sector still accounts for 54.6% of total employment in the country. Current share of potato to agricultural GDP is 2.86% out of 1.32% cultivable area. On the contrary, the two principal food crops, rice and wheat, contribute 18.25% and 8.22% of agricultural GDP, respectively from 31.19% and 20.56% cultivable area, respectively. It indicated that contribution of potato in agricultural GDP from unit area of cultivable land is about 3.7 times higher than rice and 5.4 times higher than wheat.

Potato varieties developed by ICAR-Central Potato Research Institute are very popular among farmers and cover nearly 95% of total area under potato. India produced ~ 45.87 million tonnes of potato annually during the triennium 2014-17 and contributed ` 57,512 crore annually to the Gross Value Added (GVA) at current price. The varieties developed by ICAR-CPRI contributed ` 54,636 crore annually during this period. Four varieties, viz. Kufri Jyoti, Kufri Bahar, Kufri Pukhraj, and Kufri Chipsona 1 together contributed around 75% of total area under potato. Potato being a labour-intensive crop requires



about 145 man days for cultivation of 1 ha of land. Thus nearly 293 million man-days of employment have been generated only for potato cultivation during 2013-14. Besides, large number of semi-skilled labour is required for carrying out post-harvest operations like transportation, storage, processing, marketing etc. Moreover, about 75% of the total labour force employed in potato cultivation is constituted by the women. Therefore, potato encourages gender equality in agricultural labour market. Input-intensive nature of potato crop helps in overall economic development of the country by supporting other sectors of the economy like industry, finance and services. For example, relatively higher demand of fertilizer, pesticide, farm machineries, cold storage equipment and structures, packaging materials, etc. for potato cultivation enables healthy industrial growth. Similarly, the crop supports services sectors through agricultural loans, insurance, marketing and technical consultancy etc.



Potato production growth (%) over major potato producing nations and continents during TE 2003 and TE 2013 (Data source: FAOSTAT, 2015).

Global and Indian scenario

Potato is the third most important food crop in the world after rice and wheat in terms of human consumption. Global annual potato production during the triennium ending (TE) 2013 was 370 million tonnes resulting in per capita availability of over 50 kg. As per FAOSTAT, India is the second largest annual producer of potato after China, leaving the Russian Federation far behind (43.1, 88.2 and 30.8 million tonnes, respectively, during TE 2013). Developed countries were the major potato producers as well as consumers till the last millennium. A comparison of potato production growth during TE 2003 and 2013 showed that Africa (97%) experienced the highest proportionate growth followed by Asia. India and China were not only the major contributors to the Asian growth of potato production but being producer of one third global potato, contributed significantly to world potato production. Potato consumption in India and China is accelerating due to increasing industrialization and participation of women in the job market that created demand for processed, ready-to-eat convenience food, particularly in urban areas.

During the last decade, developed world has experienced fall in per capita potato consumption (Americas Europe, Oceania, Russian Federation having -8.8, -9.4, -8.3 and -2.4% growth in per capita potato consumption, respectively), while at the same time per capita potato consumption in the developing world showed increasing trend (Africa, Asia, India, and China showed 40.6, 25.6, 37.1 and 28.8% growth in per capita potato demand, respectively) during the TE 2001 and 2011. In absolute terms Asia is the biggest gainer in per capita as well as total potato consumption during this period. However, the productivity in most of the developing countries continues to be very low.

Drivers of growth in India

Demand outlook

Potato is a predominant vegetable in India. At present most of the domestic supply of potatoes is consumed as fresh (68%) followed by processing (7.5%) and as seed (8.5%). The rest 16% potatoes are wasted due to post harvest losses. However, the proportion of potato used/ wasted due to various reasons is expected to change in the medium and long term scenario.

Fresh potatoes: Per capita consumption of fresh potatoes (FAOSTAT) increased from 1991 to 2010 at an ACGR of 2.34%. Will this consumption rise in the future at the same rate? The stagnating growth rates of cereals' productivity, large scale diversion of food grains to feed

Potato heaps under shade

Spray of CIPC on Heaps

Table 1. Per capita and total national food demand for fresh potatoes

Item	2010	2050
Per capita fresh (kg)	19.784	48.470
National demand (million tonne)	23.94	78.47

ACGR of per capita demand (2.34) is based only on fresh consumption of potato.

Table 2. Raw material demand of potato processing industry (million tonne)

Product(s)	2014	ACGRs	2050
Potato chips	2.92	4.5	14.22
Potato flakes/ powder	0.39	7.6	5.44

and bio-fuel and expected steep rise in per capita consumption of pulses, edible oil, fruits, vegetables, milk, sugar and non-vegetarian food in the regime of steadily rising population is bound to put pressure on existing cultivable land. Since, cultivable land is expected to remain more or less constant in the next 40 years, the role of crops like potato having higher production potential per unit land and time will become imperative. In this context potato crop has very high probability of making crucial contribution to the future national food security agenda.

The perceived changes in Indian socio-economics in the medium and long term are expected to enhance per capita food consumption of fresh potatoes. Potato is an important ingredient of most of the fast foods in organised as well as unorganised sector. Rapid urban population growth from 375 to 840 million over next 40 years at an ACGR of 2.04% is expected against the overall national ACGR of population at 0.78%. Faster rise of number of nuclear families, higher disposable incomes on account of fast economic growth resulting into higher tendency of out-of-home eating and rapid increase in the number of working women in the medium and long run are expected to maintain the ACGR of 2.34% in per capita consumption of fresh potatoes. Per capita food demand of fresh potatoes at this ACGR will be 48.5 kg in the long term (Table 1). The corresponding national food demand for fresh potatoes will be 78.5 million tonne in 2050.

Packaging

Processing quality potatoes: Agri-processing sector experiences very fast growth rate when an economy transforms from developing to developed economy. The rise of Indian economy from $ 1.57 to between 13 and 34 trillion (under varied scenarios; NCAP estimates) is not possible without corresponding rise in agri-processing industry. Further, potato is always the front-runner when we take processing of agri-commodities into consideration. Analysis of past experience and pattern of Indian processing industry suggests that demand for processing quality potatoes over next 40 years will rise at the fastest pace for French fries (11.6% ACGR) followed by potato flakes/ powder (7.6%) and potato chips (4.5%). The actual demand for processing potatoes will rise from 2.8 million tonne in 2010 to 25 million tonne during the year 2050 at an ACGR of 5.61% (Table 2).

Way forward

Potato in India still has to transform from simply a vegetable supplement to a serious food security option. Ability of potato to produce highest nutrition and dry matter on per unit area and time basis, among major food crops, made FAO to declare it the crop to address future global food security and poverty alleviation during 2008. Rising number of working couples, rapid rate of urbanization, enhanced tendency of eating out of home, higher disposable income levels of people and important place of potato in fast food items, create an ideal situation for expansion of potato consumption in the near and distant future. A perusal of various R&D efforts and outcomes in the field of agriculture in general and, more specifically the potato, reveals that "Business as Usual" scenario would not hold much longer. We have to anticipate and get ready to tackle much more complex and diverse future challenges in our respective fields. As the time lag between research and development efforts and the final application/ adoption of the output may stretch over decades, a long term vision and blueprint of action plan is highly important. This article attempts to envisage long term state of affairs of potato industry in India and formulate a strategy to fulfil national needs through a well-documented plan to tackle anticipated challenges.

For further interaction, please write to:
Dr A K Singh (DDG), Division of Horticultural Science, Krishi Anusandhan Bhawan - II, New Delhi, India. E-mail: ddghort@icar.org.in

S K Chakrabarti, R K Singh,
J K Tiwari and N K Pandey

ICAR-CPRI at a glance

Panoramic view of CPRI, Shimla

THE Indian Council of Agricultural Research (ICAR)-Central Potato Research Institute (CPRI) was established during August 1949 at Patna (Bihar) on the recommendation of the Agricultural Advisor to the Government of India, Sir Herbert Steward under the Ministry of Agriculture, Government of India. The institute was later on, shifted to Shimla in 1956 in order to facilitate hybridization work in potato breeding and maintain seed potato health. It was transferred to the Indian Council of Agricultural Research (ICAR) in April 1966.

The research and development activities of the institute is carried out under the six divisions, viz. Crop Improvement, Crop Production, Plant Protection, Crop Physiology, Biochemistry and Post Harvest Technology, Seed Technology, and Social Sciences. The institute headquarter is located in the heart of Shimla city, 4 kilometer from Shimla bus stand near Bemloe (Himachal Pradesh). It is located at an altitude of 2200 metres above mean sea level and has a wet temperate climate. It has seven regional stations located across the country viz. Modipuram (Uttar Pradesh), Jalandhar (Punjab), Gwalior (Madhya Pradesh), Patna (Bihar), Shillong (Meghlaya), Ooty (Tamil Nadu) and Kufri (Himachal Pradesh) to cater the need for location specific potato research and extension activities. The institute has total 521 ha farm lands distributed over the country.

The institute has created the state-of-the-art laboratories for conducting basic, strategic and applied research in potato. The All India Coordinated Research Project on potato (AICRP-Potato) is also located in this institute and has been functioning since 1971. It has 25 regional centers located in nearly all agro-climatic zones of the country for multi-location trials. The institute has developed over 60 potato varieties and several technologies related to potato production and protection for potato growers of the country. Institute also takes care of dissemination of these technologies to the ultimate consumers through various trainings, demonstrations, farmers fair, exhibitions etc.

Potato crop on terrace

Mission

To carry out research, education and extension on potato in collaboration with national and international partners for enhancing productivity and profitability, achieving sustainable food and nutritional security and alleviating rural poverty.

Kufri Bahar

Kufri Hill

Mandate

The ICAR-Central Potato Research Institute is a non-profit scientific institution under the Indian Council of Agricultural Research, working exclusively on potato. The institute has played a key role in popularizing potato cultivation and utilization under sub-tropical agro-ecosystem. We believe that potato can play an important role in food and nutritional security of India, while helping the rural poor to rise out of poverty. The institute focuses all its energy to make that belief becomes a reality.

- Basic, strategic and applied research to enhance sustainable productivity, quality and utilization of potato.
- Repository of genetic resources and scientific information on potato.
- Transfer of technology, capacity building and impact assessment of technologies.
- Disease-free nucleus and breeder seed potato production.
- Coordinate research and validation of technologies through AICRP on potato.

Facilities

The institute created state-of-the-art laboratories for conducting basic and strategic research in the field of biotechnology, genomics, genetics and plant breeding, plant protection, soil science and agronomy, plant physiology, biochemistry, and post-harvest technology. The major laboratories are:

- National Active Germplasm Repository;
- Biotechnology and Molecular Biology Laboratory;
- Potato Genomics and Bio-informatics Laboratory;
- Cell Biology Laboratory;
- Diagnostic Laboratory;
- Electron Microscopy Laboratory;
- Virus Culture Facility;
- Radioisotope Laboratory;
- Soil and Plant Analysis Laboratory;
- Late Blight Screening Facility;

Net-house crop

- Remote Sensing and GIS Laboratory;
- Tissue Culture Facility;
- Mini-processing Plant;
- Biochemical Analysis Laboratory;
- Aeroponic Facilities;
- Controlled Temperature Storage Facility; and
- Mini-phytotron Facility.

Laboratories at ICAR-CPRI

Central Potato Research Institute, Shimla 171 001
Himachal Pradesh (Headquarter)

Central Potato Research Station
Kufri-Fagu Shimla 171 012, Himachal Pradesh

Central Potato Research Institute Campus
Modipuram 250 110, Meerut, Uttar Pradesh

Central Potato Research Station,
Jalandhar 144 003, Punjab

Central Potato Research Station
Gwalior 474 006, Madhya Pradesh

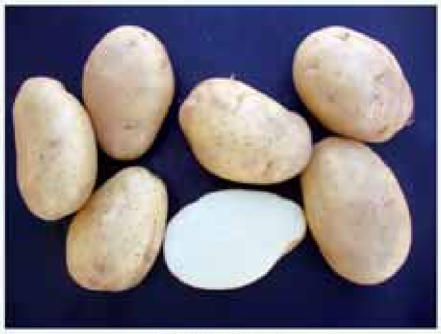
Central Potato Research Station
Patna 801 506, Bihar

Central Potato Research Station
Shillong 793 009, Meghalaya

Central Potato Research Station
Ootacamund 643 004, Tamil Nadu

Major achievements

- The institute is National Active Germplasm Repository and presently conserves more than 4500 accession of potato germplasm.



Kufri Anand

Kufri Arun

Kufri Ganga

Kufri Garima

Kufri Mohan

Kufri Sadabahar

- Partnered with 26 international institutes belonging to 14 countries in deciphering the complex potato genome sequence.
- Developed and released over 60 potato varieties for multiple traits suitable for different potato growing zones of the country.
- Developed and registered over 28 improved breeding lines as elite genetic stocks.
- Developed three interspecific somatic hybrids of potato *Solanum tuberosum* dihaploid C-13 (+) *S. pinnatisectum* and C-13 (+) *S. cardiophyllum* for late blight resistance; and C-13 (+) *S. etuberosum* for Potato Virus Y (PVY) resistance through protoplast fusion to overcome the sexual barriers.
- Developed advanced hybrids (LBY-15 and LBY-17) having combined resistance to late blight and PVY were developed through marker-assisted breeding.
- Identified potato genotypes having multiple resistance genes of late blight (*R1*&*R3*), PVY (Ry_{adg}) & cyst nematodes (*HC*, *H1* & *Gro*1) using molecular markers.
- Developed transgenic potatoes with important traits, viz. durable resistance to late blight, reduction of cold-induced sweetening, high protein content, resistance to PVY, potato apical leaf curl virus, potato tuber moth, and dwarf plant architecture.
- More than 20 genes/promoters coding for important traits have been cloned for use in genetic transformation studies.
- Developed and standardised virus detection and diagnostic techniques including dipstick assay for all important viruses.
- Replaced hazardous organomercurials chemical with the safe boric acid (3%) in seed treatment to check soil and tuber borne diseases.
- Developed IPM for management of all important diseases and pests.
- Developed potato crop growth model "INFOCROP-POTATO" to enable estimation of yield gaps and develop best management practices (BMPs).
- Developed INDO-BLIGHTCAST- a web based Pan-India model for forecasting potato late blight disease.
- Developed a decision support system "Computer Aided Advisory System for Potato Crop Scheduling" (CAASPS) for potato cultivation.
- Developed methodology for estimation of potato acreage and production using crop modelling, remote sensing and GIS.
- Development of Seed Plot Technique which enabled seed potato production in sub-tropical plains.
- Annual production of about 30000 q breeder seed of about 25 commercial varieties to facilitate supply of quality potato planting material in the country.
- Developed aeroponic technique for production of healthy seed potato.
- Developed resource management strategies for major potato-based cropping systems.
- Standardised fertigation system for potato to save water by 40-50% and fertilizer N, P and K by 25-30% in comparison to furrow irrigation with 20-30% increase in yield.
- Carried out impact assessment of potato technologies to estimate socio-economic returns to research investments.
- Dissemination of potato technologies through various extension programmes was undertaken at CPRI in order to bridge yield gap across the country.
- Developed elevated temperature and on-farm storage technologies for storing table and processing potatoes.

For further interaction, please write to:
Dr S K Chakrabarti (Director), ICAR-Central Potato Research Institute, Shimla, Himachal Pradesh. E-mail: director.cpri@icar.gov.in

V K Gupta, S K Luthra and Vinay Bhardwaj

Potato processing varieties in India

POTATOES are considered as a non-fattening, nutritious and wholesome food, which supply important nutrients to the human diet. Potatoes are either consumed directly or can be processed to give products such as chips and French fries, flakes, mashed and canned potatoes. From last two decades, there has been paradigm shift in food habit and also due to fast growth in urban population, the demand of potato based ready to eatsnacks/products has increased many folds. Further, there is a rising demand for quality processed potato products from the country particularly in Middle East. Countries like Japan, Singapore, Korea and Malaysia also have a great demand for processed potato products as well as fresh potato for processing purpose. Thus, potato processing has opened a new dimension for development of agro based industries in the country. Industry is gradually expanding its capacity in various potato based locally and internationally accepted products. India utilizes only 7.5% of the total production for processing as against 30-67% in leading potato-processing nations such as the USA, Canada and Europe. Moreover, processing sector is fast growing and it is expected that the demand for this sector will increase to 25 million tonnes by 2050. To meet this challenge, round the year availability of good quality potatoes as raw material is one of the basic needs of the industry. This calls for development of superior cultivars suitable for different agro ecologies for meeting the demand of this sector.

To meet the requirement for processing potatoes, certain morphological and biochemical attributes are necessary in potato varieties. Morphological attributes mainly include size and shape of tubers, internal and external defects, whereas bio-chemical attributes includes dry matter, reducing sugars, free amino acids, phenol content etc. These attributes not only determine the quality and recovery of the finished products but also govern the production efficiency and operational costs of the processing industry. For making potato flakes, granules and dice/cubes, size and shape of tubers are not very important; however, they are inevitable for making chips and French fries. In general, higher dry matter content in potato tubers results in higher recovery of processed products with lower energy and lesser oil consumption with better shelf life, while, low reducing sugars results in lighter and better colour of processed products. The processing genotypes should possess high dry matter (>20%), low reducing sugars (<0.15%) and acceptable chip/French fry colour. Low glycoalkaloids content (<15 mg/100 gram fresh tuber weight) and ability to withstand cold induced sweetening are added advantages.

In India till 1989, all the varieties were bred for consumption as fresh potato. Some of the varieties like Kufri Chandramukhi, Kufri Jyoti and Kufri Lauvkar were used by the chipping industry from the produce of crop grown in warmer areas where night temperatures are relatively high (around 10°C). In view of the increased demand of quality raw material for processing, ICAR-Central Potato Research Institute launched a breeding programme in 1990 for developing indigenous processing varieties and in the year 1998 first two processing varieties namely Kufri Chipsona-1, Kufri Chipsona-2 were released in India. In 2006, Kufri Chipsona-3 was developed with higher proportion of defects free processing grade tubers. After this efforts were directed to develop a processing variety suitable for hills which could fulfil the demand of raw material for processing industry after July/August. This has led to the development of variety Kufri Himsona suitable for the hills in 2008.

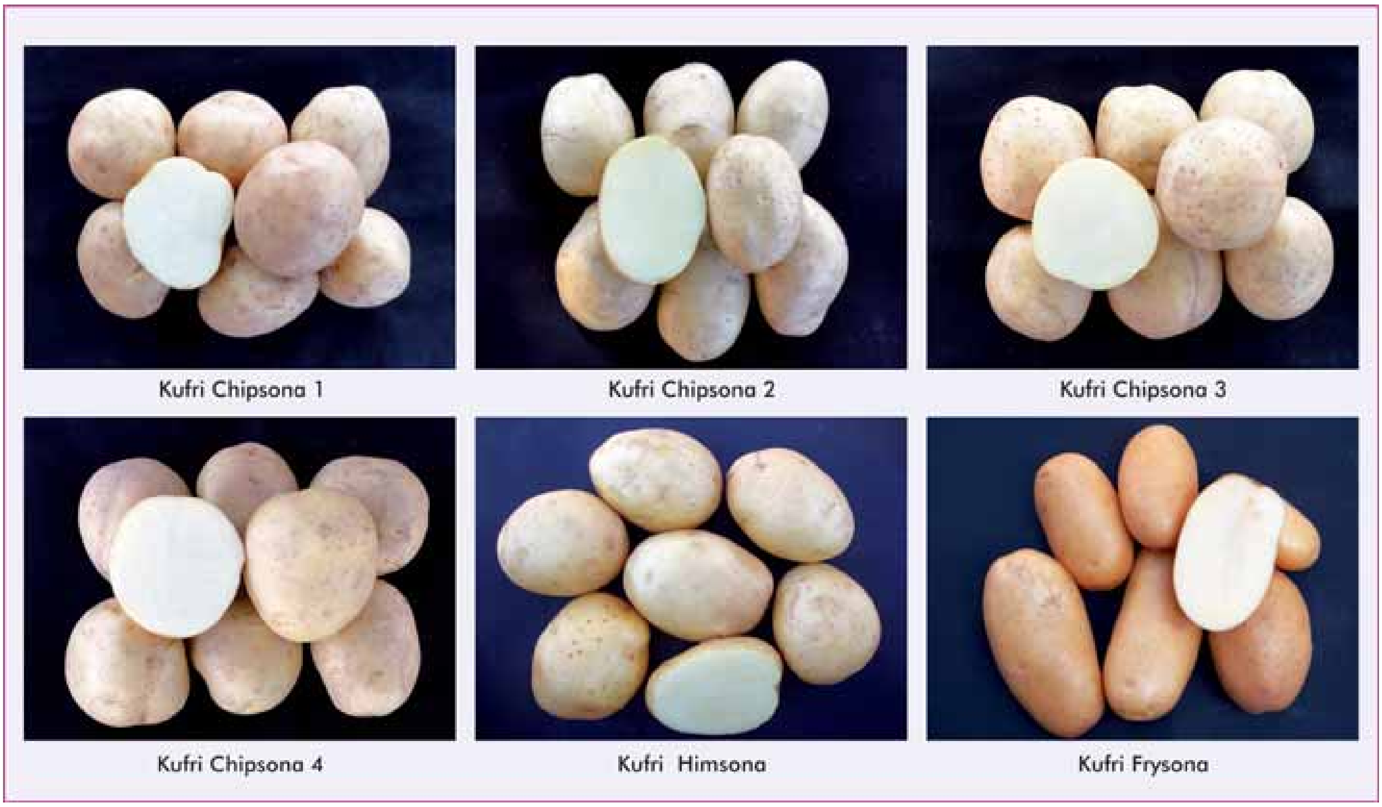
All the indigenous processing varieties in the country were of medium to long duration (100-120 days), therefore, the target was focused on development of early maturing varieties especially for warmer regions where growing window for potato production is shrinking. The region specific processing early variety Kufri Chipsona-4 was developed and released in 2010 for plateau region of Karnataka, West Bengal and Madhya Pradesh. The demand of French fry was being met either by importing frozen fries or preparing French fries from indigenous variety Kufri Chiposna-1 which produced low French fry grade tuber yield. Keeping in view the long felt demand of French fry variety, the institute developed and released Kufri Frysona for north Indian plains in 2009 and another variety Kufri FryoM recommended for release in 2018.

Kufri Chipsona-1 (MP/90-83)

The variety is a selection from the progeny of the cross CP2416 × MS/78-79. The female parent CP2416 was the Mexican genotype MEX 750826, while the male parent MS/78-79 was from Indian potato breeding programme which involved Kufri Jyoti and EM/H-1601 in its parentage. The variety produces white-cream ovoid tuber with shallow eyes and white-cream flesh. The variety produces nearly 30-35 t/ha yield under north Indian plains of the country. Its dry matter content is 20-23% and reducing sugar content is 10-75 mg/100 g fresh weight. The variety yields processing grade tubers to the tune of 60-75%. The variety has good late blight resistance and is well adapted to Indo-Gangetic plains. The tubers possess excellent keeping quality. The variety is suitable for making chips, french fries and flakes.

Kufri Chipsona-2 (MP/91-G)

The variety is a selection from the progeny of the cross CP2346 (F-6 from Peru) × QB/B 92-4. The female parent CP2346 is an accession from the germplasm collection received from International Potato Centre, Lima,



Indigenous potato processing varieties developed by CPRI

Peru, while the male parent is from an earlier breeding programme involving in its parentage an Indian variety Kufri Red and the variety Navajo from USA. The variety produces white-cream round tuber with medium eyes and cream flesh. The variety produces nearly 30-32 t/ha yield under north Indian plains of the country. The tubers of this variety have reducing sugars in the tune of 30-100 mg/ 100 g fresh weight and dry matter content is 22-24%. The variety has high degree of late blight resistance. The processing grade percentage is 65-75 and is highly suitable for chip making.

Kufri Chipsona-3 (MP/97-583)

The variety is a selection from the progeny of the cross MP/91-86 × Kufri Chipsona-2. The female parent MP/91-86 is a promising selection from the processing breeding programme. The variety produces white-cream ovoid tuber with shallow eyes and white flesh. The variety produces nearly 30-35 t/ha yield under north Indian plains of the country. The tubers of this variety have reducing sugar content of 10-100 mg/100 g fresh weight and dry matter content is 20-23%.The variety has moderate resistance to late blight and is suitable for chips and flakes preparation. The variety yields reasonably good process grade tubers to the tune of 70-80%.

Kufri Himsona (MP/97-644)

The variety is a selection from the progeny of the cross MP/92-35 × Kufri Chipsona-2. The female parent MP/92-35 is a selection from processing breeding programme. The variety produces white-cream ovoid tuber with shallow eyes and white flesh. The variety produces nearly 15-20 t/ha yield under hilly regions of the country. The tubers have dry matter content of 21-24% and reducing sugars 10-80 mg/ 100 g fresh weight. The variety has a high degree of resistance to late blight. The variety is suitable for chips and flakes making.

Kufri Chipsona-4 (MP/01-916)

The variety is selection from the progeny of cross Atlantic × MP/92-35. It produces high yield with higher proportion of chip grade tubers. It has early maturity with field resistance to late blight, thus helping farmers in saving on costly fungicides. The variety produces white-cream round-ovoid tuber with shallow eyes and white flesh. The variety produces nearly 18-22 t/ha yield during *kharif* crop in Karnataka and 30-35 t/ha tuber yield in *rabi* crop in plains of the country. It is suitable for preparation of chips owing to its round-ovoid shape, high dry matter (>20%) and low reducing sugars (40-80 mg/ 100 g fresh weight). It will fill the void of a suitable chipping variety from Karnataka, West Bengal and Madhya Pradesh where processors are in need of variety combining high tuber yield and high level of late blight resistance. Long dormancy and good keeping quality will help storage of this variety for longer period thus ensuring round the year availability of raw material to chipping industry.

Kufri Frysona (MP/98-71)

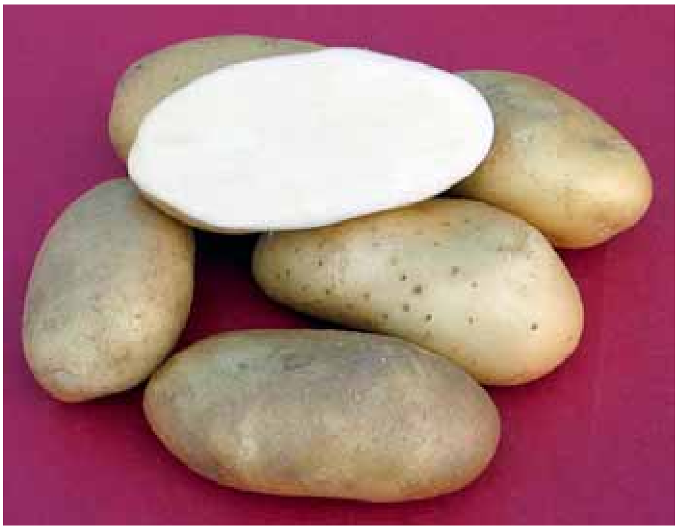
The variety is selection from the progeny of MP/90-30 × MP/90-94. It produces attractive white-cream long oblong tubers with shallow eyes and white flesh. The variety produces nearly 30-35 t/ha tuber yield in *rabi* crop in plains of the country. It possesses very good field resistance against late blight disease and has reasonably good frost tolerance. It is a good keeper under country store conditions and possess longer tuber dormancy period of more than 8 weeks. It possesses high tuber dry matter (22%), low reducing sugars (30-80 mg/100 g fresh weight) and very good quality French fries can be prepared. The industrial testing has shown the superiority of this hybrid for French fry making in terms of taste, texture and colour.

Kufri FryoM (MP/04-578)

The variety is selection from the progeny of Kufri Chipsona-1 × MP/92-35. It produces attractive white long oblong tubers with shallow eyes and white flesh. The variety produces nearly 30-35 t/ha tuber yield in plains of the country. Tubers do not show deformities like cracking or hollow heart. It has field resistance against late blight disease. It is a good keeper under country store conditions and possess longer tuber dormancy period of more than 10 weeks. It possesses 20% tuber dry matter, low reducing sugars (50-90 mg/100 g fresh weight) and very good quality French fries can be prepared.

Future thrusts

In India, processing is in developing phase as compared to USA, Canada and Europe, where 30-67% of produce is processed into various products. Due to development of indigenous processing varieties, availability of suitable raw material and adoption of improved storage technologies, the potato processing activity both in the organized and unorganized sector has increased from <1% in late nineties to about 7.5% in 2009-10. Processing has helped to reduce the post-harvest losses and it not only results in economic gains to the farmers but also provide better food and nutritional security to the country. Keeping in view the future demand of raw material for processing in India and utilization of more potato produce towards value addition, short duration varieties having good yield potential (30-35 t/ha) with high dry matter (21-23%) and low reducing sugars (150 mg/100 g fresh weight) are required.



Kufri FryoM

India is the world's second largest potato-producing nation with 51.3 million tonnes production during 2017-2018. Demand for processing quality potatoes over next 40 years is expected to rise at the fastest pace for French fries (11.6% ACGR) followed by potato flakes/ powder (7.6%) and potato chips (4.5%). The actual demand for processing potatoes will rise from 2.8 million t in 2010 to 25 million t during the year 2050 at an ACGR of 5.61% (CPRI Vision 2050). The increased demand of processing potatoes could be met by growing the new potato varieties developed by Central Potato Research Institute.

For further interaction, please write to:
Dr V K Gupta (Principal Scientist), Central Potato Research Institute, Regional Station, Modipuram, Meerut, Uttar Pradesh.
E-mail: vijaigupt@gmail.com

Jagesh K Tiwari, V U Patil, Kumar N Chaurasia, S Sundaresha, Hemant Kardile, G Vanishree, Dalamu, Vinay Bhardwaj, Shashi Rawat, Tanuja Buckseth, R K Singh and S K Chakrabarti

Role of biotechnology in potato improvement

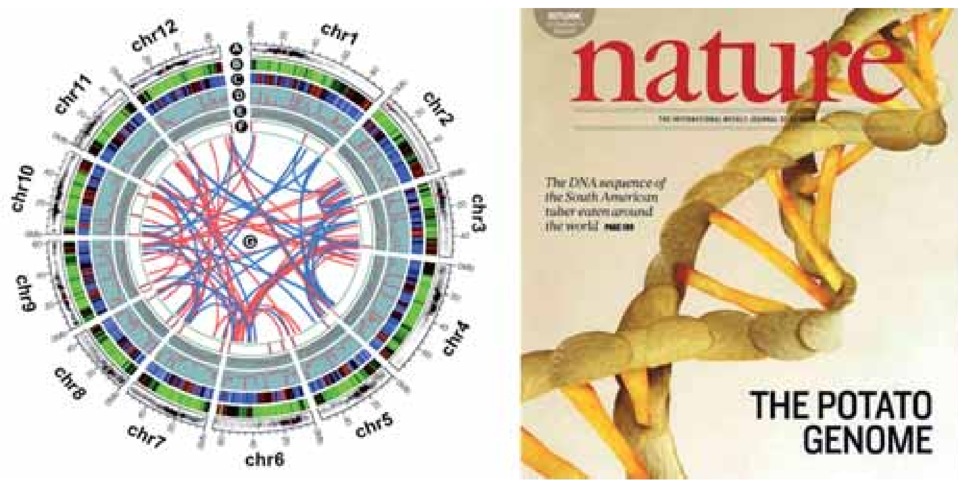
Potato is a member of the Solanaceae, a large family with more than 3,000 species. It has one of the richest genetic resources having about 200 wild and primitive species. Potato species range from diploid to hexaploid and are a rich source of genetic resources. The cultivated potato (*Solanum tuberosum* L., 2*n* = 4*x* = 48) is highly amenable to biotechnology. Tremendous advances and refinements in the techniques of plant biotechnology have allowed the problems of crop productivity and quality to be improved in new ways without adverse effects on desired crop traits. A brief summary of successful application of biotechnology in potato improvement is discussed in this article.

POTATO, being vegetatively propagated crop, is highly amenable to asexual clonal propagation techniques *in vitro* and consequently genetic engineering. Although, the crop has been a real challenge, genetic studies using molecular markers owing to tetraploidy with tetrasomic inheritance, molecular mapping and functional genomics studies have made a large progress in recent years after the genome sequencing of potato after 2011.

In vitro **culture:** Potato is perhaps the premier example of a crop plant in which *in vitro* culture technology has been most extensive. The first successful establishment of tissue culture from potato tubers was reported as early as 1951. Since then, *in vitro* produced healthy plants, somaclones, haploids and somatic hybrids, transgenics and microtubers have been developed worldwide including India. For instance, meristem culture technique in combination with thermotherapy or chemotherapy offers production of virus-free healthy *in vitro* plants of potato. This method of using disease-free stocks combined with *in vitro* clonal propagation has become an integral part of seed potato production through hi-tech/aeroponics system in India. The International Potato Centre (CIP), Lima, Peru has played a leading role in development of *in vitro* based technologies for exchange and distribution of potato germplasm worldwide.

Molecular markers: The use of molecular marker diversity analysis, marker-assisted selection, detection of mutations, marker-assisted selection and map-based cloning etc.

Disease diagnostics: Potato harbours many pests and pathogens including viruses and viroids, which deteriorate seed potato tuber quality subsequently reducing yield drastically. Molecular tools for virus/viroid detection through techniques like Enzyme Linked Immunosorbent Assay (ELISA), Immuno Electron Microscopy (IEM), Immunofluorescence etc. coupled with rapid multiplication *in vitro* have revolutionized potato seed production programme in many countries in an unprecedented way.



Potato genome

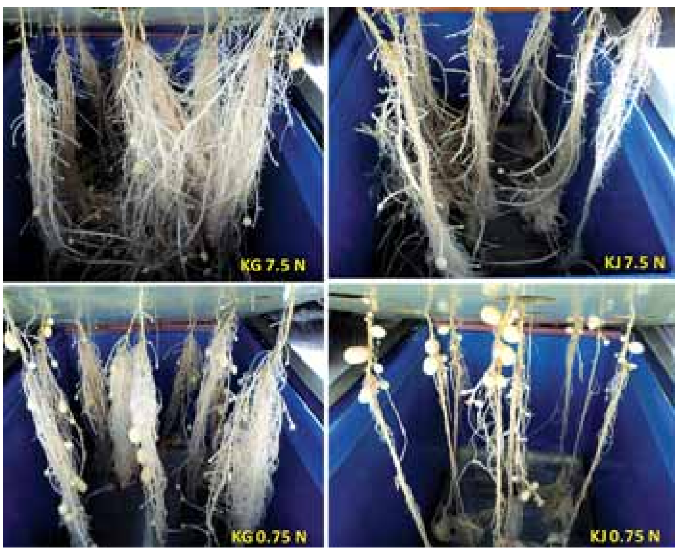
Genetic engineering: Genetic engineering is one of the major success stories in potato transgenic biology. A dominant resistant *RB* gene has been cloned from wild potato species *S. bulbocastenum*, which confers high durable resistance to late blight in potato worldwide and also under Indian condition. Introduction of gene encoding seed albumin protein from amaranth, which is rich in cysteine and methionine, has elevated the level of sulphur containing amino acids of potato proteins. Besides nutritional improvement, research

Late blight resistant RB-transgenic potato clones

is in progress on improving processing quality after cold storage, biotic stress tolerance (late blight, bacterial wilt and viral diseases), abiotic stresses like heat and drought tolerance, improving nitrogen use efficiency in plants, tuberization, starch metabolism for industrial application etc.

Structural and functional genomics: The genome sequence of potato (The Potato Genome Sequencing Consortium 2011) was deciphered using a homozygous doubled monoploid (DM1-3 518 R44 or 'DM') as well as a heterozygous diploid line (RH89-039-16 or 'RH'). This resulted in annotation of 31,039 protein coding genes, which has opened up new opportunities to rapidly identify candidate genes in regions associated with traits of interest. For example, the identification of both the *StSP6A* gene for tuber initiation and the *StCDF1* gene responsible for plant maturity phenotype was greatly aided by the genome sequence. The genome sequence data provides a catalogue of candidate genes for multiple traits. Moreover, targeted re-sequencing of many wild species of potato enables identification of several other genes in potato. The single nucleotide polymorphism (SNP) frequency is very high in potato and many SNP chips (e.g. 20K SNP array, Illumina) have been developed for high-throughput genotyping. Genome wide expression profiles of potato using RNAseq or microarray is a valuable resource to discover genes of interest. With the reduction in cost of sequencing, genotyping-by-sequencing (GBS) is now becoming feasible for species with high level of diversity and utility of genome data has been realized in genomic selection for potato improvement. Besides, there are multiple genomics related work is being done worldwide.

Genome editing in potato: A cutting edge technology like genome-editing by sequence-specific nucleases such as CRISPR/Cas9 and TALENs facilitate targeted insertion, replacement, or disruption of genes in plants. This provides an unprecedented advancement in genome engineering due to precise DNA manipulation. Genome-editing is being

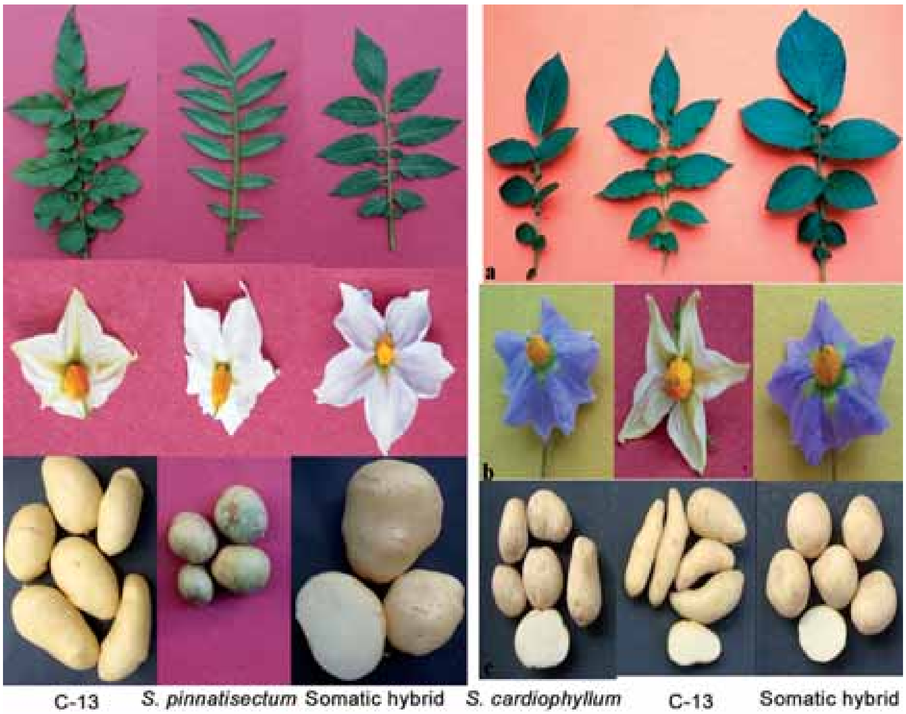


Improving nitrogen use efficiency in potato grown under aeroponics widely applied in plants and has revolutionized crop improvement including potato.

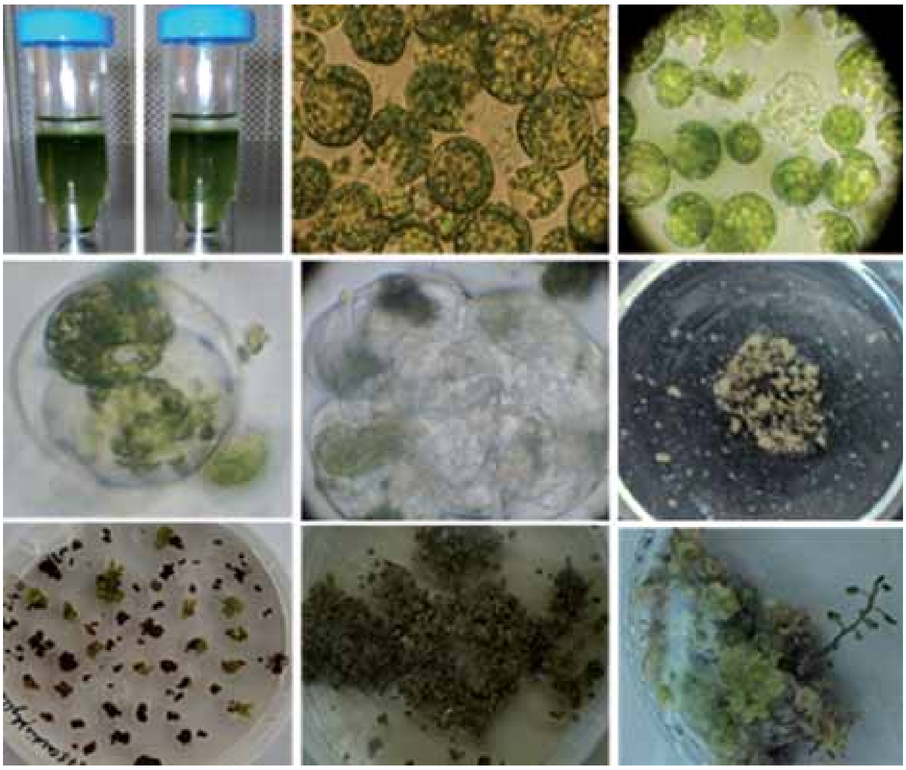
Researchers of ICAR-CPRI have applied the cutting-edge biotechnological tools in potato improvement in a wide range of areas. The institute has contributed greatly in whole genome sequencing of potato in 2011.

Biotechnological interventions at ICAR-CPRI, Shimla

1. The institute represented India in the Potato Genome Sequencing Consortium (PGSC) to decipher the potato genome sequence.
2. Accomplished genome sequencing of dihaploid potato 'C-13', *Phytophthora infestans* (late blight), *Ralstonia solanacearum* (Bacterial wilt), *Rhizoctonia solani* (Stem canker), *Fusarium sambucinum* (Dry rot) etc.
3. Developed potato transgenics for resistance to late blight, bacterial wilt and potato viruses (PVY and PALCV), dwarf architecture, cold-chipping, quality parameters etc.
4. Developed interspecific potato somatic hybrids via protoplast fusion between *Solanum tuberosum* dihaploid 'C-13' and wild potato species *S. pinnatisectum* and *S. cardiophyllum* for late blight resistance, and *S. etuberosum* for potato virus Y resistance.
5. Enhanced total seed potato production through tissue culture and aeroponics technologies (Hi-Tech seed production), which covers > 90% of potato cultivated area in India under CPRI-bred varieties.
6. Institute is the National Active Germplasm Repository for conservation including *in vitro* of potato germplasm in India.
7. Institute is an Accredited Test Laboratory (ATL) centre, certified by DBT, for testing of quarantine material and genetic fidelity testing of potatoes.
8. Developed easy and field level diagnostic techniques for detection of potato pathogens in less time.
9. Developed new molecular markers to identify Indian potato varieties, genetic fidelity, DUS characterization and germplasm characterization etc.
10. Marker-assisted selection has led to development of new advanced hybrids of potato.
11. Researchers are actively working on functional genomics for traits like biotic (late blight, viruses and bacterial wilt) and abiotic (heat and drought tolerance, and nitrogen use efficiency) stresses.



Interspecific potato somatic hybrids



Protoplast fusion and development of somatic hybrids using wild potato (*Solanum*) species

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For further interaction, please write to:
Dr Jagesh K Tiwari (Senior Scientist), ICAR-Central Potato Research Institute, Shimla, Himachal Pradesh. E-mail: jageshtiwari@gmail.com.

Tanuja Buckseth, Rajesh K Singh,
Ashwani K Sharma, J K Tiwari
and S K Chakrabarti

Hi-tech seed potato production system

Hi-tech seed potato production including aeroponics is a potential alternative to overcome the everlasting shortage of quality seed potatoes in the country, due to the advantages that seeds under hi-tech system are produced from typically pathogen tested basic material and can be produced in any region under controlled conditions. Seed potato production involving micro-propagation is finding favour among the seed potato entrepreneurs. The new Hi-tech system of seed potato production involves raising of *in vitro* plantlets followed by production of mini-tubers under protected conditions and their subsequent multiplications in the field.

SEED production through hi-tech system has been started by Central Potato Research Institute, Shimla in the recent past. Under this system, there are three different sub-systems namely microplant based seed production system, microtuber based seed production system, and Aeroponic based seed production system.

Under hi-tech seed production system, nucleus planting material is produced in the laboratory under controlled condition. The virus free plants is used as mother plant for micropropagation. The microplants/microtubers are planted in net-house at 30 cm × 10 cm spacing for production of mini-tubers (G-0). The minitubers produced in generation-0 are multiplied in generation-I at a spacing of 45-60 cm × 15 cm. The produce of generation-I is further multiplied in generation-II. The produce of stage IV and generation-II is called as breeder seed and supplied to public and private organization for further multiplication in three clonal cycle's, viz. foundation-1, foundation-2, certified seed. The adoption of hi-tech seed production technologies developed by the Institute has led to opening of more than 20 tissue culture labs throughout the country. Several private seed companies such as M/s Reliance Life Sciences, Navi Mumbai; Cadila Pharmaceuiticals Ltd., Ahmedabad; KF Bioplants, Pvt. Ltd., Pune/Bengaluru; Transgene Bioplants Pvt. Ltd., Chandigarh etc. are taking virus free *in vitro* plantlets from CPRI for further multiplication in their seed production programme.

Micropropagation of disease free mother plant

Soon after varietal release, 10-20 healthy uniform

Steps in microplant based seed production system

Steps in microtuber based seed production system

Steps in aeroponic seed production system

tubers are selected and planted under controlled conditions in the pots in poly/net house for indexing against the viruses. The ideal temperature for plant growth as well as virus multiplication should be 20-25°C. The plants are tested by ELISA for virus freedom after 6 to 7 weeks of planting or 6 to 8 leaf stage. The infected plants with viruses during ELISA testing should be destroyed and only the healthy plants should be retained for further testing by polymerase chain reaction (PCR) for virus freedom. Finally healthy plants obtained during series of testing are used as mother plant for micropropagation.

Development of healthy mother plants from virus infected plant

Sometimes we may not be getting even a single plant completely free from viruses after releasing the variety. In such situation, meristem tip culture coupled with thermotherapy has become a powerful and successful tool for virus elimination from infected plants and has been successfully applied in potato for development of virus-free plants. The steps followed during virus elimination through meristem tip culture are described here.

The plants are tested against potato viruses and viroids like PVX, PVS, PVA, PVY, PVM, PLRV, PALCV and PSTVd through ELISA, EM and PCR. In case, no plant is found free from the virus infection then the plants that are infected with minimum number of viruses are selected for meristem tip culture. Using nodal/sprout cuttings, the *in vitro* stocks of selected plants are developed and further sub-cultured in Ribavarin (20 ppm) modified MS media for chemotherapy. This culture is then given thermotherapy at 37°C and 16 h photo period (120-200 µmol/m^2/s) in the culture room for nearly 20 days. Using stereomicroscope, the apical/axillary meristem (0.2 to 0.3 mm) is excised from *in vitro* plants aseptically with the help of sterile scalpel, needle and blade. The excised meristem is grown in the test tubes containing MS medium with growth regulators and incubated in the culture tubes at 25°C and 16 h photo period (120-200 µmol/m^2/s) in the culture room until the meristem germinates. The mericlones are then sub-cultured through nodal cutting after it attains a height of 4-5 cm and the pedigree is maintained. The fully grown mericlones should be tested against potato viruses like PVX, PVS, PVA, PVY, PVM, PLRV, PALCV and PSTVd through ELISA, EM and PCR. The virus-free cultures should be sub-cultured once in every 3-4 weeks so as to get more number of virus-free microplants. The microplants should be hardened for 2 to 3 weeks in the poly/net house before planting in the pots filled with peat moss under mist in poly house. The plants are further tested against all above said potato viruses through ELISA, EM and PCR after 40-45 days of planting. The infected plants obtained during testing are removed and only the healthy plants are retained. Finally healthy plants obtained during series of testing will be used as mother plant for micropropagation.

Microplant based seed production system

Three to four weeks old microplants are transferred to protrays filled with sterilized peat moss. The microplants can be planted in protray with root or without root (cuttings). For planting with root, the media sticking to the root should be properly washed off. After transplanting, drenching is done with the mancozeb (0.25%) solution. The protrays are then transferred to the growth chambers and kept in dark for 48 h subsequently in 16 h photoperiod for 2-3 days. Once the plantlets are established in protrays (4-5 days), these protrays are transferred to hardening chamber and kept at 27°C for 10-15 days. The hardened plantlets should be removed from protrays along with peat moss and transplanted on nursery beds in mixture of soil, sand and FYM (2:1:1) in rows at 30 cm × 10 cm spacing under insect proof net house condition. 5% of the plants are tested by ELISA. All virus infected plants, off-type plants, abnormal and stunted observed during inspection are rouged out. The microplant crop is allowed to mature and minitubers are harvested. Each microplant shall yield 8-10 minitubers. Seed crop should be harvested

Aeroponics

Aeroponic growth chamber

Aeroponic mini tubers

15 to 20 days after haulms cutting when the tuber skin is hardened. The seed tubers thus produced are minitubers. Curing is done by keeping the seed tubers in heap for about 15 to 20 days in a cool shady place. After curing, the seed tuber should be graded into >3 g and treated with 3% boric acid solution for 10-15 minutes to prevent surface borne pathogen inoculum. Minitubers harvested from microplants (Generation-0) are called as nucleus seed. Store the minitubers in country store in hills while cold store at 3-4°C in the plains. Minitubers weighing >3 g will be planted in Generation-l in the field during next season. Whereas, <3 g minitubers may be recycled once again in Generation-0 under controlled poly/net house conditions if the crop meets the G-0 criteria, the produce can be used for raising G-1 crop in the field.

Microtuber based seed production system

The microplants are tested for virus freedom before initiating microtuber production. The virus-free stock plants are mass multiplied through nodal cuttings on semisolid MS medium in culture tubes (25 mm × 150 mm) following the standard procedure upto 10 cycles. 3-4 weeks old explants are transferred into 250 ml conical flasks or culture bottles containing 25-35 ml liquid MS medium without agar. The culture tubes are incubated at 25°C and 16 h photo period (120-200 μmol/m^2/s) in the culture room. After 3-4 weeks of incubation, the unutilized liquid propagation medium is decant from the conical flask/culture bottle under aseptic conditions and 30 ml of microtuber induction medium is poured into it. The microtuber induction medium is based on MS basal media supplemented with 10 mg/l N^6-benzyladenine (BAP) and 80 g/l sucrose/commercial sugar. After adding induction medium, the cultures are incubated under complete dark condition at 15°C for 60 to 90 days depending on the genotype. Microtubers develop epigeally at the apical as well as axillary buds of the shoots. In general, 15 to 20 microtubers weighing 50-300 mg are produced in each flask/culture bottles. Before harvesting, greening of the microtubers is done in the culture room by incubating microtuber induced cultures under 16 h photoperiod (approximately 30 μmol/m^2/s light intensity) at 22-24°C for 10 to 15 days. Then carefully remove the cultures along with microtubers from conical flasks or culture bottles and manually harvest the green microtubers. Avoid damaging the microtubers, especially the thin periderm during harvest. The harvested microtubers are then washed and treated with 0.25% mancozeb for 10 min, and allowed to dry in the dark at 20°C for 2 days. Grading of microtubers in <4 m, 4-6 mm and >6 mm should be done while packing. Pack the treated microtubers in perforated polythene covers and store in a refrigerator for 4-5 months until planting. Take out the microtubers from the refrigerator after about 1 month before planting for breaking the dormancy.

Aeroponic seed production system

The conventional system is quite effective but it has low multiplication rate and higher field exposure which increases the risk of viral infection. Keeping this in view, tissue culture based system of quality seed production was integrated with breeder seed production programme. The conventional way of producing potato minitubers through micro propagation is to multiply *in vitro* material in insect proof net houses. The conventional method uses substrate made of soil and mixture of various components. This method usually produces 10-12 minitubers per plant depending on cultivar. The aeroponic system offers the potential to increase production in terms of number of minitubers per plant from 3-4 times. Aeroponics is the process of growing plants in an air mist environment without the use of soil or an aggregate medium.

Aeroponic system mainly consists of an electrical unit, light proof growth chambers, nutrient solution chamber, high pressure pump, filters and spray nozzles. Interiors of growth chambers are covered with black lining to avoid any light to the root zone of plants. Aeroponic unit can be placed under insect-proof net house under natural conditions or under controlled environment conditions. For aeroponics, *in vitro* grown 15-21 days old microplants are required to be hardened before shifting to this system. For hardening, microplants are allowed gradually to acclimatize to the outside conditions and are kept at 25-27°C for 7-10 days. These hardened plantlets of about 15 cm height are planted in the holes made in the roof of the grow boxes of the aeroponic unit. All essential nutrient elements required for the plant growth are dissolved in water in nutrient tank. With the help of an automatically operated pump, the nutrient solution is regularly sprayed inside the chamber for desired duration of on/off time. By misting the solution round the clock 100% relative humidity was maintained inside the root zone. Rooting starts in a week and developed inside the growth chamber. Stolon and tuber formation initiated at different intervals depending upon cultivar. Sequential picking is done at regular interval and tubers are harvested when they attain desired size of 3-10 g. Roots, stolons and tubers develop inside the chamber and leaves are exposed to light. Nutrient solution is replenished from time to time and desired *p*H of 6.0 of the solution is maintained. Tubers are harvested sequentially as they attain the desired size. These minitubers are sequentially cured at decreasing humidity and temperature and stored at 2-4°C and used for planting in the next generation.

The aeroponic minitubers are thus harvested are called as generation-0 (G-0) and are strictly planted under nethouse in Generation-1 (Gen. 1) at a spacing of 30 cm × 15 cm depending upon the size of minituber. The produce of Gen. 1 is called as pre-basic seed. The produce of Gen. 1 (pre-basic seed) is further multiplied in generation-II (Gen. 2) at a spacing of 45-60 cm × 20 cm and the produce of Gen. 2 is called as breeder seed or basic seed.

SUMMARY

Seed potato production involving micro-propagation (tissue culture) techniques can overcome many problems associated with the conventional multiplication system. The everlasting shortage of seed potatoes in most of the potato growing nations can be overcome through micro-propagation techniques on account of faster rate of multiplication. Besides, rapid multiplication, disease freedom on account of multiplication of disease free mother stocks under controlled conditions followed by reduced number of field exposures as compared to conventional multiplication system is an added advantage of seed potato production through tissue culture techniques. Due to these numerous advantages, the new hi-tech system of seed potato production involving micro-propagation is finding favour among the seed potato entrepreneurs.

For further interaction, please write to:
Dr Tanuja Buckseth (Scientist), ICAR-Central Potato Research Institute, Shimla 171001, Himachal Pradesh. E-mail: tanujagbpuat@gmail.com

Dalamu, S K Luthra, J K Tiwari and
Ashwani K Sharma

Biofortified potato: Strategy and preparedness

Nutrient deficiencies due to unbalanced dietary habits or unavailability of balanced food especially to poor people or by compulsion is an important health issue both in developed and developing countries. Different approaches of nutrient supplementation have their pros and cons. One such approach is biofortification. It is based on the principle of genetic manipulation of crop with enhanced nutrient content by plant breeding or biotechnological interventions and/or physical application of mineral micronutrient fertilizers to crop canopy or soil. The feasibility, efficacy and cost effectiveness of crop biofortification as a means of alleviating nutrient deficiency is scientifically proven. Here, at ICAR-CPRI, Shimla potato biofortification is targeted in breeding program that mainly focuses on enhancement of antioxidants (anthocyanins and carotenoids), iron and zinc contents in new biofortified potato varieties. Biofortification is a practical, sustainable, cost-effective approach to fulfill the nutritional requirements of weaker section of the society across the globe. Malnutrition, particularly hidden hunger, is a global phenomenon. In contrast to fortification, dietary diversification and nutrient supplementation, biofortification is a one-time investment required for development of biofortified varieties where the recurrent cost is similar to any existing crop variety. There is a need to know the effect and method of cooking, and storage as well as processing on nutrient content of biofortified varieties to optimize biofortification strategies. Moreover, awareness creation among masses, building of consumer demand and supply of adequate seed of biofortified varieties is required.

BIOFORTIFICATION is defined as the process of enriching nutrient content particularly minerals and vitamins in food crop either through plant breeding, agronomic or biotechnological interventions. It is a cost-effective, food-based approach to improve the nutritional value of foods that are often low or lack in nutrients. Biofortification strategy mainly caters the nutrient requirement of under nourished populations that are remotely located and where implementation of other nutrient supplementation programs is mainly hampered due to lack of proper infrastructure. The success of any biofortification program depends on getting a well adapted nutrient dense variety that is adopted by farmers and preferred by consumers and results in significant improvement in health status of population. The program becomes more effective when combined with efforts to improve nutritional knowledge and dietary practice at the community level.

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Biofortification targets two subjects i) biofortification of staple crops to take advantage of the consistent daily consumption of large amounts of food staples by all family members, including women and children who are most at risk of micronutrient malnutrition, and ii) targets the poor mass with low income.

Biofortification is not the only solution to improve micronutrient intakes rather; it complements the efforts to increase dietary diversity and other interventions that address micronutrients deficiencies, such as fortification and supplementation. Several studies on efficacy (biological impact under

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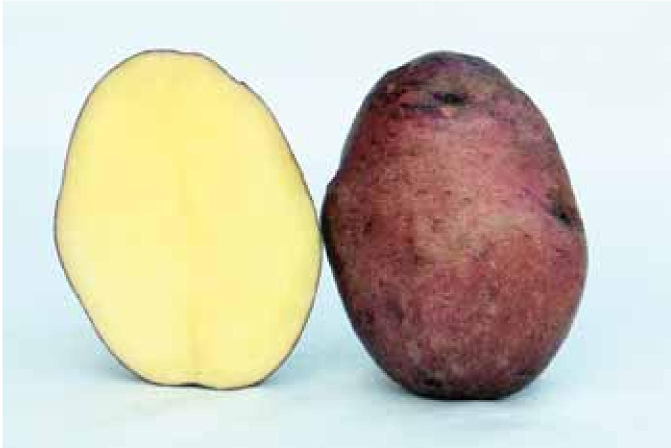

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controlled conditions similar to clinical trials) and effectiveness (biological impact in real life) depicted that biofortification is an effective tool to alleviate malnutrition.

Potato–A preferred crop for biofortification

World over potato is the third most important food crop in terms of human consumption after rice and wheat. This versatile crop is cultivated in both temperate and tropical regions from sea level to 4,700 m amsl in more than 150 countries located from Chile to Greenland. Potatoes produce more food per unit of water and are up to six- seven times more water use efficient than cereals. In general, potato is a good source of carbohydrates along with appreciable content of protein of high biological value (equivalent to egg protein), ascorbic acid, dietary fibre (in potato peel), total carotenoids, vitamins particularly B complexes, minerals like potassium, phenols and various bioactive compounds. Table 1 depicts the nutrient content of potato per 100 g fresh tuber weight.

Potato is lauded for its contribution in preventing malnutrition and is promoted as a healthy food due to the presence of vitamins and minerals, and antioxidant compounds that have free-radical scavenging properties and slow the onset of age-related chronic diseases like cancers, cardiovascular disease, and diabetes. Presence of appreciable content of ascorbic acid (vitamin C), a nutrient promoter and less content of phytates and phenolic compounds, anti nutrients that reduces the bioavailability of certain nutrients in human gut makes potatoes an ideal crop for biofortification. Potato is a good source of resistant starch. Natural resistant starch helps maintain a healthy colon and a healthy digestive system and prevents colorectal cancer and type 2 diabetes. With the rising trends of potato consumption, modifications in actual nutritional composition will tremendously impact the population health. One of the strategies for this change is through biofortification that follows the principle of enhancing nutrient composition by breeding methods.

Potato in India

India is the second largest potato producer worldwide with a total production of more than 51.31 million tonnes from total cropped area of 2.14 million hectare and net productivity of 23.95 tonnes per hectare (2017-18). The perceived changes in Indian socio-economics in the medium- and long-term are expected to enhance per capita consumption of fresh potatoes from 19.78 kg (2010) to 48.47 kg by 2050. Therefore, biofortified potato varieties may cater the nutrient requirement of common people to a great extent.

Targeted nutrients for potato biofortification

The targeted nutrients for Indian potato biofortification programme are anthocyanins carotenoids, and micronutrients like iron and zinc. Antioxidants like anthocyanins are found in the greatest quantities in purple and red potatoes while carotenoids are found largely in yellow and red potatoes. Antioxidants have been associated with important health-promoting functions such as provitamin A activity, enhancement of the immune system and reduction of cardiovascular disease or cancer and help in the prevention of atherosclerosis. Iron deficiency, anemia is a serious public health problem in India, affecting all segments of the population (50-70%), especially infants and young children, adolescent boys and girls, women of childbearing age and pregnant women and is prevalent in both urban and rural areas. Zinc deficiency causes respiratory tract infections, Pneumonia and diarrhoeal disease. Severe zinc deficiency causes short stature, hypogonadism, impaired immune function, skin disorders, cognitive dysfunction and anorexia. Nearly 4.4% of child mortality under 5 years of age in developing nations is due to zinc deficiency (5.3% in Africa and 3.7% in Asia).

Vitamin A deficiency is a major controllable nutritional problem in developing countries. India has the high prevalence (62%) of clinical and subclinical vitamin A deficiency leading to an annual 3,30,000 deaths (Akhtar *et al*., 2013).

Strategy for potato biofortification

Biofortification can be achieved by breeding, biotechnology and/or agronomic approaches.

Variation for tuber shape and colour of skin/flesh in potatoes

Breeding approach: Most breeding efforts so far have been focused on developing varieties for biotic and abiotic stresses resistance having white/yellow-fleshed potatoes. Since, the *Solanum* germplasm is a rich source of various traits, the availability of diverse germplasm allows us to strengthen potato breeding to develop biofortified varieties. The development of nutritionally superior biofortified potato varieties is based on steps described here:

i) Characterization of existing potato germplasm including wild species: Germplasm evaluation is initial step to know the existing variability in the population that will form baseline for future improvements. More than 5,000 potato varieties are known to mankind that belong to genus *Solanum* and species *tubersoum*. In addition 8 more *Solanum* species are cultivated viz., *S. ajanhuiri*, *S. curtilobum*, *S. juzpeczukii*, *S. chaucha*, *S. phureja*, *S. stenotomum*, *S. hygrothermicum* and *S. goniocalyx* which are gene pool for these targeted nutrients. There are large variations in potatoes with regards to shape and colour of tubers (skin/flesh).

In evaluation studies, carotenoids content of more than 2,000 µg was obtained in progenies of *S. phureja* × *S. stenotomum*. *Solanum phureja*, a diploid potato, is rich in ascorbic acid. *S. gourlayi* accessions has reported highest Beta-carotene content. Xanthophylls are primary carotenoids present in potato flesh. Carotenoids are available in potatoes of all colours. The composition of carotenoids in white and yellow fleshed potatoes are similar but higher concentration of xanthophylls impart the yellow colour. Carotenoids content in potato vary from 50 to 100 µg per 100 g fresh weight in white-fleshed varieties to 2,000 µg per 100 g fresh weight in deeply yellow to orange fleshed cultivars.

Beta-carotene, a precursor of vitamin A, found in traces in potato up to range of 111 µg /100 g fresh tuber weight. Anthocyanin imparts red, pink and/or purple colour to potato skin and flesh. Red colour is due to acylated glycosides of pelargonidin while acylated glycosides of pelargonidin with acylated glucosides of malvidin, petunidin, peonidin and delphinidin imparts purple tinge in potato skin as well as flesh. Anthocyanin content in coloured potatoes varies up to 508 mg per 100 g fresh weight. Iron content of 62 µg/g was observed in North American potatoes while the upper limit for zinc content was 29 µg/g.

In order to use the valuable genetic sources of biofortified potatoes in our breeding programme, we have assembled nearly 50 germplasm accession form indigenous/exotic sources in germplasm repository of the institute. Nearly 250 germplasm resources have been screened for nutritional superior components like anthocyanin, carotenoids , vitamin C , iron and zinc. The identified superior biofortified germplasm lines are being used in our breeding programme.

ii) Hybridization to develop biofortified progenies and evaluation of generated progenies: The hybridization process involves the mating among identified nutrient rich germplasm with varieties of better agronomic traits with wider adaptability to create the diverse segregating progenies with high nutritional values. The segregating progenies developed are evaluated in single hill, seedling generation, where clones are selected having desirable tuber attributes. The selected clones are evaluated in initial clonal stages (F_1C_1, F_1C_2, F_1C_3), where selection of clones is based on desirable tuber characters and presence of medium to high level of targeted nutritional components. In advanced stage trials, replicated trials are conducted for yield performance, tuber attributes, nutritional components and shelf life to identify the clone/variety for multi-location evaluation and release of variety for cultivation.

There are certain limitations in conventional way of potato biofortification like limited amount of genetic variability available for particular nutrient, low heritability of the trait, linkage drag involved with trait and long time period (10-12 years) involved from initial hybridization to final release of the variety. In India, the breeding programme aiming to develop biofortified potatoes is progressing well with possession of nearly 230 clones generated from the biofortified parents. Worldover, example of biofortified potato developed by conventional breeding is INIA 321 Kawsay variety with high iron and zinc content.

Biotechological approach

Genetic modification approaches are utilized particularly when the trait of interest is lacking in the existing germplasm. Researchers have showed transgenic manipulations for nutrient enhancement of Beta-carotene by RNAi-based silencing of beta-carotene hydroxylase gene (bch); anthocyanins and ascorbic acid by overexpression of strawberry GalUR gene, essential amino acids like methionine by coexpressing cystathionine γ-synthase genes, protein and methionine content in tubers by expressing Amaranth albumin (ama1) genes, and role of microRNA (miR828) in purple/red colour potatoes etc. Nevertheless, certain limitations are associated with transgenic crops like stringent biosafety regulatory processes and low acceptance among masses etc. However, recent genome-editing technology may address these issues in future.

Contrasting potato genotypes for carotenoids content

Agronomic approach

Agronomic approach of crop biofortification involves physical application of nutrients in soil that would temporarily enhance the nutritional composition of food crops grown over it and ultimately nutritional status of people consuming those crops. In addition, application of soil microbes likes *Pseudomonas*, *Bacillus*, *Azotobacter*, *Rhizobium* enhances the phyto-availability of mineral elements from soil to edible parts of plants and thus, improve their nutritional status. Certain examples are available regarding potato biofortification by agronomic interventions like increase in zinc concentrations in whole potato tubers by foliar zinc applications. Though agromonic biofortification is simple, easy and effective yet stringent precautions are required for nutrient source, its way of application that would be otherwise may lead to toxicity. Other concerns are affordability and availability of fertilizers with resource poor farmers.

For further interaction, please write to:
Dr Dalamu (Scientist), ICAR-Central Potato Research Institute Shimla. Email: dalamu04@gmail.com

Pinky Raigond, Brajesh Singh, Som Dutt, Sushil S Changan, Milan Kumar Lal and Dharmendra Chaudhary

Nutritional profiling of Indian potato cultivars

Food security in broader way may be realized when all people at all the times have access to sufficient, safe, nutritious food to maintain a healthy and active life. Food security depends on availability of food, affordability and proper utilization of food. Potato (*Solanum tuberosum*) locally called as 'aloo' is one such candidate that can solve the problem of food security as well as malnutrition. Potato was accepted as a primary vegetable supplement because of its mild flavour and its utilization in combination with other foods. Nutritional value of potato was known since long, specially its high content of ascorbic acid to prevent scurvy. One of the prominent publications of the Food and Agriculture Organization (FAO 2008) has emphatically considered and recommended potato as a potential crop for the poorest of the poor, to ensure global food, nutritional and income security in future.

Potato: Ray of hope and wholesome food

Potatoes yield more edible energy, protein and dry matter per unit area and time compared to other crops due to its high protein-calorie ratio (17 g protein: 1,000 kcal) and short life cycle. Serious food security problem will appear in future due to stagnation of crop yields, exhausting soils and increasing population in the country. In such a scenario, potato provides a ray of hope due to its highest per hectare, per day production of edible dry matter and vital nutrients.

Due to its versatility in way of cooking, viz. boiling, baking, deep frying etc. potato became popular over the period of time and is being consumed by one and all. In India, potatoes have been utilized largely for consumption as fresh potatoes and the major part of potato harvest (approximately 68.5%) goes to domestic table consumption. The nutritional value of potato is well acclaimed and is known as a versatile, carbohydrate-rich and low-fat food. Freshly harvested potatoes contain about 80% water and 20% dry matter, out of this dry matter approximately 60-80% is constituted in the form of starch. Its content of dry matter, edible energy and edible protein makes it a good choice for nutrients availability. On dry weight basis, potato protein content is similar to that of cereals and is very high in comparison to other roots and tubers. Potato is known to everyone as a supplier of energy but its ability to supply vital nutrients is vastly underestimated.

Potato is an excellent source of complex carbohydrates, dietary fibres and vitamin C. It also contains a variety of health-promoting compounds, such as, phytonutrients that have antioxidative activity. Among these, important health-promoting compounds are carotenoids, flavonoids, and caffeic acid, as well as unique tuber storage proteins, such as patatin, which exhibit activity against free radicals. Potato is also a substantial source of ascorbic acid, thiamine, niacin, pantothenic acid and riboflavin (Table 1).

Due to the nutritional value of potato, it is highly desirable in human diet. By itself, potato is not fattening and the feeling of satiety that comes from eating potato can actually help people to control their weight. However, preparing and serving potatoes with high-fat ingredients raises the caloric value of the dish. Since the starch in raw potato cannot be digested by humans, they are prepared for consumption by boiling (with or without the skin), baking or frying. Each preparation method affects potato composition in a different way, but all reduce fiber and protein content, due to leaching into cooking water and oil, destruction by heat treatment or chemical changes such as oxidation.

Potato: A low energy diet

Raw potato (on dry weight basis) provides about 80 kcal energy whereas a boiled potato provides about 69 kcal energy per 100 g of weight. When eaten without added fat, potato is a good food for weight conscious

Demonstration of french fries

people because of its low energy density. The energy value of potato is less than major food crops like rice, wheat, maize and sorghum. The energy value is lower than other tuber and root crops as well as food products from animal origin. Potatoes are an excellent source of complex carbohydrates. These carbohydrates take longer time for break down into glucose and result in energy that lasts longer. Complex carbohydrates are longer chains of sugars, such as starches and fiber. In potato, starch is the major carbohydrate and sucrose, fructose and glucose are the main sugars. Carbohydrates are the body's primary source of fuel for energy. The energy produced through potato gets stored as glycogen in muscle and liver and functions as a readily available energy during prolonged, strenuous exercise.

Potato: A good source of Carbohydrates

The major role of carbohydrates in nutrition is to provide energy. The complex carbohydrates present in potato are important to a healthy diet. Carbohydrates in potato are mostly found in the form of starch. On an average, potato contains 14-16% of starch on fresh weight basis. The total carbohydrate content of potato (about 18.5%) is lower than some important crops such as wheat, rice, corn, sorghum and beans. Starch furnishes most of the energy supplied by the potato. Digestibility of starch influences the energy value of the potato and hence also the bulk of potato which must be eaten to supply a given amount of energy. The digestibility of potato starch is low in raw state but improves considerably after cooking or processing.

Potato: Source of high quality Protein

Potato is a very good source of high quality protein. Average protein content of potato is 2% on fresh weight basis and about 10% on dry weight basis. Indian potato cultivars contain protein content in 0.7% to 2.7% range on fresh weight basis. Potato protein content is lower than wheat, rice, corn, sorghum, and beans but is higher than other major root and tuber crops like sweet potato, yam and cassava. Potato cultivars like K. Jawahar, K. Chipsona-2, K. Sherpa, K. Sindhuri, K. Jyoti and K. Chipsona-3 have substantial amount of protein on fresh weight basis (2.5-2.7% approximately). Soluble potato protein contains substantial levels of the essential amino acids. Free amino acids present in potatoes are totally available for absorption. Potato protein has an adequate ratio of total essential amino acids to total amino acids and a balance among individual essential amino acid concentrations to meet the needs of infants and small children. However, the digestibility of potato protein is relatively low in infants. Potato protein has a very high biological value since all the essential amino acids are present in it in a good proportion. With its high lysine content, potato can supplement diets which are limiting in lysine. Potato has a clear advantage over cereals in India because of its ability to provide high quality protein. Potato is a superb food which has correct balance between net protein calories and total calories adequate for all age groups.

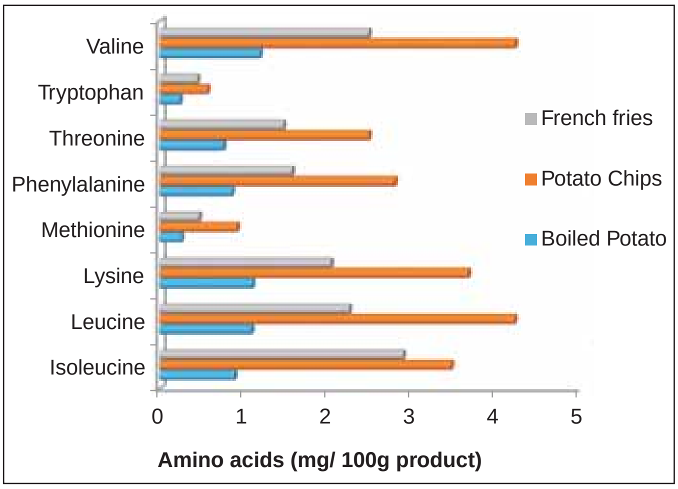
Potato: A low fat commodity

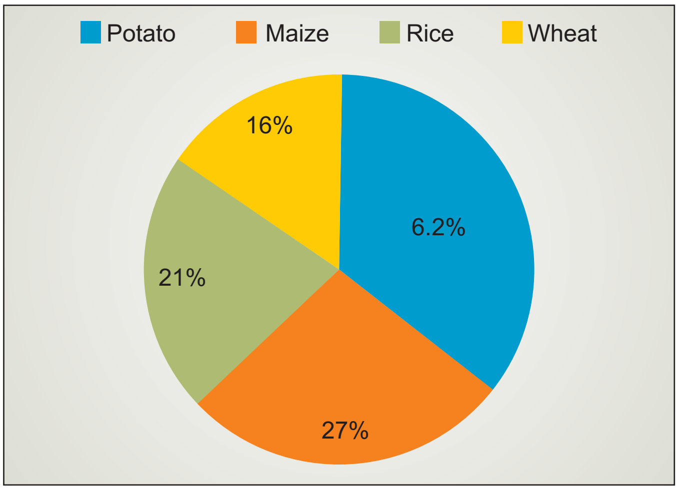
There is a common misconception that eating potato may cause obesity due to its high fat content which is not at all a true statement, since potatoes contain very little quantity of fat. The average fat content of potato is 0.1% on fresh weight basis which is too low to have any negative nutritional significance. Fat content in raw tubers of Indian potato cultivars range from 0.07–0.8%. Fat content in

Table 1. Composition of potato and its products per 100 g of edible portion

	Raw	Boiled (in skin)	Fried	Potato chips	French fries	Potato flour
Water (%)	79.8	79.8	46.9	1.8	44.7	7.6
Carbohydrate (g)	17.1	17.1	32.6	50.0	36.0	79.9
Protein (g)	2.1	2.1	4.0	5.3	4.3	8.0
Fat (g)	0.1	0.1	14.2	39.8	13.2	0.8
Iron (mg)	0.6	0.6	1.1	1.8	1.3	17.2
Calcium (mg)	7	7	15	40	15	33
Ascorbic acid (mg)	20	16	19	16	21	19
Thiamine (mg)	0.10	0.09	0.12	0.21	0.13	0.42
Riboflavin (mg)	0.04	0.04	0.07	0.07	0.08	0.14
Niacin (mg)	1.5	1.5	2.8	4.8	3.1	3.4

(Source: Ezekiel *et al.* 1999)





Amino acid content of potato and potato products

potato is lower than major cereals like rice, wheat, maize and sorghum. The little fat present in potato contributes towards potato palatability. Major proportion (i.e nearly 60-80%) of potato fat consists of unsaturated fatty acids and linoleic acid is the predominant one. The high content of unsaturated fatty acids increases the nutritive value of the fat present in potato. When eaten without added fat, potato is good for weight conscious people because of its low energy density. However, when fat is added to the fried or processed potato products, it becomes rich in energy and may certainly become a cause of concern. Especially excessive consumption of processed potato products such as chips and French fries containing up to 40% fat may cause obesity.

Potatoes: Good source of Vitamins

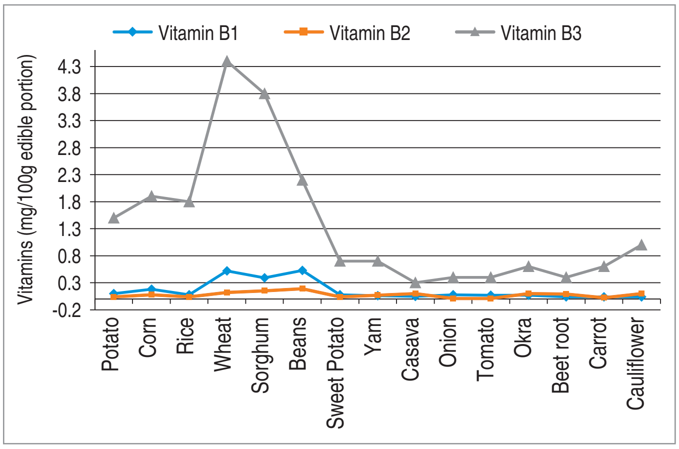
Potato is one of the rich natural source of vitamin C or ascorbic acid as it contains 17-35 mg of ascorbic acid per 100 g tuber. Potatoes have high quantities of vitamin C than other vegetables like carrots, onion and beet root. When consumed in sufficient quantities, potatoes itself can meet all the vitamin C requirements of an individual. Potato is an important source of thiamine, niacin and pyridoxine and its derivatives (vitamin B6 group). It also contains pantothenic acid (vitamin B5), riboflavin and folic acid. B-vitamins are essential for general health and growth, since they are water soluble. A small potato can deliver more than 20% daily value of vitamin C and vitamin B6.

Vitamin C: Potato contains 17-35 mg/100 g vitamin C which is far high compared to corn, wheat, rice, sorghum and beans. Indian potatoes are a good source of vitamin C and it ranges from 20 to 59 mg/100 g fresh weight in raw tubers. This water-soluble vitamin acts as an antioxidant and stabilizes or eliminates free radicals, thus helping to prevent cellular damage. Potato as major source of vitamin C provides protection against scurvy. Vitamin C enhances the absorption of iron in human body and may help support the body's immune system. The ascorbic acid content of potato declines when potatoes are stored, cooked or processed. Though potato loses some of its vitamin C during storage, substantial amounts are retained until it sprouts. Potato being in reach of all income groups may serve as the main source of vitamin C, especially for poor people.

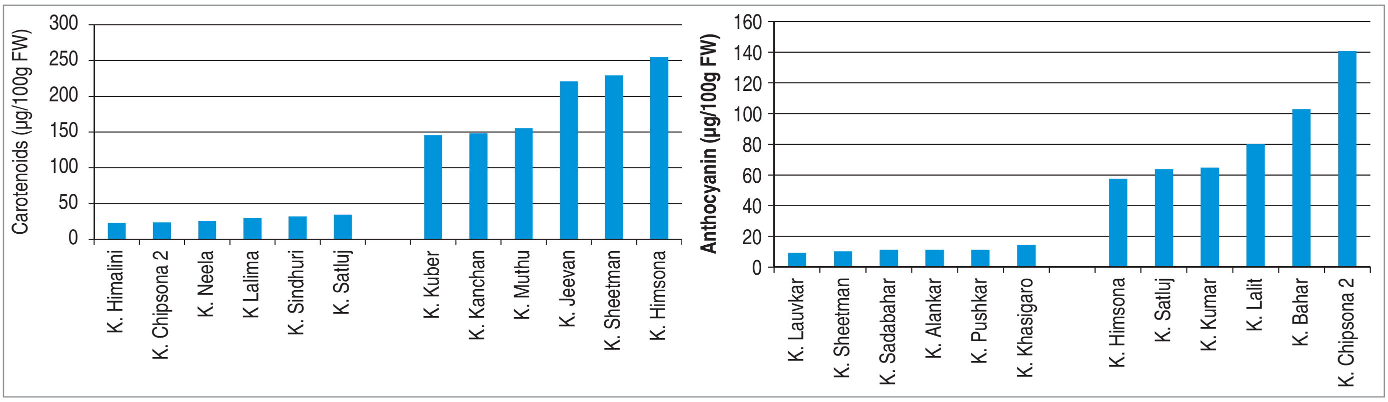
Vitamin B Complex: Potato is an important source of vitamin B complex. All B-vitamins help the body to convert food (carbohydrates) into fuel (glucose), which is used to produce energy. These B-vitamins, often referred to as B complex vitamins, also help body to use fats and protein. B complex vitamins are needed for healthy skin, hair, eyes and liver. They are also required for proper functioning of nervous system. Potatoes are important source of thiamin, niacin and pyridoxine. They provide 0.10 mg vitamin B1 (thiamine) per 100 g of freshly harvested potatoes. Insufficient intake of thiamine results in a disease called 'beriberi'. Potato contains 0.01 mg riboflavin per 100 g freshly harvested potatoes. Being an important source of niacin (Vitamin B3) potato provide 1.5 mg niacin per 100 g freshly harvested potatoes. Potatoes contain 0.3 mg pantothenic acid per 100 g of freshly harvested potato. Potatoes contain 14 mg folic acid per 100 g of freshly harvested potatoes. The role of potato as a source of some vitamins of B complex is vastly underestimated. A 100 g of boiled potatoes (boiled with skin) can fulfill the daily requirement of thiamine, niacin, folic acid and pantothenic acid.

Minerals in Potato

Potato is a good source of important minerals and



B-Complex vitamins of potato and some other plant foods



Carotenoids (*left*) and anthocyanin (*right*) in Indian potato cultivars

trace elements. A 100 g of potato contains approximately 40-65 mg of phosphorus. The lower phytic acid content of potatoes enhances phosphorous bioavailability to human body and also helps in increased bioavailability of calcium, iron and zinc. The potassium content of potato is also relatively high i.e 247-455 mg/100 g fresh weight. Because of high potassium content, potatoes are not included in the diet of patients with renal failure. On the other hand, the sodium content of potato is very low and the content is 11 mg/100 g fresh weight. Potatoes are a good source of iron and their iron content is comparable to most of the other vegetables. A 100 g of cooked potato can supply between 6 and 12% of daily iron requirement for children or adult. Moreover, due to high ascorbic acid content of potato, bioavailability of non-haem form of iron from potato is increased. Potatoes mixed with other food are also beneficial as it increases the bioavailability of iron from other foods also due to its high ascorbic acid content. Moreover, iron availability from potato is higher compared to other foods such as kidney beans, wheat flour and bread, reason being the high proportion of iron from potato is soluble. Potatoes provide up to 22 mg/100 g fresh weight of magnesium. Potato can be consumed with foods low in magnesium such as milk. Zinc is an important trace element found in potato. Though zinc content of potato is not very high but its availability is high because of the low phytic acid content. Potato can supply at least part of daily requirements of trace elements like copper, manganese, molybdenum and chromium. Traces of boron, bromine, iodine, aluminium, cobalt and selenium are also present in potato. A small potato can deliver 10% daily value of folate, manganese, magnesium and phosphorus. Therefore, potato being in reach of poorest of the poor can play a vital role in eradication of 'Hidden Hunger' which is also known as micronutrient malnutrition.

Potatoes: A rich source of Antioxidants

Potatoes contain a number of small molecules, many of which are beneficial phytonutrients such as phenols, flavonoids, kukoamines, anthocyanins and carotenoids. Coloured potatoes may serve as a potential source of natural anthocyanin pigments and also a powerful source of antioxidant micronutrients. Potato antioxidants have potential role in immune function and disease prevention. Anthocyanin content in Indian potato cultivars range from 9 to 141 µg/100 g of fresh weight. Yellow pigmented potatoes are known to have high carotenoids content such as lutein, zeaxanthin, violaxanthin and antheraxathin. Most of the Indian potato cultivars are white-cream in flesh colour and contain carotenoids in range of 23 to 255 µg/100 g fresh weight. Potato carotenoids are primarily oxygenated carotenoids which are also known as xanthophylls. Purple pigmented potatoes have health benefit against cardiovascular disease while consumption of yellow pigmented potatoes enhances immune response. Lutein, zeaxanthin, violaxanthin and neoxanthin are the major carotenoids present in potatoes and â-carotene has been detected only in trace amounts. The orange colour of the tuber flesh is due to zeaxanthin, whereas the yellow colour is due to lutein. Generally high phenolic contents such as anthocyanin are present in dark colored potatoes. But white/ cream fleshed potatoes also contain phenolics to some extent.

Some misconceptions on potatoes: Far from truth

There are many misconceptions prevalent in society concerning the nutritional value of potato.

- The most common misconception is that potatoes are fattening. With a fat content of less than 0.1% and very low calorie content, by no means it can cause obesity. Potatoes are known to absorb considerable amount of fat while frying, which is a common way of consuming potatoes in Indian recipes.
- Another common misconception is that potatoes can cause or worsen diabetes. Resistant starch present in potato helps in more gradual rise and fall in blood sugar levels after eating and hence potatoes are not an unhealthy food for diabetics. In western countries, potatoes are consumed by one and all.
- One more misconception is that all of the potato's nutrients are found in the skin. While the skin does contain approximately half of the total dietary fiber, the majority (>50%) of the nutrients are found within the potato itself. As is true for most vegetables, cooking does impact the bioavailability of certain nutrients, particularly water-soluble vitamins and minerals, and nutrient loss is greatest when cooking involves water (boiling) and/or extended periods of time (baking). To protect most of the nutrition in a cooked potato, steaming and microwaving are the best methods of cooking potatoes.

Conclusion

'Global Hunger Index 2012' report of International Food Policy Research Institute showed serious concerns about food security in India. To overcome such serious and alarming situations potato provides a way out to tackle the problem of hunger and provide food and nutritional security. Potato can be a perfect substitute for other cereals due to its high nutritional value and high production and productivity. Potato is a nourishing food. It's low energy density is advantageous when eaten without much added fat. Potatoes contain high quality protein rich in essential amino acids. It is a rich source of vitamin C and is far superior in this respect to most other vegetables and cereals. Considerable quantities of some of the B group vitamins are also present in potato. Potatoes contain many minerals and trace elements and simultaneously are low in fats. Moreover, among the major food crops, bioavailability of minerals is potentially high in potatoes because of the presence of high concentrations of the compounds that stimulate micronutrient absorption such as ascorbate. Low concentration of absorption inhibitors such as phytate and oxalate also improve the bioavailability of minerals from potato. Hence, potato as such is a wholesome food and anyone can live by eating potatoes alone. With ever increasing population, potatoes are destined to be very crucial for providing food and nutritional security to populations in the developing countries including India.

For further Interaction, please write to:
Dr Pinky Raigond (Scientist), ICAR-Central Potato Research Institute, Shimla-171 001, Himachal Pradesh India. Email: jariapink@gmail.com

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Potato late blight and its management

Late blight caused by *Phytophthora infestans*, an oomycete pathogen that was responsible for infamous Irish potato famine, has historically been an important disease of potatoes and tomatoes worldwide. It cuts global potato production by around 15%. The disease has become a major biotic factor in limiting potato production across the country including the plains and plateau. This article is aimed at educating the Government functionaries and the farmers about the late blight disease and its management.

Phytophthora infestans is considered as re-emerging pathogen due to regular emergence of its novel strains with increased virulence and its appearance in new locations with surprising intensity. In India, losses are more in hilly regions where the crop is grown under rain-fed conditions as compared to the plains.

Symptoms: Late blight affects all plant parts especially leaves, stems and tubers. On leaves, the initial symptoms appear as pale green water soaked spots (2-10 mm) mostly on the margin and tips. In moist weather, spots may appear anywhere on the leaves, enlarge rapidly and turn necrotic and black, killing the entire leaf instantly. Often, the spots have a purplish tinge and on the lower side, white mildew (cottony growth) ring forms around the dead areas. In dry weather the water soaked areas dry up and turn brown. On stems and petioles light brown elongated lesions develop, often encircling the stem/petiole. Stem infection is more severe under high temperature and relative humidity conditions. Under favourable conditions, the whole vine may be killed and blackened and the disease spreads rapidly, killing the entire crop in a few days. Tubers are readily infected in soil by rain borne spores from blighted foliage. Initially the tubers show a shallow, reddish brown dry rot that spreads irregularly from the surface through the flesh. (Rusty brown discolouration of the flesh is the typical symptom). Initially the infected tubers are hard but associated secondary pathogens may set in soft rot symptoms.

Late blight

Generally, late blight appears on lower most leaves of the plant which goes unnoticed, particularly if the disease appears after closure of crop canopy. Slowly, the disease spreads to the middle and then upper leaves. It is only then that it gets noticed by the farmers. But it is too late to manage the disease at this late stage. Therefore, farmers are advised to inspect their crop daily and verify the symptoms as described above. Initially, only a few foci measuring 1-2 meters are visible. Subsequently, the disease spreads faster and the entire crop gets killed as if burnt by fire.

Identification and confirmation test: Visit the field early morning and collect the leaves showing brown lesions and turn them upside down. If a white cottony growth is visible on the lower surface, then the disease is confirmed to be late blight. Many a time white cottony growth is not visible due to low relative humidity and exposure to sunlight. In such situations, the infected leaves may be collected and kept in any small utensil lined with moist cotton. The utensil may be covered and kept overnight. If white cottony growth appears on the leaves, the disease is confirmed to be late blight.

Primary source of infection: The infected seed tubers carrying late blight infection serve as primary source of the disease. The *P. infestans* spores get washed down from the infected plant parts to the soil/exposed tubers by rain/dew drops. The spores germinate and infect the exposed tubers. Under high disease pressure, especially under rainy conditions, the tuber infection goes very high. Although, some of the infected tubers get completely rotted by the time crop is harvested, still a lot of tubers carry incipient infection limited to a few mm sized late blight lesions which go unnoticed during harvest and subsequent sorting. Such tubers if used as seed become the source of infection of the disease in the next crop season.

Late blight symptoms (a) Foliar blight on upper surface, (b) On lower surface, (c) On stem, (d) On tubers

Integrated Disease Management

The disease can be contained if farmers follow the integrated management schedule developed by the ICAR-CPRI, Shimla which is given here.

Use of healthy seed: Only disease free seed should be used. Avoid seed from the field which has been infected by late blight in the previous year. The infected tubers should be thoroughly checked for late blight infection. The infected tubers should be removed and buried in the soil. This practice of sorting out late blight infected tubers can also be done at the time of planting. The late blight symptoms are easy to be identified in cut-pieces where bronzing of the flesh can be seen easily.

Resistant cultivars: Select varieties which have moderate to high degree of resistance to late blight. The varieties which possess resistance to late blight are given below.

North western plains: Kufri Khyati, Kufri Badshah, Kufri Chipsona-1, Kufri Chipsona-3, Kufri Ganga, Kufri Garima, Kufri Mohan, Kufri Neelkanth.

West central plains: Kufri Khyati, Kufri Badshah, Kufri Chipsona-1, Kufri Chipsona-3, Kufri Ganga, Kufri Frysona, Kufri Garima, Kufri Mohan, Kufri Neelkanth.

North eastern plains: Kufri Khyati, Kufri Chipsona-1, Kufri Chipsona-3, Kufri Frysona, Kufri Ganga, Kufri Mohan, Kufri Neelkanth, Kufri Kanchan, Kufri Lalit.

Plateau: Kufri Khyati, Kufri Badshah, Kufri Garima.

North western hills: Kufri Girdhari, Kufri Himalini, Kufri Himsona.

North eastern hills: Kufri Girdhari, Kufri Himalini, Kufri Megha, Kufri Kanchan.

Southern hills: Kufri Girdhari, Kufri Himalini, Kufri Neelima, Kufri Swarna.

Cultural methods: Important cultural methods include:

i) Selection of well drained soils for potato cultivation.
ii) High ridging to prevent exposure of infected seed tubers which serve as primary source of the disease. Besides, it helps in the reduction of new tuber infection.
iii) Scouting of the field for identifying primary infection foci and their destruction by removal of the infected plants after drenching them with recommended fungicides. Nearby plants should also be sprayed.
iv) As soon as the weather conditions become congenial for late blight, irrigation should be stopped wherever

Congenial weather conditions for late blight

Temperature

- Fungal growth : 16-20°C
- Spore production : 18-22°C
- Spore germination (indirect) : <14°C
- Infection and disease development : 7.2-26.6°C

Humidity

- Spores are formed in moisture saturated atmosphere.
- Spore germination and infection requires 100% humidity.
- Spores get killed under low humidity (less than 75%).

Light

- Spores are produced during night and are sensitive to light.
- Cloudiness favours disease development.

Movable screens in rose production

- Use movable screen, an important tool for rose cultivation.
- It can help growers manipulate environment conditions — lowers temperature, changes humidity and influences production numbers.
- The movable screens can be used year-round and in a variety of climates — from the Netherlands to India.

applicable. Only light irrigation may be given later, if required.

v) Destroy and remove the haulms from the field when the disease severity reaches >80% to reduce tuber infection.

vi) Harvest the crop 12-15 days after cutting haulms, sort out the late blight infected tubers and store the seed after treating it with boric acid (3%).

Chemical control: The use of fungicides in the management of late blight is unavoidable because of quick development of disease in the field. Nevertheless, one can economise on fungicides by scheduling sprays as per forecasting model. The institute has developed ‘Jhulsacast’ and ‘Indo-Blightcast’ models for prediction of appearance of late blight and scheduling of fungicides as per severity values thereby reducing the fungicide load in the environment. A schedule of minimum of 4 fungicide sprays is recommended. However, the number of sprays may be increased or decreased depending on disease pressure.

I spray: As a prophylactic measure, spray the crop with contact fungicides like mancozeb 75% WP (0.2%), propineb 70% WP (0.2%) or chlorothalonil (0.2%) as soon as the weather conditions become congenial for late blight, or about a week in advance of canopy closure whichever is earlier. Do not wait or allow late blight to appear and establish in the field. Always use a sticker @0.1% for proper sticking and uniform spread of fungicide on leaf surface.

II spray: As soon as the disease is noticed in the field, apply any of the systemic fungicides viz. cymoxanil + mancozeb (0.3%) or dimethomorph + mancozeb (0.3%) or fenamidone + mancozeb (0.3%) fungicides.

III spray: Apply contact fungicides viz. mancozeb (0.2%), propineb (0.2%) or chlorothalonil (0.2%) after 8-10 days of 2nd application of fungicides. However, if weather is highly congenial, repeat application of systemic fungicides may be resorted.

IV spray: Apply systemic fungicides or contact fungicides as mentioned above depending on disease severity and weather conditions.

Ensure thorough coverage of plants top to bottom with fungicides. Special attention should be given to lower leaves which need to be covered with fungicides.

For further interaction, please write to:
Dr Sanjeev Sharma (Principal Scientist), CAR-Central Potato Research Institute, Shimla 171 001 Himachal Pradesh. E-mail: sanjeevsharma.cpri@gmail.com

Vinay Sagar

Management of soil and tuber borne diseases of potato

Several soil and tuber borne diseases are known to affect potato and result in heavy losses. These diseases not only reduce quality and market value of the produce but also spread to new un-infested fields through infected seed potato tubers. Diseases such as black scurf, common scab and powdery scab disfigure potato tubers and reduce their market value whereas dry rots, charcoal rots and soft rots spoil the harvested produce during storage causing significant losses. Potato wart is a serious disease which once established is difficult to eradicate and thus require quarantine measures. Bacterial wilt or brown rot of potato is another serious disease which has threatened potato cultivation in many potato growing areas of the world including India. The article discusses important soil and tuber borne diseases, and their management in brief.

Fusarium dry rot

Fusarium dry rot is an important post-harvest disease of potato tubers. It causes significant losses in storage and during transit of both seed and table potatoes. The initial symptoms on potato tubers appear as small brown lesions on surface. These lesions subsequently enlarge, appear dark, sunken and wrinkle producing white, pink, or blue pustules. In later stages, a cavity often develop in the centre of the concentric ring and whitish, pinkish or dark brown growth of fungal mycelium may become visible. Rotten tubers may shrivel and get mummified.

As many as 13 species of *Fusarium*, viz. *F. sulphureum* (syn. *F. sambucinum*), *F. coeruleum*, *F. oxysporum*, *F. avenaceum*, *F. culmorum*, *F. acuminatum*, *F. crookwellense*, *F. equiseti*, *F. graminearum*, *F. scirpi*, *F. semitectum*, *F. sporotrichioides* and *F. tricintum* (Corda) Sacc. cause dry rot of potato. In India, at least 10 species of *Fusarium* have been reported to cause dry rot of potato in stores. Infected or rotting tubers are main source of spread of the inoculum of *Fusarium* spp. and results in soil infestation. The pathogen may also get introduced to new locations through contaminated soil, farm implements, through wind and irrigation water etc. The pathogen cannot infect intact periderm and lenticels of tubers however, cuts and wounds created during harvest, grading, transport and storage predispose them to infection. Development of disease is also affected by moisture and temperature. The fungus grows well between 15-28°C, however, disease development continues at low temperature in cold stores especially dry rot due to *F. sambucinum*.

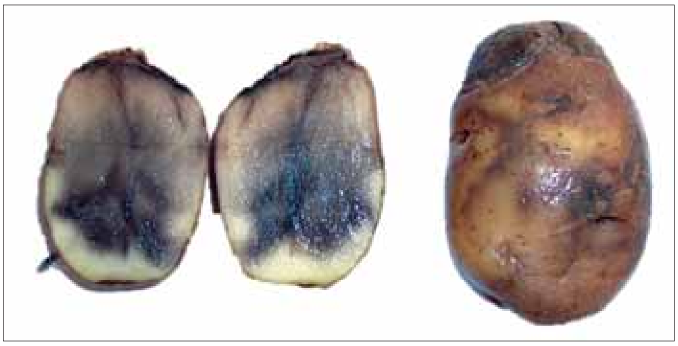
Symptoms of *Fusarium* dry rot on tubers

Management

Some level of *Fusarium* dry rot is almost always present in commercially available seed and it is not possible at present to be 100% sure that a seed lot is completely free of dry rot. Practicing the following procedures will help prevent dry rot.

- Use only healthy, disease free/ certified seed tubers.
- Clean and disinfect seed storage facilities thoroughly before receiving seed tubers.
- Treat tubers with 3% boric acid (either dip tubers for 30 minutes or spray ensuring full coverage of tuber surface) and dry under shade before cold storage (for seed purpose only).
- Seed tubers should be stored at 4-5°C, 85-90% RH and be kept ventilated.
- Monitor stored tubers often for dry rot. Grade out rotten tubers when tubers are removed from storage for marketing/ planting.
- Disinfect seed cutting and handling equipment often and make sure that cutters are sharp enough to give smooth cut that heals easily.
- Preferably plant whole tubers only. If cut seed tuber is used, treat the seed with fungicide (tuber dip in mancozeb 72WP @ 0.25% for 10 minutes) and dry under shade before planting to control seed piece decay and sprout rot.
- Adopt sanitation measures to avoid soil contamination through farm implements, irrigation water etc.
- Reduce soil inoculum through crop rotation and eliminating volunteer potatoes which can reduce the risk of dry rot.

(a) Stem canker, (b) rosetting of plant tops and (c) black scurf caused by *Rhizoctonia solani*



Charcoal rot of potato tubers

- Delaying harvesting for about two weeks after haulm destruction when skin of the tubers have matured and avoiding injury to tubers during harvest, handling and transportation minimize the dry rots.
- Harvested potatoes should be stored at around 13-18°C under shade and moderate humidity for two to three weeks for bruises to heal before putting the potato in cold stores.

Black scurf

The disease affects tuber quality by the development of sclerotia on progeny tubers, thus their market value is reduced. Yield losses up to 35% primarily due to reduced crop stand have been reported. The disease can kill eyes during storage; affect stems before emergence (stem canker) and form black scurf (black irregular lumpy encrustations of fungal sclerotia) on progeny tubers after senescence. Infected sprouts become blackened and may not emerge in severe cases. Reddish brown lesions develop on stems and often girdle them. Partial or complete girdling of the stems results in rosetting of plant tops, purple pigmentation, upward chlorosis or rolling of leaves. Formation of aerial tubers in axis of leaves due to interference with starch translocation, are also observed in the infected plants.

The disease is prevalent in most potato growing regions of the world including India. In India, it has spread widely in most potato growing regions.

The disease is caused by a fungal pathogen *Rhizoctonia solani* Kuhn (perfect basidial stage: *Thenatephorus cucumeris* (Frank) Donk). The pathogen is both soil and seed borne but the disease spreads to new growing areas primarily through sclerotia-covered seed tubers. Soil-borne infection emerges later in the season since the fungus needs some time to grow into proximity with its potato host. Optimum temperature for germination of sclerotia is 23°C and for development of stem lesions is 18°C. Sclerotial development on tubers is initiated depending on environmental conditions. Maximum development of sclerotia takes place in the period between dehaulming and harvest of the crop. Late harvested crop show more black scurf incidence. The host range of *R. solani* is very wide and the pathogen causes diseases of many economically important plants belonging to Solanaceae, Fabaceae, Asteraceae, Poaceae and Brassicaceae as well as other ornamental plants and forest trees.

Management

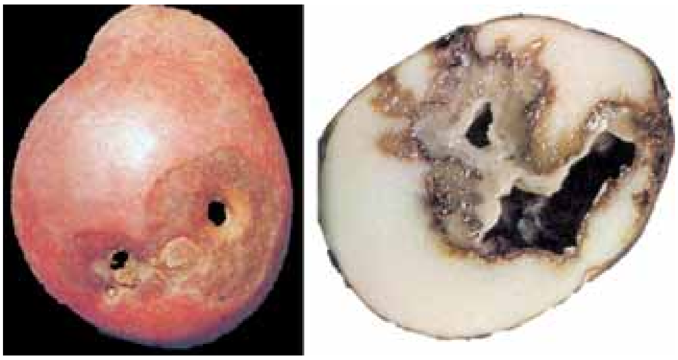
The practices like use of healthy seed tubers free from sclerotia, seed tuber treatment with 3% boric acid (dip for 30 minutes/ spray) before cold storage or pencycuron (@ 0.25%) as spray on tubers at planting, planting in relatively dry and warm soil with shallow covering of seed tubers to achieve rapid crop emergence with less opportunity for the fungus to attack, two to four year crop rotation with cereals and legumes, soil solarization with transparent polyethylene mulching during hot summer months especially in Indian subtropical plains have been found very effective for control of the disease. Bio-control agents such as *Trichoderma viride*, *T. harzianum* and fungicides such as benomyl, thiabendazole, carboxin, and azoxystrobin have been reported effective for control of the disease. A continuous use of treated seed for 2-3 crop seasons has been found to completely check the disease. Wherever possible, crop rotation of 1-2 years may be followed.

Charcoal rot

The disease is favoured by high soil moisture coupled with temperature exceeding 28°C. The affected tubers rot both in field and during storage and can cause severe losses under unusually warm wet weather. The fungus attacks the growing plants and tubers at harvest and storage. Affected plants in field exhibit stem blight or shallow rot similar to black leg and cause the foliage to wilt and turn yellow. Early symptoms on tubers develop around eyes, lenticels and stolon end where a dark light grey, soft, water soaked lesion develop on the surface of the tuber. Subsequently, the lesions become filled with black mycelium and sclerotia of the pathogen. Secondary organisms may develop in such lesions especially under wet conditions causing significant losses.

The disease is incited by a fungus *Macrophomina phaseolina* (Tassi) Goidanich. Black, smooth, hard 0.1 to 1.0 mm sized sclerotia of the fungus develop within roots, stems, tubers and leaves. *M. phaseolina* is a weak parasitic soil fungus and over-winters in soil as micro-sclerotia in plant debris, weeds and alternate host crops. The pathogen spreads through the infected seed tubers and through the infested soil carried along with the implements. Poor plant nutrition and wounds predispose the plants to charcoal rot. Temperature around 30°C or above are very favourable for infection, the rot is slow at 20 to 25°C and stops at 10°C or below. Fungal growth stops in tubers placed in cold stores but it resumes the growth after cold storage. The fungus is found on underground parts of an extremely wide range of plants, both cultivated and wild.

Warty outgrowths on stem and tubers of potato



Soft rot symptoms (*left*) and potato tuber cut to show tissues affected by soft rot (*right*)

Management

Charcoal rot which used to be a major problem in Bihar and eastern Uttar Pradesh, was eliminated by adjusting the dates of planting and harvesting. The disease is active only when soil temperature goes beyond 28°C. Therefore, planting early maturing cultivars, frequent irrigations to keep down the soil temperature and harvesting before the soil temperature exceeds 28°C can reduce the disease incidence in eastern plains of India. Rotation with non-host crops and use of seed from disease free area, avoiding cuts and bruises at harvest can also be followed to reduce disease incidence. Grade out the rotten/ diseased tubers at harvesting. Harvested potatoes should be stored at around 13 to 18°C under shade and moderate humidity for two to three weeks for bruises to heal before putting the potato in cold stores.

Wart

Potato wart is an important and serious disease worldwide. The disease once established is difficult to eradicate since the resting sporangia can survive inter-host periods for up to 20 years. Rough warty mostly spherical outgrowths or protuberances appear on buds and eyes of tubers, stolons, or underground stems or at stem base. Wart may appear occasionally on above ground stem, leaf or flowers. Underground galls are white to light pink when young and become brown or light black with age. Above ground galls are green to brown or black. The wart tissues are soft and spongy. Tubers may get completely replaced by warts which desiccate or decay at harvest. Potato wart has been reported in Asia, Africa, Europe, Oceania, North America, and South America. In India, the disease occurs in Darjeeling hills and has been managed by enforcing strict quarantine legislation.

The disease is caused by *Synchytriun endobioticum* (schilberszky) Percival, a member of *Chytridales*. Numerous pathotypes of the fungus exist and at least 43 pathotypes have been described from Europe. Wart is favoured by periodic flooding followed by drainage and aeration since free water is required for germination of sporangia and dispersal of zoospores. Mean temperature below 18°C and annual precipitation of about 70 cm favour disease development.

The pathogen spreads from one locality to another through infected seed tubers, infested soil adhering tubers, machinery and other carriers of contaminated soil. Resting sporangia survive passage through the digestive track of animals fed with the infected potatoes, and the contaminated manure, therefore, can disperse the inoculum. Earthworms have been found to serve as means of inoculum dispersal. The resting sporangia can also be dispersed by wind-blown soil or by flowing surface water. Resting sporangia of *S. endobioticum* are endogenously dormant and can remain viable for 40 to 50 years at depths of up to 50 cm in soil. Potato is the principal host of the pathogen, although, experimentally a number of species of *Solanaceae* takes infection upon artificial inoculation.

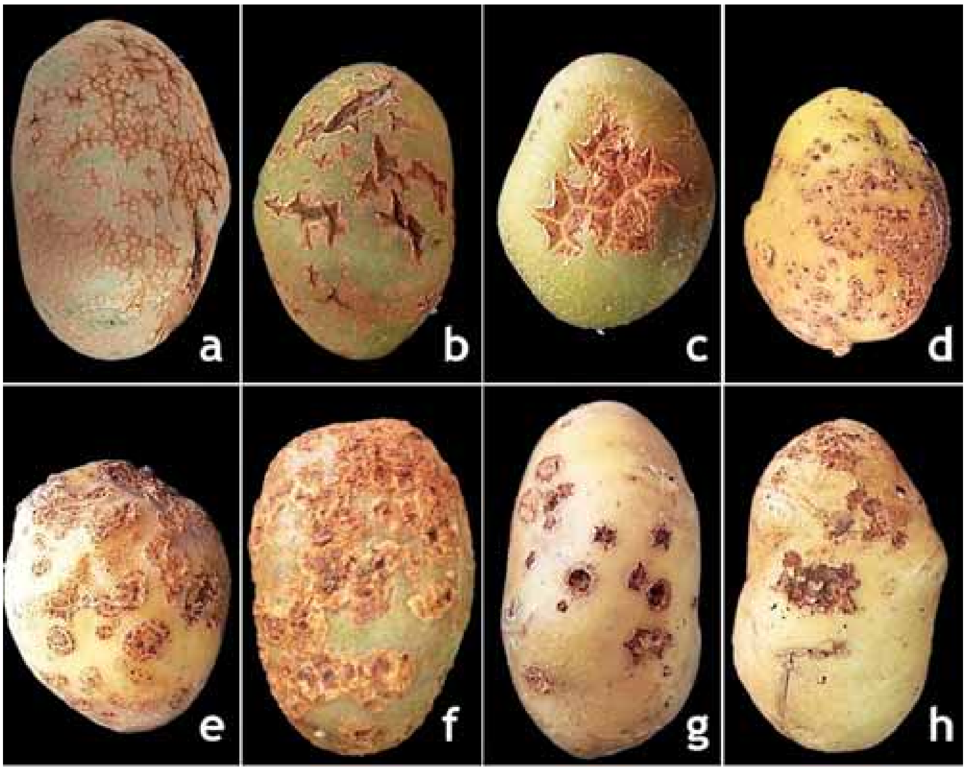
Management

The disease has been successfully managed by sanitation, long crop rotation (e.g. maize/cabbage/pea followed by bean or radish), growing resistant and immune varieties (e.g. Kufri Jyoti, Kufri Sherpa, Kufri Bahar, Kufri Kanchan, Kufri Khasigaro etc.) and by enforcing strict quarantine legislation in India. Periodic surveys are however, required to monitor viability of the pathogen in soil and efficiency of the quarantine measures.

Bacterial soft rot

Bacterial soft rot can cause significant loss of potato tubers at harvest, transit and storage. Losses due to poor handling of the produce, poorly ventilated storage or transit may go up to 100%. Soft rot bacteria usually infect potato tubers which have been damaged by mechanical injury or in the presence of other tuber borne pathogens. On tubers, the disease appears as small soft water soaked spots around lenticels which enlarge under high humidity. A brown to black pigment may develop around the lesion. The soft rot affected tubers become slimy and foul smelling and brown liquid oozes out from the affected tubers. The tuber skin remains intact and sometimes the rotten tubers are swollen due to gas formation. At harvest, many small rotten tubers with intact skin can be seen. The disease affect the crop at all stages of growth but it is more serious on potato tubers under poor storage conditions especially in warm and wet climate.

Pectobacterium atrosepticum (syn. *Erwinia carotovora* sub sp. *atroseptica*), *Pectobacterium carotovorum* sub sp. *carotovorum* (syn. *Erwinia carotovora* subsp. *carotovora*), *Dickeya* spp. (including *D. dianthicola*, *D. dadantii*, *D. zeae*) (syn. *Erwinia chrysanthemi*) have been found to cause soft rot. Soft rot bacteria may be carried latently in lenticels, wounds and on surface of tubers without any visible symptoms and spread to healthy tubers in stores, during seed cutting, handling and planting. Water film on surface of tuber which cause proliferation of lenticels and creates anaerobic conditions and injury on surface of tuber predispose potatoes to soft rot. Decaying tubers in soil could serve as source of contamination for healthy tubers. Tubers harvested in wet soil, poor ventilation in transit and storage promotes the rot. In warm climates, where one potato crop follows another or where only short rotation cycles are applied, the bacteria can pass easily from one crop to the next, especially in poorly drained soil. The bacteria can survive at places where rotten potatoes and vegetables are dumped.



Various types of scab symptoms caused by *Streptomyces* species on potato tubers

Management

Soft rot bacteria are carried deep inside the tuber, in lenticels and surface wounds making it difficult to eradicate. These quiescent bacteria proliferate in high moisture condition and require water film that cause anaerobic conditions leading to disease development. Surface injury predisposes the tubers to soft rot infection. Based on ecology and epidemiology of the disease following management practices have been worked out:

- Avoid excess irrigation, provide proper drainage and restrict nitrogen dose to minimum (150 kg/ha).
- Adjust planting time to avoid hot weather during plant emergence. Harvest the crop before soil temperature rises above 28°C.
- Harvest the crop only when tuber skin is fully cured.
- Avoid injury to tubers and sort out bruised/injured tubers.
- Store harvested potatoes at around 13-18°C under shade and moderate humidity for 2-3 weeks for bruises to heal before putting the potato in cold stores or transporting them.
- Treat tubers (meant for seed purpose) before storage with 3% boric acid for 30 minutes and dry under shade.
- Clean and disinfect seed storage facilities/ transporting means thoroughly before storing/ transporting tubers.
- Store the produce either in well-ventilated cool stores or cold stores.

Common scab

Common scab causes superficial lesions on surface of potato tubers. The disease seldom affects yield but economic losses may be high as the affected tubers fetch low price in market due to their poor appearance. Seed lots exceeding 5% incidence are rejected by seed certification agencies (in India) causing huge loss to seed industry. Scab begins as small reddish or brownish spot on the surface of the potato tubers and its initial infection takes place during juvenile period of tubers. Infection takes place mainly through lenticels and surrounding periderm turns brown and rough. Lesion becomes corky due to elongation and division of invaded cells. Under Indian conditions multiple kinds of symptoms have been recorded and they are grouped as; a mere brownish roughening or abrasion of tuber skin; proliferated lenticels with hard corky deposition, might lead to star shaped lesion; raised rough and corky pustules; 3-4 mm deep pits surrounded by hard corky tissue; concentric series of wrinkled layers of cork around central black core.

At least 13 different *Streptomyces* spp. viz. *Streptomyces scabies*, *S. acidiscabies*, *S. turgidscabis*, *S. collinus*, *S. griseus*, *S. longisporoflavus*, *S. cinereus*, *S. violanceoruber*, *S. alborgriseolus*, *S. griseoflavus*, *S. catenulae* have been found to cause common scab on potato worldwide. *Streptomyces* spp. may be pathogenic or non-pathogenic. The pathogenic species produce thaxtomins which are phytotoxins and cause hypertrophy and cell death. Ability to produce thaxtomin toxin is strongly correlated with the pathogen's pathogenicity.

Potato is physiologically most susceptible to *Streptomyces* spp. in the period following tuber initiation. *Streptomyces* species infects the newly formed tubers through stomata and immature lenticels. Once the periderm has

Symptoms of bacterial wilt **a.** brown discolouration of stem tissues **b.** bacterial streaming in clear water from stem cut section of potato **c.** infected with *R. solanacearum*

Vascular browning of tubers (*left*) and emergence of bacterial mass through eye due to *R. solanacearum* (*right*)

differentiated, tubers are no longer susceptible to the pathogen. The pathogen is both seed and soil borne. It can survive in soil for several years in plant debris and infested soil. Soil conditions greatly influence the pathogen. Favourable conditions include *p*H between 5.2-8.0 or more, temperature in the range of 20-30^{o}C and low soil moisture. The pathogen is aerobic in nature and maintaining high soil moisture for 10-20 days after tuber initiation can help in reducing the common scab. The organism is a tuber-borne and is well-adapted saprophyte that persists in soil on decaying organic matter and manure for several years. Infected tubers serve as source of inoculum in the field, giving rise to infected progeny tubers.

Management

The pathogen is difficult to eradicate because of long survival both on seed tubers and in soils. Therefore, following practices to minimize the inoculum and creating adverse condition for pathogen spread/disease development are recommended:

- Use only disease free seed tubers.
- Give tuber treatment with boric acid (3% for 30 minutes) and dry under shade before cold storage (for seed purpose only).
- Irrigate the crop repeatedly to keep the moisture near to field capacity right from tuber initiation until the tubers measure 1 cm in dia.
- Maintain high moisture in ridges at least for a few weeks during the initial tuberization phase.
- Follow crop rotation with wheat, pea, oats, barley, lupin, soybean, sorghum, bajra, and adopt green manuring to keep the disease in check.
- Plough the potato fields in April and leave the soil exposed to high temperatures during summer (May to June) in the North Indian plains.

Brown rot bacterial wilt

Brown rot or bacterial wilt is one of the most damaging diseases of potato. The disease causes wilting of plants in standing crop and also causes rot of infected tubers in field, storage and transit. The earliest symptom of the disease is slight wilting in leaves of top branches during hot sunny days. The leaves show drooping due to loss of turgidity followed by total unrecoverable wilt. Bacterial wilt in field can be distinguished from other fungal wilts by placing the stem cut sections in clear water. Within a few minutes, a whitish thread like streaming can be observed coming out from cut end into water. This streaming represents the bacterial ooze exuding from the cut ends of colonized vascular bundles. The same test can also be carried out to see infection in tuber. In tubers, the vascular tissues of a transversely cut tuber show water soaked brown circles where dirty white sticky drops appear in about 2-3 minutes. In advanced stages of wilt, bacterial mass may ooze out from eyes.

The disease is caused by a Gram-negative bacterium *Ralstonia solanacearum*. The pathogen infects roots of healthy plants through wounds. Infected tubers and plant debris in infested soil are two major sources of inoculum. Mean soil temperature below 15^{o}C and above 35^{o}C do not favour the disease development. Soil moisture influences the disease in at least four ways; (i) increasing survival of the bacterium in the soil; increasing infection; increasing disease development after infection, and increasing exit of the bacterium from host and spread through the soil. *Ralstonia solanacearum* is capable of causing brown rot in a wide range of soil types and levels of acidity. In majority of the cases, the disease has been reported in acidic soils (*p*H 4.3 to 6.8) and only in a few cases in alkaline soils**.** Under favorable conditions, potato plants infected with *R. solanacearum* may not show any disease symptoms. In this case, latently infected tubers used for potato seed production may play a major role in spread of the bacterium from infected potato seed production sites to healthy potato-growing sites.

Management

Absolute control of the disease is difficult to achieve due to seed and soil borne nature of the pathogen, however economic losses can certainly be brought down considerably using the following eco-friendly solutions.

Healthy seed: Use of healthy planting material can take care of almost 80% of bacterial wilt problem. We fortunately have bacterial wilt free areas in western and central Indo-Gangetic plains. Do not cut seed tubers as cutting knife spreads pathogen from diseases to healthy tubers. Also cut tubers contact disease from soil easily.

Field Sanitation: Where the field is already infested, the best way to minimize the disease is to adopt the following agronomic practices:

Crop rotation: Follow 2-3 years' crop rotation using crops like maize, cereals, garlic, onion, cabbage and sanai. Do not rotate vegetables like brinjal, ginger, chillies and other solanaceous crops. Paddy and sugarcane although are not host, still they carry pathogen and contribute to the disease perpetuation.

Avoid tillage operations: Pathogen enters in plants through root or stolen injuries. Such injuries cannot be avoided during intercultural operations. Therefore, restrict tillage to the minimum and it is advisable to follow full earthing-up at planting.

Off-season management of field: The pathogen perpetuates in the root system of many weeds and crops. Clean the field from weeds and root/foliage remnants and burn them. The pathogen in remnants can be exposed to high temperature above 40ºC in summer in plains and plateau and low temperature below 5ºC in hills by giving deep ploughing. This may cause extinction of pathogen from the field.

Early planting: Early planting of crop in February, reduces the wilt in north-eastern and north western hills. In eastern and Nilgiri hills, planting the autumn crop in the month of September prevents wilt by 80%.

Chemical control: Application of stable bleaching powder @ 12 kg/ha at the time of potato planting in furrow along with fertiliser reduces pathogen population from field and gives effective control.

Based on intensive ecological and epidemiological studies at Central Potato Research Institute, Shimla, the following integrated practices are recommended for checking the bacterial wilt in different agro-climatic zones of the country.

Zone I: Non-endemic areas (Gujarat, Maharashtra, north-western and north-central plains). This zone mainly is characterised by hot and dry summer (April-June) with scanty vegetation; temperature can go up to 40-43°C. Bacterial wilt is no more a major problem. Therefore deep ploughing in summer and use of disease free seed is adequate for the disease control.

Zone II: North-western mid hills (up to 2,200 masl), north-eastern hills and the Nilgiris. This zone comprises typical complex, diverse and risks prone areas. It is characterised by mild summer, profuse vegetation and maximum temperature range of 26-30°C. Winter temperature may go as low as 3-6°C. Many weed hosts can provide perpetual niche for colonisation and survival. The use of disease free seed plus application of stable bleaching powder @ 12 kg/ha mixed with fertiliser at planting, ploughing the field in September- October and exposing the soil to winter temperature are adequate for disease control. The application of bleaching powder can be substituted by 2 year crop rotation with crops like wheat, barley, finger millet, cabbage, cauliflower, knol-khol, carrot, onion, garlic etc. Early planting and early harvesting are also recommended.

Zone III: Eastern plains and Deccan plateau. Here crop is cultivated as short day crop during winter months (October-March). Day temperature sometimes reaches to 38°C. Heavy precipitation occurs due to western disturbances. The area is relatively rich in vegetation. Eastern plains and Deccan plateau have many symptomless carriers of the pathogen. Therefore, management of the disease is most difficult. However, the disease can be kept under check with practices like use of disease free seed, application of bleaching powder, blind earthing-up and ploughing in March and leaving the soil exposed to summer temperatures during April- May and crop rotations along with clean cultivation.

Zone IV: North-western high hills above 2200 masl (excluding Kumaon hills). This zone has a temperate climate with severe winters; daily temperature range from –10 to 5°C during December–January. Snow is common during these months. Bacterial wilt is not endemic and the use of disease free seed alone is adequate.

For further interaction, please write to:
Dr Vijay Sagar (Principal Scientist), ICAR-Central Potato Research Institute, Shimla, Himachal Pradesh, India. Email: vsagar.cpri@gmail.com

Kamlesh Malik, Anuj Bhatnagar,
M A Shah, Kailash Naga,
K V Raghavendra and S Subhash

Integrated pest management of economically important insects and pests of potato

Potato production is often afflicted by a number of biotic and abiotic factors including insect pests of economic importance. Insects cause direct damage to leaves and tubers, and indirect damage by transmitting the viruses; which reduces both quality and yield of potato. The major insect pests attacking potato are aphids, whiteflies, leaf hoppers, thrips, white grubs, cutworms, potato tuber moth and mites. These insect pests can efficiently be managed by the methods described in this article.

Aphids, *Myzus persicae* **(Sulzer) (Hemiptera: Aphididae)**

Economic importance: Aphids are phloem sucking insect pests which are economically important in potato primarily because of their role as virus vectors although they can cause direct plant damage at high densities. Both nymphs and adults suck the sap from the underside of leaves and shoots. The potato crop in India is infested by more than 10 aphid species. Among these aphids, *M. persicae* and *A. gossypii* are most common and predominant vectors of potato viruses like *Potato virus Y* (PVY), *Potato leaf roll viruses* (PLRV), *Potato virus A* (PVA), *Potato virus M* (PVM), *Potato virus S* (PVS) and transmit them to healthy plants in the field.

Myzus persicae

Biology: *M. persicae* is a small tiny insect with complex life cycle, and is known to have primary and secondary hosts. The primary host in India is peach. In temperate regions, many aphids produce eggs to survive during winters. In spring, eggs hatch and the aphids migrate to secondary, summer host plants. In subtropical conditions, aphids reproduce through parthenogenesis for several generations. One adult female can give birth to 20-50 nymphs that can mature in 14 to 21 days under summer conditions. Over-crowding coupled with high temperature and low humidity results in appearance of alates for migration. The winged aphids move from hot plains to temperate hills which is evident from high peak of aphids during February and March at Shimla almost coinciding with time of appearance of winged aphids in plains.

Yellow water trap

Management: Use of yellow sticky traps/yellow funnel traps @ 5-10/ha traps early appearing aphid population and prevent their further buildup. After appearance of aphids, two sprays of imidacloprid 17.8% SL @ 0.03% may be repeated at an interval of 12-15 days depending on duration of the crop and level of infestation. Application of horticultural mineral oil @ 1-3% successfully protects potato plants from aphids and aphid transmitted potato viruses by affecting the biology, physiology and feeding of aphids, and also makes the potato plants less attractive to aphids. Conservation of natural enemies like coccinellids, syrphids, chrysopids and parasitoids etc. can help in managing the aphid populations.

Whiteflies, *Bemisia tabaci* **(Gennadius) (Hemiptera: Aleurodidae)**

Economic importance: Whiteflies are small white-coloured sucking insects that inject toxic saliva into the host plants, which is associated with virus transmission. *Bemisia tabaci* is a pest of more than 600 host plants including vegetables, fibre crops, spices, ornamental plants, and weed plant species. *B. tabaci* is a complex of 11 well-defined high-level groups containing at least 24 morphologically indistinguishable species.

Whiteflies cause severe damage to crop plants indirectly by transmitting the viruses of the genus *Begomovirus*. Both nymphs and adults suck plant sap from the underside of the leaf during which virus acquisition and transmission takes place. Whiteflies are

Whitefly

Symptoms of apical leaf curl virus

known to transmit *Tomato leaf curl New Delhi virus-potato* (*ToLCNDV-potato*) in potato since its first report during the year 2000, and at present it is an emerging disease posing threat to healthy seed potato as well as ware potato production in India. The symptoms of the diseases in potato are curling and bunching of apical leaves along with mosaic and chlorosis, hence, referred as potato apical leaf curl disease. The yield losses to the extent of 50% in early planted and susceptible cultivars have been reported.

Biology: The female lays around 150-300 eggs singly on the underside of the leaf which hatch in 4-7 days. The first instar nymph known as crawler, is the only mobile stage that moves to look for feeding sites. The other instars are sessile and they complete their lifecycle on the same leaf. The nymphs become adults in 10-14 days. The healthy adult lives for 10-20 days. The total life cycle is completed in 20-30 days under favourable weather conditions. However, whiteflies can complete three generations on potato crop. They also reproduce parthenogenetically.

The whitefly appears on the young crop in the month of October and continues to build up to reach peak during November and starts decline during December in Modipuram, Uttar Pradesh, India. The whitefly population is relatively low on main crop as compared to early crop. The heavy rainfall is detrimental to whiteflies. They cause huge economic loss in potato in Gwalior region (Madhya Pradesh) by transmitting the virus.

Management: Varieties like Kufri Bahar have shown high tolerance and can be planted in whitefly prone areas. Elimination of weed and alternative host plants of the virus and its vector helps to reduce virus transmission to potato plants. Trap crop of cucumber is a favoured host plant for whiteflies but a non-host for virus, and whiteflies are known to lose their viruliferous capacity after feeding for few days on this plant. Placing yellow sticky traps (15×30 cm^2) just above the canopy height @ 60 traps per hectare at equidistance from each other and seed treatment with imidacloprid at 0.04% for 10 min and its foliar application at 0.03% at emergence with repeated application after 15 days is standard recommendation in seed potato. Sprays with thiamethoxam 25WG @ 0.05% after 15 days of crop emergence, foliar sprays of spiromesifen 240SC at emergence @ 96g a.i./ha (400 ml/ha) would also check whitefly population build up.

Potato leafhoppers, *Amrasca biguttula biguttula* **(Ishida) (Hemiptera: Cicadellidae)**

Economic importance: Potato leafhopper is a polyphagous pest distributed worldwide and causes major loss to potato crop. In India, the leafhoppers are distributed in all potato growing regions of Indo-Gangetic plains. There are several species of leafhoppers and among them-*Amrasca biguttula biguttula* (Ishida), *Alebroides nigroscutulatus* Distant, *Empoasca solanifolia* Pruthi, *Empoasca kerrimotti* Pruthi, *E. fabae* Harris, and *E. Punjabensis* Pruthi are important which damage potato crop.

Amrasca biguttula

Both the nymphs and adults of the leafhoppers suck the sap from lower side of the leaves causing extensive damage by direct feeding of the plants. The late instar nymphs are more harmful and cause almost twice yield losses as compared to the adults. They also inject a toxin into the plant, which causes yellowing, browning, cupping and curling of leaves that can be easily identified in the form of triangular mark of burn, at the tip of the leaf. In potato, the leaf veins turn yellow, the leaf margins turn brown and brittle followed by drying of entire leaf. The severely infested field gives a burnt look appearing in a circular ring commonly known as “hopper burn”. Yield losses can be tremendous if the pest is not controlled within 30-40 days of planting.

Biology: The life cycle of the pest is completed in about one month. The leafhopper lays 18-22 eggs in veins and petioles. These are transparent and pale yellow in colour. They hatch in about 7-10 days and the newly hatched nymph is yellow in colour. Five nymphal-instar period lasts for 12 days. The nymphs and adults are pale green, slightly wedge-shaped. They move diagonally when disturbed. The total life cycle is completed in 25-35 days depending upon weather conditions.

Management: Crop rotation with suitable non-host crops and maintaining proper isolation distance in potato crop would reduce the pest population. Judicious use of nitrogenous fertilizers and balanced plant nutrition checks the hopper multiplication. Early planted potato crop must be protected from leafhoppers through foliar spray of systemic insecticides. Spraying late in the day or in the evening may provide better control than spraying early in the morning. Potato leafhopper is attacked by a variety of natural enemies, including generalist predators (lady beetles, damsel bugs, minute pirate bugs and lace wings) and egg parasitoids (*Anagrus* spp.) of the family Mymaridae.

Thrips, *Thrips palmi* **Karny (Thysanoptera: Thripidae)**

Economic importance: More than seven species have been found infecting potato crop. *T. palmi* is the predominant species and most efficient vector of stem necrosis disease caused by *Groundnut bud necrosis virus* belonging to Tospo virus group. Thrips population moves from the preceeding crop to the other cultivated host plants and weeds in the vicinity. Adults tend to feed on young growth and prefer to hide in complex plant parts and so are found on new leaves. Potato stem necrosis disease causes 15-30% yield loss in potato in northern Gujarat and parts of Madhya Pradesh.

Thrips

Stem necrosis

Biology: These are small insects that completed life cycle in about 20 days at 30°C. Eggs deposited in leaf tissue are colourless to pale white and bean-shaped. Larvae resemble the adults in general body form though they lack wings and are smaller. Larvae feed in groups, particularly along the leaf midrib and veins, and usually on older leaves. Adults are pale yellow/whitish in colour, the slender fringed wings are pale. There are two active larval instars and the life cycle lasts only 17.50 days at 25°C.

Management: Growing tolerant potato varieties for early planting like Kufri Sutlej, Kufri Badshah and Kufri Jawahar, and seed treatment with Imidacloprid 17.8 SL @ 5 ml/l of water for 10 min or spray with the same insecticide just after the emergence of crop @ 3 ml/10 l water effectively controls thrips. Frequent irrigation reduces the activity of thrips on crop.

White grub, *Brahmina coriacea* **(Hope) (Coleoptera: Scarabaeidae)**

Economic importance: White grubs are polyphagous, cosmopolitan in nature. Larvae live in soil and these larvae are called white grubs/root grubs. They feed mainly on root and live a concealed life. The number of grubs can be more in light soil with high organic matter content. In plains, white grub has long been associated with sugarcane crop and is now causing damage to potato crop also. Twenty species of white grub have been reported on potato from India. Of these, *Brahmina coriacea* , *Holotrichia seticollis* Moser, *H. longipennis* (Blanchard), *Anomala dimidiata* Hope and *Melolontha indica* Hope are most destructive in north-west hilly region and others are found in different parts of the country.

White grubs

White grub, *B. coriacea* was first reported to cause serious damage to potato in 1980 and the damage ranged from 10-90% in variety Kufri Jyoti. These grubs appeared in epidemic form in Shimla hills especially in Shillaroo area where they even damaged pome, stone fruits and forest trees too. On fruit trees, *B. coriacea* was first reported from Kullu valley of Himachal Pradesh. *Brahmina coriacea* constitutes around 50% of total scarabaeid fauna in mid hills of Himachal Pradesh. In hills, it is believed that beetles feed on oak trees, which is the preferred host of the beetles, and grubs feed on wild grasses growing on the forest floors. Due to deforestation, leading to decrease in number of oak trees, beetles have moved to agricultural land and crops for survival. The damage is done by second and third instar grub (larval stage) that make large shallow and circular holes in the tubers. In potato, the tuber damage may exceed 50% in endemic areas.

Biology: In India, adult beetles emerge from the soil during April to June in response to pre monsoon showers. The second fortnight of June is observed to be the peak period of emergence of beetles and emergence continued until the first fortnight of August, adults mate in the evening and at dawn. Females return to the ground to deposit the eggs in the soil depending upon the softness of the soil. The white grubs complete one life cycle in a year.

Management: Management strategy can be divided in two parts, viz. adult beetles and grubs.

Adult beetle: Light traps having water mixed with kerosene are useful to trap and kill the adults as soon as they emerge after first shower. In nature, white grub population is kept in check by predatory birds like Indian myna and jungle crow. In India and Nepal, *Metarrhizium anisopliae* and *Beauveria bassiana* are being used against white grub. Entomopathogenic nematodes (EPN) like *Steirnernema carpocapsae* and *Heterorhabditis indica* are effective in management of white grubs in potato crop.

Grub : Deep ploughing after harvest of potato is the best way to expose white grubs to high temperature and natural predatory birds. Removal of weeds from bunds around the field reduces the chances of egg laying. Deep placing of seed tuber is recommended. Only well rotten farm yard manure should be applied to the fields. Spray of chlorpyriphos 20 EC (0.1%) immediately after first monsoon shower on weeds and bunds around the field will reduce the number of grubs emerging out of eggs. Spray the crop (ridge portion) with chlorpyriphos 20 EC @ 2.5 l/ha after earthing-up to kill the larvae. There should be sufficient moisture in the soil at the time of application and the insecticide should be thoroughly mixed in the soil so that sufficient quantity of insecticide is present in the root zone.

Cutworms, *Agrotis segetum* **(Denis & Schiffermuller) (Noctuidae: Lepidoptera)**

Economic importance: Cutworms are polyphagous and most destructive insects. *Agrotis segetum, A. ipsilon, A. flammatra* and *A. interacta* are reported to occur on potato. In India, cutworms are more serious in northern region than south. *Agrotis segetum* is commonly found in hills and *A. ipsilon* is common in plains. Peak activity occurs during May-June in Shimla hills, in August in peninsular India and in March-April in Bihar and Punjab. In Bihar, the tuber damage is reported upto 12.70% and in Himachal Pradesh 9-16.4% tubers were damaged by cutworm.

They cause damage in many different ways: (i) young larvae feeding on leaves (ii) mature larvae cutting the stem of the plant just near the ground and (iii) making irregular holes in the tubers. Larvae also feed on roots. They feed at night on young shoots or underground tubers. Smooth, greyish-brown, greasy and plump looking caterpillars are found hiding in the soil near to the stem of the plant during day time. Tuber damage ranges between 9-16%. After tuber formation, they start feeding on tubers and roots which results in a variety of holes, ranging from small and superficial to very large deep ones so it directly affects the tuber yield and its market value.

Biology: The freshly laid eggs are cream coloured, laid singly or in clusters. Eggs are laid on vegetation, on moist ground around plants, or in cracks in the soil. They hatch in 10 to 28 days. Young caterpillars are smooth, stout, cylindrical with blackish brown in colour dorsally. Old caterpillars have a plump body and colour varies from grey, dark green to brown or black with shiny, greasy-looking skin. Fully grown caterpillars are 4-5 cm long. The larvae curl when disturbed and remain motionless for a short period. Older caterpillars feed at the base of plants or on roots or stems underground. They are nocturnal and hide in the soil or under stones and plant debris during the day. At night, they move up to the soil surface to feed. They pupate in an earthen cell and adults are dark grey, black or brown coloured medium sized moths with markings on the front wings. Females are darker than males. The life cycle can be completed in 6 weeks under warm conditions.

Management: Deep summer ploughing in potato fields to expose immature stages to predators and sun. Vegetation and weeds should be destroyed 10-14 days before planting. Flooding of the field for a few days before planting can help to kill cutworm caterpillars in the soil. Light traps installed in/around potato fields attract the adult moths. For effective chemical control the best time is when caterpillars are small and still feeding on the haulms. Once the caterpillar is big enough and moves to the soil, it is difficult to control as older caterpillars are generally less susceptible to insecticides. For efficient chemical control thorough coverage of foliage with good amount of water is needed. Chlorpyriphos 20 EC @ 2.5 l/ha is effective against cutworms on potato.

Potato tuber moth (PTM), *Phthorimaea operculella* **(Zeller) (Lepidoptera: Gelichiidae)**

Economic importance: Potato tuber moth was introduced into India in 1906 through seed potato imported from Italy and since then this insect has been causing damage both in potato stores and field. The potato tuber moth also referred as PTM, probably originated in the tropical mountains of South America but today it has became a cosmopolitan pest. It has been reported from more than 90 countries worldwide. The common PTM is principally a post-harvest pest damaging potatoes kept in farm stores but it can be an important field pest as well. In India, PTM damage has been reported from Maharashtra, Bihar, Madhya Pradesh, Kangra valley of Himachal Pradesh, Tamil Nadu, North Eastern hill states, plateau region and Karnataka. The range of infestation is 30–70% in farm stored potato.

Biology: The male and female moths are brownish grey in colour and wings are folded to form a roof like structure. The adult moth prefers to lay eggs on green foliage than on tubers, on underside of the leaf in the field. The young larvae feed and create a tunnel between two layers of leaf tissues. The larvae destroy the crop by injuring the leaves, boring into petioles and terminal shoots causing wilting of plants. After tuberization, the eggs are laid by the adults on eyes of exposed tubers and tubers in soil through the cracked soil. The larvae enter into the tubers and feed on them causing mines. The activity of larvae on tubers placed in heaps, results in production of heat which promotes significant rotting of the produce. In country stores, 18-83% tuber damage due to PTM has been reported in the north eastern hills.

Management: Selection of healthy potato tubers before cold storage is the best way to control potato tuber moth. Cultural practices can contribute significantly to reduce PTM infestation at harvest. Deep planting for at least more than 10 cm, proper earthing up, lifting of all tubers from field at harvest and destruction of self-grown potato plants are some of the cultural practices which can reduce the initial infestation and subsequent build-up of population in storage. Use of water traps could catch the greatest number of moths of PTM per trap. Covering of potato heaps with 2.5 cm thick layer of chopped dried leaves of Lantana (*Lantana camara*) or Eucalyptus (*Eucalyptus globosus*) both in dried and powdered can prevent tuber infestation of PTM up to 6 months.

Apanteles subandinus and *Copidosoma koehleri* are being widely used in classical biological control of *P. opercullela* in different parts of the world. Predators such as *Coccinella septempunctata* and in storage, use of Granulosis Virus (GV) @ 350 larval equivalent (LE) per kg talc powder are extremely effective in reducing PTM damage. PTM can also be effectively controlled by spraying chlorpyriphos 20EC @ 2.5 ml/l under field conditions and CIPC treatment @ 0.1% in stores.

Mite, *Polyphagotarsonemus latus* **Banks (Acarina: Tarsonemidae)**

Economic importance: It is commonly known

Mite damage on leaf

Mite damage in field

as yellow mite or broad mite, and is polyphagous in nature. It has been reported on more than 100 plant species including cotton, beans, citrus, potatoes, mango, papaya, jute and many ornamental plants. Mites cause severe damage (20-60%) to early potato crop in Indo-gangetic plains, part of Himachal Pradesh, Maharashtra, Karnataka, Gujarat, Madhya Pradesh and Western Uttar Pradesh.

Management: Delay in potato planting, avoiding dry conditions and frequently spraying of plain water, destruction of severely affected plants mechanically during the initial stage of infestation are some practices that reduced the mite population. Suitable crop rotations with non-host crops like wheat in pest prone areas and proper isolation to potato crop from susceptible hosts like chilies, brinjal *etc*. Spraying Bifenazate 240SC/Spiromesifen 240SC @ 0.75 ml/l or Fenazaquin 10EC/ Fenpyroximate 5EC/ Propargite 57EC @ 2 ml/l is recommended for the management of *P. Latus*.

For further interaction, please write to:
Dr Kamlesh Malik, ICAR-Central Potato Research Institute Reginal Station, Modipuram (U.P.), India, [2]ICAR-Central Potato Research Institute, Shimla (H.P.), [3]ICAR-Central Potato Research Station, Jalandhar (Punjab), E-mail: malikkamlesh7@gmail.com

Rajesh K Rana, S K Chakrabarti
and Rajbir Singh

Doubling farmers' income with potato

India is predominantly a farmers' country as about half of our population derives livelihood from agriculture. However, more than two thirds of Indian farmers being small and marginal, their farm income is inadequate to meet family needs satisfactorily. Higher rate of inflation than the rate of nominal growth in farm income and tremendous enhancement in the family expenses mainly on account of children's education and medical care have led Indian farmers into the state of financial distress and despair. As the rate of growth of farmers' income is much slower than the rate of growth of expenses of the farm families, this financial discomfort is becoming deeper and deeper with the passage of time.

Scenario of farmers' income

The report of the Situation Assessment Survey of the NSSO (2012-13) provides benchmarks on farmers' component wise income and size categories (Table 1). The survey highlighted that there were slightly more than 9 crore farm families in India out of which about 86.6% were having 2 ha or less holding size of their farming. The average holding size of Indian farmer was 1.036 ha and average farming income of an average farmer was ` 36,960 per year. However, the family income of an average farmer was ` 77,888 per year. More than two thirds of India farmers had farm size equal to or less than 1 ha.

Why doubling farmers' income is a difficult task?

Past performance of growth of farmers' income in one decade during 2002-03 and 2012-13 (Table 2) depicts a 3.1 times nominal enhancement. However, when farmers' 2012-13 income was adjusted to Consumer Price Index (to set aside inflation) the farmers' real income increased with meagre 1.04 times. If we leave aside the seven years under consideration for doubling farmers' income (i.e. 2015-16 to 2022-23) and take full decade of 2013-14 to 2022-23 into account even then the past performance paints a gloomy picture. Although the rate of inflation has been benign during 2013-14 to 2022-23 as compared to the preceding decade yet the terms of trade which were in favour of agriculture sector during 2003-04 to 2012-13 have become adverse in the current decade. Taking all these factors into consideration the goal of doubling farmers income in seven years' time period is not at all an easy task.

Basic framework for doubling farmers' income

After duly recognising and understanding the unfavourable terms of trade for agriculture sector in India and the resultant plight of our farmers, the Government of India contemplated the idea of doubling farmers' income by 2022. Despite being highly debatable issue, it has become the best ever source of direction and action towards ensuring better economic health of Indian farmers. Ministry of Agriculture and Farmers Welfare has suggested a highly thought out seven points meticulous action plan for Doubling Farmers' Income by 2022 by way of increasing farm production and productivity, lowering cost of cultivation, ensuring better prices of farm produce,

increasing non-farm income of farmers, diversification towards high value crops and efficient post-harvest management of agricultural produce by food processing and mitigation of post-harvest losses as the major components (Box-1). Potato is one of the best crops that covers large number of components of the action plan for Doubling Farmers' Income and this article attempts to aptly describe this unnoticed potential.

The Indian economic thinktank has estimated contribution of different components of farming for enhancing farmers' income during 7 years' period ending 2022-23 (Box 2). Potato crop has very high relevance even in these components as the use of drip irrigation technology, better quality seed potato, better potato technologies and efficient dissemination of technical knowhow to potato farmers will bring higher than 17.6% yield enhancement in potato crop. Similarly, with the help of soil health cards, neem oil coated urea, drip irrigation application and fertigation are estimated to bring more than 13.3% cost reduction in potato crop. Area enhancement under potato crop is expected to be much higher than just 4.1 suggested in the box, hence crop diversification benefits for potato crop have been considered overweight. With the rapidly increasing demand for processed potato products, seed potato and specialty potatoes; tremendous benefits of eNAM and Model Act; and storage and transportation efficiencies

Basic Framework for Doubling Farmers' Income

- Increase in production and productivity
- Decreasing cost of cultivation
- Reduction of post-harvest losses
- Value addition
- Reforms in Agricultural Marketing (eNAM and Model Act)
- Risk, security and assistance
- Allied activities
  - Horticulture (Huge potential, high value crops like potato)
  - Integrated farming system (income/ risk at small farms)
  - White revolution (65% higher income in one acre than crops)
  - Blue revolution (Punjab; demand is picking)
  - Sub-mission on agro-forestry (Supplementary income)
  - Beekeeping (Income of ` 2500/ box; without land resources)
  - Rural backyard poultry (Income/ nutritional security); Others (Mushroom, agri-tourism, consultancies for landless farmers)

Estimated contribution of different components for Enhancing Farmers' Income (EDI)

Components of EFI	% share	Relevance for potato
Crop productivity	17.6	Overweight on account of drip irrigation technology, better quality seed potato, better potato technologies and efficient dissemination of technical knowhow
Livestock productivity	12.5	Nil
Improvement in resource use efficiency/cost reduction	13.3	Overweight due to soil health cards, neem oil coated urea, drip irrigation application and fertigation
Crop intensity	4.2	Nil
Crop diversification	4.1	Overweight as higher area is estimated to come from low value crops to potato than just 4.1%
Better price realisation	7.1	Overweight on account of higher demand for processed potato products, seed potato, specialty potatoes, eNAM, storage and transportation efficiencies.
Shift to non-farm occupation	7.7	Nil
Total increase in income in 7 years	66.5	

Actual coverage of micro-irrigation scheme in India

Micro irrigation	(Area; 2018-19)
Drip	3.26 Lakh ha
Sprinkler	3.01 Lakh ha
Total	6.27 Lakh ha
Other interventions	
Potential created for protective irrigation	0.12 Lakh ha

are expected to create price realization for potato farmers sufficient enough to raise their farm income way higher than just 7.1%.

Non-integration of agricultural markets in India as evident from the huge difference in prices of the same agri-commodity in different agricultural markets has been found a big cause of concern for potato farmers. This government has contemplated the idea of implementation of electronic National Agricultural Market (eNAM). So far more than 585 markets (in 16 states) have been enrolled under this scheme. This initiative will stop market malpractices and unreasonable variation of product prices in different markets of the country. This scheme has huge potential of ensuring higher price especially for the potato farmers without compromising their bargaining power in the market on the pretext of being small in size or carrying low volumes. The scheme has been expected to significantly enhance the actual prices realisation by the potato farmers as potato is a bulky produce and informed selling decision will save him/ her from distress sale on account of heavy cold storage/ transportation charges.

APMC act has some bindings on the farmers which reduce latter's freedom in selling the produce at his/her will. For ensuring better prices to the farmer the government have been tirelessly pursuing implementation of Model Act throughout the country and a greater number of states is adopting the Model Act. This reform will make modern agricultural practices like Contract Farming more effective for the farmers to get better prices and to mitigate their market related risk with his/her ability to exercise the freedom to sell to multiple buyers. Potato farmers being one of the biggest beneficiaries contact farming will continue to benefit to higher level under the Model Act.

Steps and schemes for income supplementation

After duly recognising the urgency of increasing farmers' income, the union government of India announced and implemented steep enhancement in support price of principal agricultural commodities during 2018-19 under the famous '50% plus cost of cultivation scheme (A2 cost plus imputed value of family labour)'. However, this measure being not sufficient in itself, the promulgation of farmers' income supplementation schemes like *Pradhan Mantri Kisan Samman Nidhi* (` 6000 per year income supplementation) provides the additional evidence of concerted efforts towards this gargantuan goal. Some of the resource rich states have also announced farmers' income supplementation schemes through Direct Benefit Transfer like Rythu Bandhu scheme of Telangana and Krushak Assistance for Livelihood and Income (KALIA) scheme of Odisha as prominent examples. As potato farmers were not the beneficiary of higher support price, small and marginal of them could get some support out of *Pradhan Mantri Kisan Samman Nidhi*, Rythu Bandhu scheme of Telangana and KALIA scheme of Odisha.

Farm production and productivity enhancement

Feeding ever increasing population is perceived as one of the future threats by the Indian agricultural

Table 1. Component wise income of Indian farmers and their size of holdings

Farm size	Average holding	Component wise income (`/family; 2012-13)					Households	
category (ha)	size (ha)	Farming	Livestock	Non Agri Enterprises	Wages/salary	Total	Crore	%
<0.01	0.005	356	14557	5366	34825	55104	0.239	
0.01-0.40	0.19	8232	7685	5505	28629	50051	2.877	
0.41-1.00	0.66	25726	8467	5546	24135	63874	3.148	86.58
1.01-2.00	1.38	50501	11090	7113	20735	89439	1.556	
2.01-4.00	2.57	88297	15155	6643	19882	129977	0.843	
4.01-10.00	5.66	182916	19112	10338	24377	236743	0.330	13.42
10.00+	15.25	428224	33157	21244	15730	498355	0.037	
All	1.036	36960	10046	6212	24847	77888	9.020	100.00

Source: NSSO Situation Assessment Survey 2012-13

Potential benefits of application of drip irrigation in potato crop

Attribute	Benefit
Yield advantage	33 to 39.5%
Fertilizer saving	25%
Labour saving	30-35%
Higher price of the produce	25%
Overall income enhancement	` 50000/ ha

Note: Estimated 5% potato area in India was under drip-irrigation during 2015-16 and another 5% is expected to be covered under this irrigation system by 2022-23.

Role of high-tech seed potato production in India (including the aeroponics system)

About 30% potato area was covered by healthy seed during 2015-16. Estimated 25% additional potato area is expected to be covered under healthy seed potato by 2022-23. Average potato productivity in India was 22.94 t/ha (TE 2015-16)	Healthy seed potato will enhance potato productivity by 20% on 5.5 lakh ha (estimated 5.3 lakh farmers) resulting in additional average ` 20000/ha or ` 20720/farm.

professionals and policy makers. Due to the very strict constraint of additional availability of agricultural land for producing more food, enhancement of agricultural productivity becomes very important component of the overall strategy of Government of India to ensure food security for their people. Although Indian potato productivity is much higher than the world average and about 95% potato production comes under short days conditions in *rabi* season where yield potential is already compromised *vis-à-vis* the long day conditions, yet India can easily enhance its potato productivity by 25% during the period of 7 years. This productivity enhancement is possible with the help of two simple developments in the form of ensuring healthy seed potato and spreading the extent of micro-irrigation (especially drip irrigation) technology in areas which are still left out.

Significance of judicious use of water is generally practiced at very low level in India. There is a potential of saving more than 50% irrigation water with the help of micro-irrigation systems in potato cultivation. Fortunately, the current union government has been stressing very high on this aspect.

Drip irrigation, during recent years, has become a new successful technology in Indian potato cultivation. In a survey study based on farmers' personal experiences, 33% higher potato yield was reported in Gujarat state of India under drip irrigation system (Benefit-Cost Ratio=1.67) compared to furrow irrigation (Benefit Cost Ratio=1.37). In an agronomy field trial having row-to-row distance of 60 cm, plant-to-plant distance of 10 cm and height of the ridge at 20 cm (tuber placed at 10 cm depth), it was found that potato yield under drip irrigation system (with fertigation) was equal to 43.1 t/ha compared to furrow irrigation system (30.9 t/ha). This yield advantage of 39.5% under the drip irrigation system was supported by 2.48 Benefit: Cost Ratio against 1.98 for furrow system. In addition, irrigation water saving up to 50%, higher dry matter contents of potato tubers (resulting in superior quality), 10-15% higher number of tubers (making the system further better for seed multiplication), 20-25% higher processing grade tubers (creates an opportunity of getting still better prices for selling raw material to processing industry), 25% fertilizer economy (saving farmers' money and beneficial to the environment) and 30-35% labour economy were also reported in the scientific literature. Duly standardized agronomic requirements for application of micro-irrigation technology to potato in India by the ICAR-Central Potato Research Institute, Shimla, is another great added advantage in the direction of its large-scale adoption. Hence, application of drip irrigation technology to potato crop has the potential of enhancing farmers' average income by `50000/ha or `51800/farm for nearly 5% of potato farmers.

ICAR-Central Potato Research Institute Shimla has invested tremendous time and energy for transforming seed potato system from traditional to high tech (with biotechnology applications and further using aeroponics technology) during one decade or so. This technological upgradation has started paying dividends in terms of better availability of healthy seed potato throughout the country and higher potato yields realization. During 2015-16, about 30% of potato area in India was estimated to be under healthy seed potato with average triennium ending yield of 22.94 t/ha. By 2022-23, 55% of Indian potato area is estimated to be covered under healthy seed potato with 20% yield enhancement in the additional 25% to be brought under healthy seed potato coverage which will transform into ` 20000/ha or ` 20720/farm for about 5.5 lakh ha area and 5.3 lakh farmers.

Table 2. Assessment of growth in farmers' income during 2002-03 and 2012-13

Period	Component wise income (2012-13)					
		Farming	Livestock	Non Agri Enterprises	Wages/ salary	Total income
2002-03	`/ farm	11628	1092	9828	11628	34176
	Percentage	34.02	3.20	28.76	34.02	
2012-13	`/ farm	36960	10086	6212	24847	77888 (3.1 times)
	Percentage	47.45	12.77	7.88	31.90	
CAGR (%) of income	12.26	24.72	-4.60	7.89		

Source: NSSO data

Non-farm income enhancement

More than two thirds of farmers in India being the cultivators of less than 1 ha land need non-farm employment at very high level of priority. Increasing non-farm income of farmers is also at very high level of importance inour country where half of the population is employed in agriculture but gets less than 14% of national income distributed among themselves. The central government have promoted, supported and integrated schemes like 'STARTUP' India into agriculture so that farmers can initiate agro-enterprises and integrate non-agricultural elements into their businesses. Similarly Agricultural Skill Council of India has been integrating agricultural skills with the non-agricultural skill for making farmers better integrated in their businesses. Although the actual outcome of this initiative will be realized in the long term but initial results are encouraging. The initiatives of the union government of India for promoting non-farm employment will benefit potato farmers too and these farmers will also be in position to augment their family incomes along with other farmers in the country.

Better post-harvest management

Post-harvest management of agri-produce in general and potato in particular is a matter of serious concern in India as a very large proportion of our produce is wasted during post-harvest operations including the process of marketing. Under *Pradhan Mantri Krishi Sampada Yojana*, special emphasis has been laid on value chain development and making the supply chains more efficient. Enabling forward and backward linkages in the agro processing clusters has been taken very seriously. A bundle of schemes have been implemented under *PM Kisan Sampada Yojana*, viz. mega food parks; integrated cold chain and value addition infrastructure; creation/expansion of food processing/preservation capacities (Unit Scheme); infrastructure for agro-processing clusters; creation of backward and forward linkages; food safety and quality assurance infrastructure; and human resources and institutions etc. Potato being one of the first choice of agri-processors is bound the get benefitted out of these initiatives and the benefits will be distributed among potato farmers too.

Farmer producer organizations

Farmer Producer Organizations (FPOs) have been promoted in a big way for ensuring scales of operations and better prices to the small farmers. The FPOs have very high emphasis on post-harvest management of agricultural produce. The government has decided to keep income of FPOs free from the income tax. NABARD has been supporting FPOs across the country promoting agro processing, government procurement scheme, dairy, organic farming, seed production and marketing, fishery and other allied activities. The apex development bank is expected to achieve the milestone of promoting 5000 FPOs shortly for helping farmers to enhance their farm as well as non-farm income. The constitution of FPOs is highly beneficial for potato farmers and their income is expected to rise through this route.

Financial liquidity through warehouse receipts

Lack of monetary liquidity is one of the biggest constraints for majority of the farmers in India especially the potato farmers who have to sell their produce under distress in order to meet minimum level of financial obligations. Loans against negotiable warehouse receipts for providing additional liquidity of money to small farmers, strengthening of storage facilities in the production centres and promotion of integrated cold chains has been believed to bring positive results in mitigation of post-harvest losses especially in the rural India. In conjunction with eNAM scheme this scheme is a boon for potato farmers who are now in a position to sell their produce at the right time and price.

Imperative role of KVKs

Krishi Vigyan Kendras (KVKs) are the biggest success story in Indian National Agricultural Research and Extension System during recent decades. At national level we are proud to have 714 KVKs. In addition to their mandated activities of technology assessment, refinement and demonstration, our KVKs are also carrying out a large number of extension activities including all crops and farm activities including the potato crop. KVKs have been playing vital role in dissemination of technical knowhow and technologies to farmers. Potato farmers being one of the most responsive to the extension stimulus are expected to benefit the most in terms of enhancing their farm income with the active support of KVK system.

For further interaction, please write to:
Dr Rajesh K Rana (Principal Scientist), ICAR ATARI Zone I, Ludhiana, Punjab. E-mail: rkrana2004@yahoo.com

Brajesh Nare and Sukhwinder Singh

Mechanization in potato cultivation

Potato is a crop with huge output per unit area. Production, handling and processing of potato takes lot of time and energy if all the operations are completed manually or with the help of animal drawn equipments. A number of efficient farm machineries and equipments are available in India to carry out timely field operations like seedbed preparation, fertilizer application, planting, weeding, earthing, digging, grading and seed treatment. Therefore, in this era of competitive agriculture, for efficient use of expensive inputs like seeds and fertilizers, farmers should opt for precise application of the farm inputs through mechanization and should use potato planters, fertilizer applicators, weeders, diggers, graders and other available machines. Some of these machines are expensive and are not in the reach of small farmers. In cases such group of farmers can purchase the machine or an individual farmer can have it and go for custom hiring for more returns. Similarly, cooperatives can be useful for having processing machineries at village or cluster levels.

POTATO is one of the most important food crops in developed as well as developing countries. Production wise it ranks third among the major food crops after wheat and rice in the world. Lot of energy is required for production and processing of potatoes due to bulky and watery nature. Potato is a short duration crop of 90-120 days, having highest yield per day per unit area as compared to other major crops. Being a relatively short duration crop in the plains of India, its mechanization assumes a special importance in order to accomplish various farm operations in limited available time. Manual production of potato is time consuming and tedious job, it requires about 1,600-2,000 man-hours per hectare for all the operations. With the emergence of new crop rotations and enhanced cropping intensity, many farmers experience scarcity of time and labour. Efforts have been made at various levels to mechanise both production and processing to reduce the manpower requirement, drudgery and cost of production. Various mechanical tools, implements and machinery have been developed for land development, fertilizer application, seed treatment, planting, weeding, harvesting, grading, sorting, storage and on-farm processing of potato.

Field preparation: After burying green manure crop (usually *dhaincha*) with disc plow, mould board plow or disc harrow or rotavator followed by one planking makes field conditions favorable for decomposition of green manure. Potato requires good tilth soils to ensure covering of stolons/tubers and also to provide adequate aeration for respiration of roots and tubers. To get a good yield, soil should be loose and friable with good drainage and aeration. Subsoiler is an important primary tillage implement. It breaks the hard pan below the soil surface and provides good drainage environment. Pre-sowing irrigation has to be done before field preparation to have uniform germination. After 5-7 days of pre-sowing

Green manuring with disc harrow, deep tillage with sub-soiler improves infiltration and final field preparation with rotavator

Fertilizer applicator cum marker

irrigation, 2-3 cross harrowing or 3-4 tiller operations followed by two planking make the required seedbed for a good crop of potato. Among the primary and secondary tillage implements, the rotavator is most popular for preparation of field which provides fine level of soil tilth. All these implements are easily available in the market and are being used for other crops also.

Fertilizer application

Fertilizer type, quantity and placement are important factors for good production of potato crop. Precise and judicious use of fertilizer is of prime importance to ensure efficient utilization and reduce the cost of farm input and environmental risk. After seedbed preparation, a fertilizer drill-cum-marker or fertilizer broadcaster can be used for fertilizer application. Fertilizer drill-cum-line marker is a machine which ensures uniform placement of fertilizer in furrows and marks the line impressions at 600 or 650 mm fixed row spacings for tuber placement. With this machine fertilizer rate can be adjusted between 50-300 kg/ha with a field capacity of 4.0 ha/day. In case, fertilizer unit is attached with the planter then the use of fertilizer drill can be avoided. In potato crop, fertilizer should be placed 5-7 cm below the seed tubers and should not come in direct contact with the seed. Band placement helps in improving efficient utilization of fertilizer which results in improved production. Generally, fertilizers are hygroscopic in nature, hence, it is recommended to properly clean the applicator after use.

Seed tuber planting

About 80-85 thousand seed potatoes have to be planted per hectare for good yield of the crop. This can be achieved by planting 35-55 g of seed potato tubers per hectare. Uniform placement of tubers in prepared soil bed at specified spacing and depth is also important for better emergence as well as production of the crop. Uniform plant emergence can be achieved by planting of seed material with tractor operated potato planters. Function of the planter is to open a furrow, meter the seed tubers with a suitable metering mechanism, place the tubers in the furrow and cover them with a soil layer of about 6-8 cm. These machines maintain uniformity of planting in terms of row to row (60 cm), plant to plant spacing and depth (6-8 cm) of planting. Various types of machineries available in India for planting of potato are rotating drum type, revolving magazine type, belt and cup type and picker wheel type

First two are semi-automatic type planters in which one person per row puts seed tubers in to the seed metering cells of the machines. Function of these machines is to open a furrows and drop the seeds into the soil through seed delivery tubes. Seed tubers are dropped in lines and a ridge of soil mass is formed over the tubers. Automatic planters are becoming popular due to their various advantages over the other types. In this type of machine, labour is required only for filling of hopper. All other activities like lifting individual tubers, dropping them into rows and covering with soil mass are carried out by the machine.

Weeding, top dressing and earthing

Mechanical and chemical weed control methods are used in most of the crops. Potato being a tuber crop, is highly responsive to inter-row cultivation. Three row tractor operated inter-row cultivator is operated in 22-25 days crop when plant height is 8-10 cm. After operating this weeding machine, three or five row ridger is used for earthing up and remaking the ridges. Ridger makes uniform ridges and accumulates sufficient soil mass around the plants. For light soils and low weed intensity areas, another multipurpose machine is available which performs weeding, furrow opening, fertilizer application and re-earthing

Potato planting with semi automatic and automatic planters

Interculturing and fertilizer top dressing before earthing operations in potato crop

simultaneously. For chemical weed control, tractor operated multinozzle sprayer or spray gun is used to achieve fast and uniform coverage.

Potato harvesting with tractor operated digger elevator

Plant protection

Potato crop needs to be protected from different disease carriers, insects and pests by applying chemical formulations. Commonly, liquid chemicals are sprayed on crop canopy for protection. Many times delay in chemical spray can lead to huge losses particularly in case of late blight disease. Delay of 1-2 days can result in complete loss of crop. Therefore, timely and uniform application of plant protection chemicals is important, which is possible with high capacity tractor operated sprayers. Multinozzle boom sprayer, having 12-16 nozzles, is also useful for potato crop. However, spray gun is especially effective for late blight in potato plants as it covers lower surface of leaves more effectively. For small holdings, manually or battery

Spraying with power sprayers

Low cost blade type digger

Two row potato combine harvester

operated knapsack sprayer can be used which has a field capacity of 0.5 ha/h.

Potato digging

Before starting harvesting operation haulms are removed manually using sickles or with chemical methods. Potato digging is a cumbersome process and involves a lot of manpower. About 600-700 man-hours/ha are required for manual digging of 300-400 quintals of potato from huge soil mass of around 10,000 quintals. In manual harvesting spade or *khurpa* is used which results in up to 10% tuber cut or bruise which is a huge loss to the farmer. In manual harvesting some portion is always left behind in the field. Animal drawn plow is another tool for potato digging. This method is faster as compared to manual digging but in case of large scale farming, harvesting is delayed with this method and fields become dry. Tractor operated diggers are fast, economical and cause least damage to the produce.

Digger elevator is an efficient machine which exposes 90-95% tubers in optimum field conditions. This machine has to be maintained properly as there are many parts which move in soil and cause more wear and tear. Multipurpose passive blade potato digger is another less expensive equipment. It exposes about 80-85% potatoes and is easy to maintain. It can be used in early crop (60

Rubber belt sreen type potato sorting and grading machine

days without cutting haulms) and can also successfully work in dry field conditions.

Potato combine harvester

A two row potato combine harvesters has been developed at CRPI to carry out potato digging and picking together. Some other firms have also developed single and two row potato combine harvesters in recent years. Functions of the combine harvester machine are to dig the potato tubers from 15-20 cm deep soil, separate the tubers from soil clods, convey the tubers to the sorting platform and collect them in a hopper. Further, it can be unloaded into a transporting trolley or on a heap. Four workers have to be employed with these machines to sort the rotten tubers or soil clods passing on to the sorting table. These machines are usually powered by a 50 to 60 hp tractor.

Grading

Graded, sorted and properly packed potatoes fetch good price in the market. Manual grading is not uniform and it requires a lot of time and energy which brings down the overall returns. Various manual as well as power operated graders have been developed for size grading of the potato tubers. Rubber belts having different size round or square shaped perforations are generally used in the grading system. Lot of labour is required in these high capacity graders for feeding, sorting and packaging of the potatoes.

Seed treatment

Disease free seed is the most important requirement to grow healthy potato crop. Seed potatoes need to be treated before stroge to protect against diseases. For controlling tuber and soil born diseases, viz. common scab, black scurf and powdery scab, 3% boric acid treatment can be given with an electric powered seed treatment machine. In this machine boric acid is sprayed on the potatoes moving and rolling over a conveyor. All the surfaces are coated with the chemical and the used solution is re-circulated. This machine can treat about 300-350 quintal potatoes per day.

For further interaction, please write to:
Dr B. Nare (Scientist), Farm Machinery and Power Engineering, ICAR-Central Potato Research Station, Jalandhar. E-mail: brajeshagengg@gmail.com

R K Singh, Tanuja Buckseth, Ashwani K Sharma, J K Tiwari and S K Chakrabarti

Potato seed certification in India

Certification of seed potato tubers, minitubers and true potato seed is essential so as to ensure seed quality and prevent seed degeneration as well as spread of pests and diseases. Seed certification is managed by Central Seed Certification Board though 'Seed Act' which provides a set of rules for regulation of quality and purity of the seed material. The rules framed by the Central Seed Certification Board are followed by the State Seed Certification Agencies for carrying out the certification. The responsibility for the quality standards of seed that enters the trade market lies with the state seed certification agencies.

AS per the national policy of seed multiplication, the multiplication phases of seed have been grouped into three categories i.e. i) breeder or basic seed; ii) foundation-I and II and iii) certified seed. The breeder seed is considered to be pure, disease free and no tolerance limit is fixed while for foundation (FS-I and FS-II) and certified seed the tolerance limits for viruses off-type, tuber-borne diseases and grades have been fixed by Government of India. There shall be two types of seed potatoes, namely the hill and plain grown and shall be designated as hill seed and plain seed respectively. Hill seed shall be grown in the high hills generally 2500 m above the mean sea level or in situations declared technically suitable for seed production. Plain seed shall be grown in such areas where aphid infestation is low during crop growing season and which are technically suitable for seed production. A crop of seed potato shall not be eligible for certification if grown on land infested with wart *(Synchytrium endobioticum)*, common scab *(Streptomyces scabies)*, brown rot or bacterial wilt *(Ralstonia solanacearum)* and or cyst forming nematodes (*Globodera pallida, G. rostochinensis*) or non-cyst forming nematodes within the previous three years.

Certification standards for the conventionally grown seed potatoes

A minimum of four inspections shall be made as follows:

- The first inspection shall be made about 45 days after planting in the hills and about 35 days of planting in the plains to verify the isolation, off-types and the extent of disease infection with specific reference to mild and severe mosaic, leaf roll, yellows, brown rot and other relevant factors.
- The second inspection shall be made about 60-65 days after planting for early varieties and about 70-75 days after planting for late varieties or at appropriate growth stage depending on the crop duration of the variety concerned.
- The third inspection shall be made immediately after haulms cutting/destruction in order to verify that haulms have been cut/ destroyed by the prescribed date and in proper manner.

Tuber indexing

- The fourth inspection shall be made in about 10 days after haulms cutting/destruction and before harvesting in order to verify that no re-growth of haulms has taken place.
- Minimum four counts of 100 plants each are taken randomly on four spots in a zigzag manner in one hectare area. For each additional hectare or part there of two samples of 100 plants each are observed for all visible mosaics, other diseases and off-types.

Final field inspection for certification is carried out provided if the following two conditions are fulfilled:

i) The previous history of the field, crop operations followed, manuring and plant protection schedule should be made available at the time of inspection and

ii) Final roguing should be done before certification inspection. At the time of roguing, all off-type and diseased plants should have been removed along with the tubers.

Field standards

Minimum isolation distance of 5 m is to be given for foundation-I, foundation-II and certified seed crop from the fields of other varieties and also the fields of the same varieties not confirming to varietal purity requirements for certification. The minimum permissible limits for the certification of potato seed are given Table 1.

Of the two inspections, the higher virus percentage will be considered for the purpose of the specified limit of tolerance.

Monitoring in net-house

The presence of brown rot infected plants within the specified limits of tolerance shall be permitted in the areas known to be infected with this disease. In case of plants suspected to be infected with brown rot, the neighboring plants, one on the either side also are to be rogued along with tubers.

Standards for re-growth after destruction of haulms shall be met at 4th inspection to be conducted about 10 days after haulms cutting. Gaps in the seed plot should not be more than 10.0% and haulms must be destroyed as close to the ground as possible before the date specified by the certification agency. Failure to destroy haulms in time shall be render the crop liable for rejection.

Seed standards

Specifications in respect of size and weight of seed material for FS-I, FS-II and certified class are given in Table 2.

Internal and External seed health monitoring by the Seed Certification officers

The size of tuber will be decided either on the basis of mean of two width of a tuber at the middle and that of length or on the basis of corresponding weight of tuber. In a seed lot, tuber not confirming to specific size of seed shall not exceed more than 5% (by number). The seed material shall be reasonably clean, healthy, firm and shall confirm to the characteristics of the variety. The tubers not confirming to the varietal characteristics shall not exceed 0.05% and 0.1% (by number) for foundation and certified classes respectively. Cut, bruised, un-shape, cracked tubers or those damaged by insects, slugs or worms shall not exceed more than 1% (by weight). Greenish pigmentation on tubers will not be a

Inspection of seed crop

disqualification for certification. Maximum tolerance limit of tuber showing visible symptoms of the diseases are given in Table 3.

Seed certification standards for potato-tissue culture raised minitubers (PTCMT)

The general standards are basic and together with the following specific standards constitute the standards for approval of PTCMT. As the name implies, these standards are applicable to tissue culture raised minitubers under laboratory, greenhouse, and aeroponic conditions. The general standards to apply specifically to the PTCMT are as described below:

Eligibility requirements for certification

The PTCMT to be eligible for certification shall be from a source meeting the following standards for laboratory and greenhouse facilities.

- Laboratory and greenhouse facilities used for production of plantlets/ micro tubers / minitubers as

Table 2. Seed standards for hill and plain grown seed tubers

Type of seed	Grade	Size (mm)	Corresponding weight (g)
Hill seed	Seed size	30–60	25–150
	Large	Above 60	Above 150
Plains seed	Seed size	30–55	25–125
	Large size	Above 55	Above 125

Table 1. Field standards for seed potato certification

Factor	Stage	Maximum permissible limits		
		Foundation-I	Foundation-II	Certified
Off-types	1st and 2nd inspection	0.05%	0.05%	0.10%
Mild mosaic	1st and 2nd inspection	1.0%	2.0%	3.0%
Severe mosaic, leaf roll and yellows	1st and 2nd inspection	0.5%	0.75%	1.0%
*Total virus	1st and 2nd inspection	1.0%	2.0%	3.0%
**Plants infected brown rots	1st and 2nd inspection	None	None	3 plants/by hectare
***Re-growth of plants after haulms cut	4th inspection	0.5%	0.5%	0.5%

Seed crop monitoring

well as aeroponic tubers shall be maintained free of potato pests or virus vectors. Failure to keep such pests under control may cause rejection of whole lot maintained in the facility.

- All potting or growth media shall be sterile. Clean water shall be used in a laboratory or greenhouse operation.
- Hygienic conditions shall be observed strictly during micro-propagation, potting, planting, irrigation, movement, use of equipments, other laboratory and greenhouse practices to guard against the spread of diseases or pests in the facilities used for seed multiplication.
- All micro-propagation and greenhouse facilities must be approved as per the standard/guidelines. These facilities must have a changing area between the double doors.
- The greenhouse (protected environment) must be "insect proof" and be equipped with a double-door entrance, a provision for footwear disinfestations prior to entering the protected environment and an insect proof ventilation screening on intakes and exhaust openings.
- The persons entering the protected environment should use Wellington boots (Plastic boots) and wear lab-coat in the changing area to reduce the chances of inadvertent introduction of vector insects clinging to the clothes.
- The materials to be initiated for producing PTCMT must be of a notified variety with confirmed identity. It must be duly documented with respect to origin.
- The plants of potato varieties being initiated for tissue culture should be tested in an accredited laboratory for freedom from the following viruses: PVA, PVS, PVM, PVY, PVX, PLRV, PALCV, GBNV, PSTVd, endophytic and epiphytic bacteria and fungi.
- Tests must be carried on a minimum of 10 plantlets of each variety. For virus testing ELISA or an equivalent method should be used and for viroid RT-PCR should be used. For fungi and bacteria light microscopy and culturing on media should be done.

Table 3. Standards for tuber borne diseases for certification

Disease	Maximum permissible limits (by number)		
	Foundation-I	Foundation-II	Certified
Late blight, dry rot or charcoal rot	1%	1%	1%
Wet rot	None	None	None
*Common scab	3%	3%	5%
**Black scurf	5%	5%	5%
***Total diseases	5%	5%	5%

*Even if a single tuber infected with common scab is detected in a seed lot, the entire seed lot shall be treated with approved fungicide before seed lot is declared fit for certification. Seed lot having infected tuber more than prescribed limit will not be certified even after treatment. **A tuber carrying 10% or above scurfed surface will be considered as one infected unit. However, seed lot having black scurf infection more than prescribed limits could be certified after treatment with approved chemical/fungicide. ***For all diseases, the higher disease percentage will be considered for the purpose of the specified limits of tolerance.

Sources of seed

- The facility should use recognized aseptic initiation and propagation procedures (i.e. follow procedures and use equipment, which will maintain sterile conditions as per standard tissue culture norms).
- The initiating facility must maintain information on each variety for review and audit by the competent authority once in a year which includes variety identification and origin, date of initiation and testing results from accredited laboratory.
- Valid pathogen testing results are required prior to the initiation of the microtuber production cycle or planting of test tube plantlets in the greenhouse or aeroponics.
- PTCMT shall be produced and multiplied from certified *in vitro* plants or micro tubers, as per the requirements.

Greenhouse/controlled environment requirement

1. All micro propagation and greenhouse facilities must meet the standards given above under eligibility requirements.
2. The soil used for PTCMT production should not be infested with pathogen and pests of potato, particularly, Wart (*Synchytrium endobioticum*) (Schilb.) Perc. and or cyst forming nematodes (*Globodera rostochiensis* and *G. pallida*); brown rot (*Ralstonia*

Table 4. Standards of PTCMT at net/poly house/ aeroponics

Maximum permissible limit	
*Off types	0.05%
**Plants showing symptoms of	
Mild mosaic	0.05%
Severe mosaic, leaf roll, yellow and apical leaf curl disease	0.05%
**Plants infected by brown rot (syn. Bacterial wilt) (*Ralstonia solanacearum*)	0.00%

*Maximum permitted before dehaulming. **Maximum permitted at final inspection.

solanacearum) (E. F. Smith) or non-cyst forming nematodes within the previous 3 years; common scab (*Streptomyces scabies*) (Thaxt.) Waks, and Henrici.

Inspection of controlled environment facility used for production of PTCMT

1. The grower must notify the competent authority of his production plans well in advance of the planting.
2. The crop must be grown from certified basic *in vitro* plants or microtubers which were produced, in an aseptic environment.
3. A minimum of 3 inspections shall be made as given below.
   i. The first inspection shall be made 35 and 45 days after planting for plains and hills respectively to verify growing conditions, extent of disease infection and off types and also to confirm isolation requirement.
   ii. The second inspection shall be made at 60-65 days after planting to verify off types, disease infection (if any) and pathogen testing on a representative sample comprising of 1% of the plants with a minimum of 5 and a maximum of 25 plants sampled for each variety.
   iii. The third inspection shall be made immediately after haulms cutting/destruction in order to verify that haulms have been cut/destroyed by the prescribed date and by proper manner.
4. Effective sanitation practices including insect and disease monitoring and prevention must be adhered to.
5. Basic stock can be planted in commercially available medium, which has not been recycled. If nursery beds are used, the substrate should be properly sterilized before planting.
6. The greenhouse must be free from all potato and solanaceous plant debris before planting.
7. No field-produced seed potatoes (including pathogen tested clonal selections), non seed potatoes, nor any other solanaceous species of plants can be grown in the protected environment while used to produce Basic Stock.
8. Varieties must be separated by appropriate partitioning of greenhouse to prevent varietal mixture.
9. If testing performed by an accredited laboratory reveals the presence of banned virus (es), fungus or bacteria all the crops in the protected environment will not be eligible for certification and the entire material will be destroyed.
10. All micro-propagation and greenhouse facilities must be notified (approved) by DAC as per the standards given above under eligibility requirements.
11. *In vitro* multiplication for custom production of an imported variety or a non-notified variety can be taken up by the industry exclusively for export purposes. Such varieties, however, should be introduced following the approved guidelines of government of India.
12. In the eventuality of detection of insect (particularly aphids, thrips and white files) vectors (for which yellow sticky traps should be put at least at 3 places in a greenhouse) by competent authority, the grower must provide post harvest test results to this authority. A representative sample of each variety grown in the protected environment must be post harvest tested and if the results are negative for PVA, PVS, PVM, PVY, PVX, PLRV, GBNV and PALCV, the crop will be assigned basic stock status or otherwise rejected.
13. Field standards for foundation crops and certified crop raised out of Potato Tissue Culture Mini Tuber (PTCMT) including aeroponic minitubers shall be same as prescribed for the conventional method (Table 1-3).

Table 5. Standards for PTCMT produced tubers

Weight of mini tuber (Minimum)	1.0 g
Germination/ Sprouting	90.0% (Minimum)
Physical purity	98.0% (Minimum)
Varietal Purity	99.0% (Minimum)
Seed-borne virus	0.01% (Minimum)

Standards of PTCMT at net/polyhouse/aeroponics

General Requirements: Minimum isolation distance of 1 m is to be given between different varieties grown in net/ poly house or greenhouse so as to avoid mechanical mixture.

Specific requirements

General requirements for accreditation of a laboratory for virus testing

i. The laboratory must be adequately equipped for virus diagnostic work. It must have basic equipments like ultracentrifuge, electrophoretic system, PCR machine, ELISA reader etc.
ii. The laboratory must have facilities for growing plants under insect-proof conditions.
iii. The laboratory must have at least two scientists with good training in virology preferably PhD in Virology and experience of working in virus diagnosis.

Labeling of potato-tissue culture minitubers (PTCMT)

PTCMT shall be supplied in sealed containers. A cloth-lined label of 12 cm × 6 cm containing following information shall be affixed on the container.

The container should have printed on it the kind, variety and name of institution.

A. The label shall be rubber stamped with signature, name and designation of the concerned Agency.

Table 6. Label for breeders seed produced through PTCMT

Crop	Potato	Label No.
Variety		
Class of seed	PTCMT	
Lot No.		
Approved laboratory and reference		
Date of test		
Germination/Sprouting (Minimum)	%	
Producing Agency (Name and address)		

Colour of the label shall be diagonally yellow No. 356 (IS 5-1978) and opaline green (IS No.) 275).

B. PTCMT producing agency shall maintain the account of labels printed and issued.

(*Source:* National Certification System for Tissue Culture Raised Plants, Department of Biotechnology, Ministry of Science and Technology, Government of India. Oct. 2006. www.dptmicropgation.nic.in.)

Field inspection procedures

- The crop should be grown in such area and period where the aphid infestation is low and technically suitable for seed production.
- A crop of seed potato shall not be eligible for certification as seed if grown in land infested with wart or cyst forming nematodes, brown rot, non cyst nematodes within previous 3 years of cultivation and common scab.
- A minimum isolation distance of 5 m must be kept between potato varieties grown for seed certification, 15 m between seed and table potato crop to avoid mechanical mixtures and spread of contagious viruses.
- Gaps in seed crop should not be more than 10%.
- A minimum of 4 inspections shall be made to verify the isolation, off type plants, diseases such as mild and severe mosaics, leaf roll, brown rot and other relevant factors specified in the seed standards.
- First inspection should be made at 35 days and 45 days after planting for plains and hills respectively to verify growing condition, extent of disease infestation and off types and to confirm isolation between different varieties.
- Second inspection should be made at 60-65 days after planting for early varieties and 70-75 days for late varieties or at appropriate growth stage depending upon crop duration of the varieties to verify isolation, off types, mild and severe mosaics, mycoplasmal diseases, brown rot and other relevant factors. All the off types and diseased plants must be rogued out along with tubers and destroyed before the crop is submitted for inspection.
- Third inspection shall be made immediately after haulms cutting/destruction to verify that the haulms have been cut/destroyed by the prescribed date and in proper manner. Failure to cut/destroy the haulms by the specified time shall render the crop liable for rejection.
- Fourth inspection shall be made about 10 days after haulms cutting/destruction to verify that no re-growth of the haulms have taken place.
- Details of previous history of the field such as previous crop, field operations carried out, manures and pesticides applied to the crop should be made available to the inspection team.
- The crop should be inspected by taking a minimum count of 100 plants from 4 locations selected randomly in a zig zag manner per ha of the crop. For every additional hectare or part thereof 2 samples of 100 plants should be examined. Observations for each count should be filled in the relevant pro forma and the overall appraisal of these counts inspected shall form the basis of selection or rejection of the seed crop.
- The graded produce should be inspected for size grades and surface borne diseases.

Since, large scale production of Gen. 0 is quite cumbersome on account of stringent measures involved in the maintenance and production of healthy mother stocks, the subsequent field multiplications of such precious planting material is necessity for the generation of required quantities of breeder seed. Keeping in view this, two field multiplications of Gen. 0 material as Gen. 1 (pre-breeder seed) and Gen. 2 (breeder seed) are followed for the production of breeder seed potatoes at ICAR-CPRI.

Planting method and spacing

I. The minitubers produced in net/poly house condition/ aeroponics is Generation-0 (Gen. 0), should be multiplied in Generation-1 (Gen. 1) at a spacing of 30-40 × 10-15 cm depending upon the size of minituber. The produce of Gen. 1 is called as pre-basic seed.

II. The produce of Gen. 1 (pre-basic seed) is further multiplied in generation-II (Gen. 2) at a spacing of 60 cm × 20 cm and the produce of Gen. 2 is called as breeder seed or basic seed.

Field testing of seed crop

In Generation-I (Gen. 1), test randomly selected 300 plants/ha by ELISA.

In Generation-II (Gen. 2) only 150 plants/ha should be tested through ELISA.

Rogue out all the diseased as well as off-type plants observed during field inspection.

General crop husbandry

The general crop husbandry operations for Gen. 1 and 2 under Hi-tech system are the same as for Conventional system of seed potato production. The only difference lies in the field multiplication of mini-tubers under Gen. 1 where on account of small size of mintubers the spacing is to be maintained closer and thus plant populations are higher.

Quality control

Quality control test is done to determine the genetic purity of a given seed lot of released cultivars and the extent to which the given sample confirms to the prescribed standards. The samples for grow out test is to be drawn simultaneously by the seed supplier and the seed recipient by following the standard procedure. In a lot of 100 q, 250 seed potato tubers are drawn by each party along with tag having details of source of seed, variety and lot number. Grow out test is performed by growing the sample seed tubers in the next crop season as per standard package of practices. During this test, observation on germination, morphological characters and incidence of viruses are recorded to ascertain their genetic purity.

For further interaction, please write to:
Dr R K Singh (Principal Scientist & Head), ICAR-Central Potato Research Institute, Shimla 171001, Himachal Pradesh. E-mail: rjan_1971@yahoo.co.in

Salej Sood, Vinay Bhardwaj, Hemant Kardile and Dalamu

Role of *Solanum* wild species in potato improvement

The cultivated potato, *Solanum tuberosum* L. (2n=4x=48) is an important part of people's diet. It belongs to family Solanaceae and genus *Solanum* having nearly 200 tuber bearing species. As per latest estimates, the potato germplasm resource is composed of 107 wild relatives, four landrace cultivated species and modern cultivars. Although most cultivated potatoes are tetraploid, nearly three-fourth of wild species are diploid. Wild potatoes are mostly distributed in Andean highlands, which is the centre of origin of potato. There are abundant reports of disease and pest resistance in wild species of potato.

AMONG the world's ten most important crops, potato has largest number of wild relatives. Genebanks worldwide maintain wild potato relatives along with potato cultivars and genetic stocks. These facilities provide a rich resource for potato breeders and other plant and crop scientists. At present, ICAR-CPRI, Shimla has 762 Andigena accessions and 482 accessions of over 100 wild and semi-cultivated species.Wild species are reservoir of genes which are not available in cultivated potato and are rich source of stress resistance and tuber quality genes.

Wild species in potato improvement

Potato breeders have turned to wild relatives as sources of disease resistance and improved tuber quality. The introgression of a few specific genes from wild species has had a significant impact on cultivar development. An understanding of hybridization barriers and the development of strategies to overcome these barriers have allowed breeders to access the potato germplasm resource. Breeders have focussed on introducing diploid wild germplasm into cultivated potato at the diploid level, with the goal of returning to the tetraploid level for cultivar development. Although recently there is growing interest in diploid breeding and hybrid diploid cultivars. *Solanum tuberosum* Andigenum group has been an important source of genes for cultivated potato improvement. There are many notable examples of cultivated potato improvement through genes contribution from wild species.

Wild species for resistance breeding: The wild species mainly used in resistance breeding include *Solanum acaule, S. chacoense, S. demissum, S. brevicaule, S. stoloniferum* and *S. vernei* mainly as sources of major genes for resistance to late blight, viruses, and potato cyst nematodes. The initial attempts to use wild species were transfer of R1, R2 and R3 late blight resistance genes from *Solanum demissum* in the cultivar Pentland Dell. Later on RB, a dominant resistance gene from *S. bulbocastanum* was incorporated into cultivated potato through cisgenics approach, which provides broad spectrum resistance to late blight. For potato virus Y resistance, Ry_{sto} gene from *S. stoloniferum*, Ry_{adg} from *S. tuberosum* Andigenum group and Ry_{chc} from *S. chacoense* have been introgressed into elite cultivars. Wild species have also played a major role in improving the chipping quality of potato. e.g. *S. chacoense* and *S. tarijense* have contributed to this.

S. chacoense, a wild species is a source of self-incompatibility inhibitor (*Sli*) gene.

Table 1. Wild *Solanum* species as donor of desirable traits

Trait	Source/species
Late blight	*S. demissum, S. verrucosum, S. stoloniferum, S. chacoense, S. berthaultii, S. microdontum, S. vernei, S. bulbocastanum*
Potato Virus Y	*S. stoloniferum, S. chacoense, S. tuberosum subsp. andigena, S. demissum*
Potato Virus X	*S. acaule, S. berthaultii, S. tuberosum subsp. andigena*
Potato Leaf Roll Virus	*S. acaule, S. demissum, S. tuberosum subsp. andigena*
Potato Cyst Nematode	*S. tuberosum subsp. andigena, S. berthaultii, S. vernei*
Heat Tolerance	*S. chacoense, S. commersonii*
Bacterial wilt	*S. chacoense, S. microdontum*
Wart	*S. acaule, S. berthaultii*
Common scab	*S. tuberosum subsp. andigena, S. chacoense*
Aphids	*S. bulbocastanum, S. berthaultii*
Frost	*S. acaule, S. ajanhuiri, S. commersonii, S. vernei*

Wild species for quality improvement: *Solanum phureja* has contributed different tuber colour and flavour traits to modern yellow-fleshed potato cultivars. Lenape, a cultivar developed using genes from *S. chacoense* is in the pedigree of many modern chip cultivars and is credited with contributing to major advances in breeding for chip quality in the late 20th century. Later on, it was removed from the market due to excessive levels of glycoalkaloids in its tubers, likely coming from *S. chacoense*. Many wild species like *S. tarijense* and *S. raphanifolium* have been found to give acceptable chip colour after cold storage.

Wild species as source of self-compatibility: The diploid wild species are self-incompatible due to gametophytic self-incompatibility system. A dominant self-incompatibility inhibitor gene (*Sli*) has been identified in the wild species *S. chacoense*. Wild potatoes can be genetic sources of self-compatible breeding system that can revolutionize potato breeding through development of hybrid potatoes from diploid inbred lines. Besides this, *Solanum phureja* has been used as pollinator for dihaploid induction, which is very important from the view point of diploid hybrid potato breeding.

Wild species in cultivar development in India: A few wild species have been indirectly used in potato breeding in India for introgression of disease resistance genes, which is evident from the pedigree and cytoplasm types in the cultivars. Almost all Indian varieties except few have wild genes for resistance to biotic stresses in them. The most notable wild species used in Indian potato breeding programme are *S. demissum* and Andigenum group species.

The potato germplasm resources are abundant, particularly the wild relatives. The proportion of diversity used in cultivated potato improvement is very small. Although efforts were made earlier and are still on, lack of information on desirable traits in particular species, hybridization barriers as well as sterility problems have limited the use of wild species in potato improvement. The efficient use of potato wild species require better understanding of genetic diversity within a species, high throughput screening, genomics and use of computational tools. Linkage between genomic data and phenotype at the individual level will lead to identification of lines having high value for research and breeding. Although this work requires concerted efforts at the international level, the identified genes or genomic resources will provide long term benefits in future.

For further information, please write to:
Dr Salej Sood (Scientist), ICAR-Central Potato Research Institute, Shimla 171 001, Himachal Pradesh. E-mail: salejplp@gmail.com

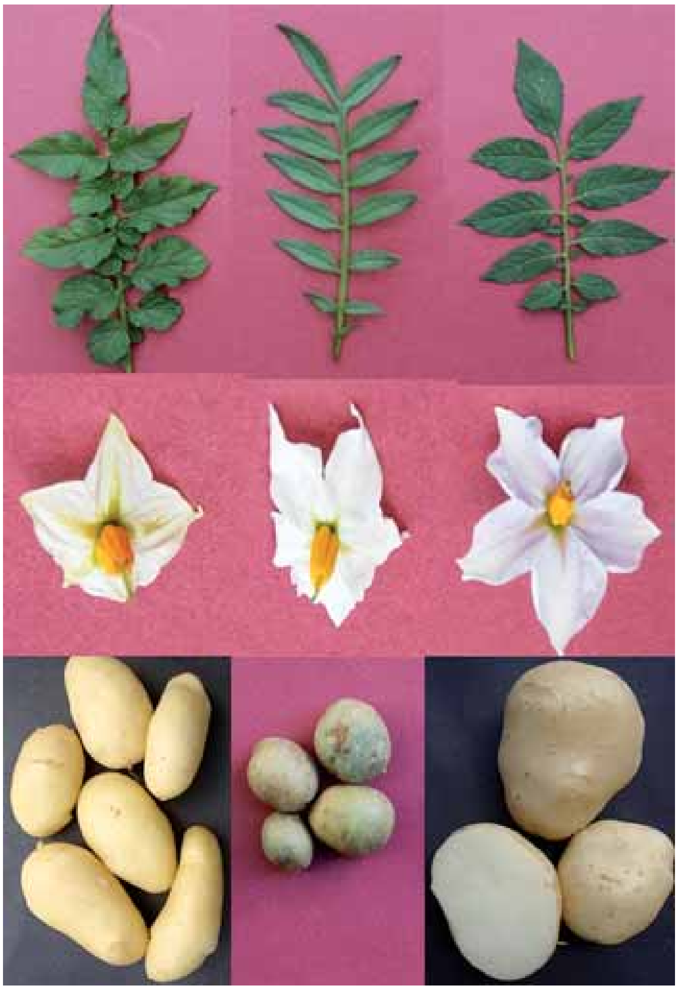
**Jagesh K Tiwari, S K Luthra,
Vinod Kumar, Rasna Zinta, R K Singh
and S K Chakrabarti**

New potato somatic hybrids: *Solanum tuberosum* (+) *S. pinnatisectum*

Scientists of ICAR-Central Potato Research Institute, Shimla, developed new interspecific potato somatic hybrids (*Solanum tuberosum* + *S. pinnatisectum*) by overcoming sexual incompatibility through symmetric protoplast fusion between the cultivated potato (*Solanum tuberosum*) dihaploid 'C-13' and the Mexican wild species *Solanum pinnatisectum* for durable and high resistance to late blight which is the most devastating disease of potato.

THE complex nature of emerging problems especially late blight-the most devastating disease of potato, and the narrow genetic base necessitate applications of modern technologies to address the above issues. To develop tailor-made varieties applying state-of-the-art technologies via harnessing rich genetic diversity available in *Solanum* species is inevitable. Albeit, wild *Solanum* species are not crossable with common potato due to the differences in ploidy number and the endosperm balance number (EBN). Biotechnological approaches like somatic hybridization is a tool to subdue the problems of sexual incompatibility via protoplast fusion for any trait of interest to be transferred from wild species into cultivated potato.

Development of interspecific potato somatic hybrids via symmetric protoplast fusion between cultivated potato *Solanum tuberosum* dihaploid 'C-13' and wild species *Solanum pinnatisectum* for late blight resistance at the institute will certainly be useful in developing potato varieties. The somatic hybrid clone P-7 has been registered with the NBPGR, New Delhi with Registration No. INGR



Somatic hybrid clone P-7 registered with the NBPGR, New Delhi (Registration No. INGR 11051)

Leaf of progeny of somatic hybrid

Salient features of interspecific potato somatic hybrids

- Protoplast fusion products: *Solanum tuberosum* (+) *S. pinnatisectum*
- The non-crossable wild potato species *Solanum pinnatisectum* and the cultivated potato *Solanum tuberosum* dihaploid 'C-13' are sexually incompatible
- Overcome sexual incompatibility by protoplast fusion
- Tetraploid (like common potato) confirmed by flow cytometry
- Very high resistance to late blight disease
- Diverse genetic base
- Nuclear and cytoplasm genes of two *Solanum* species
- Long tuber dormancy
- Male and female fertile
- Crossable with cultivated potato varieties
- Confirmed hybridity by molecular markers and phenotypes

11051 for its elite traits like high resistance to late blight, high pollen fertility and diverse gene pool of two *Solanum*

Progeny of somatic hybrid

Somatic hybrid tubers

species developed by protoplast fusion technique. This would be helpful to the resource poor farmers to save cost of cultivation by growing resistant varieties which would be developed using these lines as parents in breeding programmes.

For further interaction, please write to:
Dr J K Tiwari (Senior Scientist), ICAR-Central Potato Research Institute, Shimla 171 001, Himachal Pradesh. E-mail: jageshtiwari@gmail.com

Gardening provides you . . .

- Feeling of peace and tranquility, reduces stress, and offers a sense of self-esteem and mastery of environment
- Horticultural therapy, which is utilized in psychiatric hospitals, general hospitals, physical rehabilitation centres, homes for elderly, prisons and schools
- This therapy helps the individual to overcome the diagnosed problems or cope with the problem much better while developing relationship with plants and landscaping.
- The patients can achieve higher level of personal development and satisfaction.

Tanuja Buckseth, Rajesh K Singh,
Clarissa Challam, Jagesh K Tiwari,
Ashwani K Sharma and S K Chakrabarti

Apical root cutting: A novel technique for the production of quality seed potato

India is the second largest producer and consumer of potato in the world. In the past five decades, potato production has steadily increased from around 8.3 million tonnes in 1980 to 48.6 million tonnes in 2017, an increase of more than 500 percent. In the past ten years, the production has increased more than 60 percent with both area and yield contributing to the increase. The national average potato yield in 2017 was around 24 tonnes per hectare. However, there are wide variations in yield level within India, ranging from 31.5 tonnes per hectare in Gujarat to 10 tonnes per hectare in Assam. Among different constraining factors for yield growth, the limited availability of quality seed material is considered as the most important factor for lower yield levels in eastern states. The high cost of seed (` 60,000-75,000 per hectare), which accounts for 40-50% of the total cost of production, has been a key deterrent for small farmers to take up production in many of these states.

In India, potato seeds are produced in Punjab using seed plot technique and aeroponic technology and transported up to 2,000 km to potato growing states of eastern and southern India. The high transportation cost is borne by the poor farmers who have to pay high seed prices as well. To make matters worse, the high price does not

Procedure of Apical Rooted Cuttings Production

Healthy microplants

Mother plants in nursery

Apical cutting

Apical rooted cutting ready for transplanting in the field

Series of cuttings in pro-tray

Planting of apical cutting in pro-tray

guarantee high quality, thus making it difficult for small and marginal farmers to invest such a large sum in seed purchases which accounts for nearly half of the total cost of production. The spread of aeroponic technology has been limited to Punjab because of its high capital requirement and long gestation period of nearly four years before any return comes in. If a low-cost technology can be made available to produce seed potato at cheaper price then these eastern and southern states have immense potential to increase potato production by improving productivity and lowering cost of production. Potato Vegetable and Flower Research Centre (PVFC) in Dalat, Vietnam is a leader in apical rooted cuttings for producing mini tubers and seed tubers. Recently, this technology has been standardised at ICAR-Central Potato Research Institute Shimla, India for the very first time. The results were remarkable which suggests that the technology can be used for production of quality planting material at low cost by the local growers. The soil and environment in many parts of the eastern and southern regions are suitable for cultivating potato seed in *rabi* season (October-March) and in some areas like Hassan in Karnataka and Koraput in Odisha, it can be grown in *kharif* season (July-October) also. Specifically, the north eastern states could be potato seed hub supplying seeds to West Bengal, Odisha and Bihar.

Introduction to apical cuttings

Apical cuttings are rooted transplants produced in a glasshouse from tissue culture plantlets. Rather than allowing tissue culture plantlets to mature and produce minitubers, cuttings are produced from the plantlets. Once rooted, the cuttings are transplanted into the field to produce seed tubers. In aeroponic, tissue culture plantlets are used to produce minitubers using capital intensive aeroponic technology in screen houses, whereas in apical cuttings the tissue culture plantlets are used as mother plants in cocopeat for producing cuttings. Apical cuttings are an alternative to minitubers in current production seed systems for potato.

Principle

When the apical bud is removed, the lowered IAA concentration allows the lateral buds to grow and produce new shoots. Once the apical dominance has been lifted from the plant, elongation and lateral growth is promoted and the lateral buds grow into new branches which are further used to increase the multiplication rate.

How it works

The healthy microplants are used as a mother stocks which are planted either in trays or nursery beds. The first round of cuttings can either be used to expand parent material in the first month of production with the remaining months dedicated to commercial production of rooted cuttings or can be directly used for the production of rooted cuttings. Mother plants are used as a stock up to ~3-4 weeks until the first cuttings will be planted in the field. Thus, any new shoots forming after this cut off time will be placed into plugs for transplanting – the commercial product which will continue to be produced over a 1-2 month period. Thus, apical cuttings involve:

i) Production of rooted cuttings (transplants) originating from tissue culture plantlets in the glasshouse.
ii) Production of seed tubers in the field from transplants.

a. Initial tissue culture plantlet ready to remove apical stem to avoid apical dominance; **b.** Multiple shoots development which increases the multiplication rate

Transplanting tissue culture plantlets in the glasshouse

The variety used for the standardization was Kufri Chandramukhi. The initial tissue culture plants were planted in nursery beds or crates at a spacing of 5-15 × 5-15 cm. The spacing depends whether one will collect minitubers from the residual mother plants, and the size of the minitubers to be produced. Fill the bottom of the crate with cocopeat, vermiculite, sterile sand or soil or mixture thereof, depending on what is available, deep enough to plant the tissue culture plantlets that will serve as mother plants. After 10 days depending upon the plant growth, the first apical cutting was taken which was 2-3 cm long with two true leaves. These cuttings were planted in irrigated pro-trays filled with cocopeat. Once the apical dominance was lifted, the lateral buds grow into new branches which were further used to increase the multiplication rate. In 4-5 weeks, 5 cuttings were taken which increased the multiplication rate at 1:7-8 times, respectively. These rooted apical cuttings are ready for transplanting in the field.

Cuttings ready for transplanting/ commercial sale

Cuttings can be transported in the same trays they were produced in. Alternatively, they can be planted in the field. The same package of practices of hi-tech seed potato production can be followed for the minituber production.

Way Forward

Rooted cuttings have the potential to transform potato seed systems. The rapid and high rate of multiplication will significantly contribute to reducing seed potato shortages. Each cutting produces 7 to 10 tubers, and up to 15+, which are multiplied further for a season or two and then the harvest is sold as seed. This is very high-quality seed, equivalent to basic or certified seed in seed certification systems. This means that the seed that farmers buy is extremely high quality and will produce high yielding crops, encouraging seed multipliers and farmers to keep coming back to buy more. The further refinement in this low cost technology is much needed and is under investigation at ICAR-CPRI, Shimla.

For further interaction, please write to:
Dr Tanuja Buckseth (Senior Scientist), ICAR-Central Potato Research Institute, Shimla (Himachal Pradesh) 171 001. E-mail: tanujagbpuat@gmail.com

Bandana, Vineet Sharma,
Brajesh Singh and Manoj Kumar

Processing of potato for domestic and commercial use

Potato is one of the traditional and most used food items in India. Potatoes are versatile for a variety of culinary uses in most Indian households and are used for many purposes throughout the year. Global consumption of potatoes is shifting from fresh potatoes to value-added and processed food products. Processing has the potential to enable potatoes to achieve industrial status. This will not only create more employment but will also improve nutrition and increase the income of potato farmers.

IN THE year 2007-08, about 7% of potato production was used in processing industries. According to industry trends, the demand for potato as a processing will increase rapidly for the next 40 years in which chips, french fries and flakes and powder are estimated at 4.5, 11.6 and 7.6%, respectively. Processing increases the value of potato of the smallholder farmer which leads to better prices and also improves the household income. In addition, processed potatoes have extended shelf life.

To make potato chips, very simple machinery/ equipment is required. Processing not only reduces post-harvest losses, but also benefits farmers after selling finished potato products. Women play an important role in the management of diet along with ensuring the adoption and use of potatoes indoors. On a small scale, women or youth can be employed to sell potato chips in the local market and earn money other than their basic income. It can also provide employment opportunities for rural women. Setting up smaller units of chips, papads, etc. in rural areas and connecting them to urban markets can be one of the options to increase income and employment opportunities for women. By promotion and propagation of potato products and value addition, potato consumption may increase, which will ultimately increase the demand for potato and benefit the farmers.

Classification of processed products

- **Industrial products:** Chips, frozen French fries, flakes, starch, custard powder, soup, potato bhujia etc.
- **Small scale and cottage industry products:** Dehydrated chips, dices, cubes, wadi, papad, vermicilli, cakes, biscuits, naan-khatai, sticks, cuttings, shreds, pickles etc.
- **Fast food outlets and restaurant products:** Aloo tikki, samosa, French fries, idli, vada, aloo masala dosa, aloo parantha etc.
- **Domestic Products:** Potato Pickle, Lachha, Marmalade (murabba), Potato tikki, Potato jam, Potato samosa, Potato lollipop etc.

Potato chips

Classification of processed substances

Processed substances can be mainly classified into three categories

- **Fried:** Potato chips, French fries, aloo lachha, aloo bhujia etc.
- **Dehydrated (dry):** Potato flakes, potato powder, potato shreds, potato custard powder and soup thinner etc.
- **Canned**.

Need for processed potato product

In India, approximately 87% potato is produced in sub-tropical Indo-Gangetic plains where the harvest of crop in February and March is followed by the hot summer months. Potato is semi perishable crop and contains about 80% water and 20% dry matter. Potatoes are stored usually from the month of march for about >5 months. Post harvest losses in potato have been estimated to be 15-20%. More processing not only can tackle the situation like potato glut but can also meet the growing demand for potato products in various ways as given under:

- Value addition may directly promote income.
- Correct use of increasing yields.
- Increased demand for processed products in cities.
- Help working women using ready-to-eat products (RTE).
- Increase in income in addition to selling of raw potato.
- Fulfillment of interest of youth and children towards processed products.
- Easy storage and increased shelf life of processed products

Different Potato Products

Potato chips preparation: Potato chips are mainly used as fried snacks. Potatoes are first washed and peeled. Potato are cut into slices 1-1.8 mm thickness, washed and dried. After drying the moisture from the surface of the slices, the slices are fried at 180°C. The chips are fried until the bubbling stops. Finished product can be stored in nitrogen sealed packets by adding salt or spices as per taste.

Potato French fries: The practice of French fries is highly appreciated by people of all ages and the demand for it is expected to increase continuously in the coming times. In addition to serving French fries fresh, frozen French fry is being increasingly practiced in large hotels and restaurants. Frozen French fries were already practiced in developed countries. With the changing lifestyle and eating pattern, the custom of Frozen French Fries too has reached early in India.

Potato French fries

The thin potato strip is cut into 0.70 × 0.70 cm or 1 × 1 cm in length. After drying moisture from the surface of the strip, it is fried for five minutes at 180°C. Whereas, for making frozen French Fry, strips are fried (one minutes) and keep it in the deep freezer and can be fried for three minutes before serving.

Dehydrated potato products: Potato dehydrated chips, potato pieces, potato granules, flakes, wadi and papad etc. can be kept for long time by making dehydrated potato products. Dehydrated potato chips absorb less oil and finished product will prove to be good for those who are health conscious.

Dehydrated potato chips

Dehydrated chips: To make dehydrated potato chips, the potatoes are cut into 2.0 mm thick slices and put in boiling water for about 15-20 minutes. Potato slices can be dried in sunlight and stored in air tight containers (for about 6 months). Dehydrated potato chips can be prepared domestically and sold at market rate.

Potato flour: Potato flour can be used in various potato products such as cookies, stuffing, etc. Potatoes are peeled and cut into thick pieces and boiled in a pressure cooker, mashed and dried. Potato flour of Indian variety Kufri Chipsona-3 is suitable for making potato flour. Potato flour is rich in quality, good in flavour and tasty compared to potatoes stored in storage. Potato flour can be dried and kept in sealed polythene packing or containers for six months.

Potato flour

Potato flakes: Potato flakes are small pieces of potato which are kneaded immediately after adding warm water. Keeping the busyness of common man and working women in mind, this potato product is becoming very popular now-a-days. Potato parantha, potato tikki, burger, samosa and dosa stuffing with diced potato flakes are being used on large scale. The price of one kilogram of packing of potato flakes is about ` 500. Potato farmers can get maximum benefits by sowing good varieties of potato. Peeled potatoes are cut and washed into pieces about 15 mm thick. The potato pieces are kept in hot water (71–74°C) for 20 min and put in cold water. The slices are then steamed in a screw conveyor steam cooker for 30 minutes. The slices are mashed into the mixer. The mesh is dried in a single drum drier and taken off as a dry sheet, and the flakes are broken and peaked.

Potato flakes

Potato starch: Potato starch is used in paper industry, textile and pharmaceutical companies due to its high capacity and density. It is also used in instant pudding as compared to other cereal starch. To make potato starch, the amount of dry matter in potato should be more than 20% then the recovery of starch is maximum.

Potato starch

Serious issue in India is food security for the growing population and various strategies have been suggested to manage this threat (Chauhan *et al.*, 2016; Rana *et al.*, 2017). In the developed world, potatoes and processed potato products have been a significant food security option. The processing of potato may help in the reduction of post-harvest losses by utilization of surplus production by developing various value-added potato based and commonly consumed food products to meet the growing demand in the country.

For further interaction, please write to:
Dr Bandana (Senior Scientist), ICAR-CPRIC, Modipuram, Meerut - 250 110 (Uttar Pradesh). [2]ICAR-CPRI, Shimla 171 001 (Himachal Pradesh). E-mail: bandana.cpri@yahoo.com

S K Chakrabarti, Brajesh Singh
and Sanjeev Sharma

Export opportunities of Indian potatoes

India contributes around 13% of the total world potato production but our contribution to world potato export is around 1.6% only, which is not even 1% of the total potato production in the country. Potato being semi-perishable and bulky agri-commodity, its export from India was not guided by a long term policy support. As potato is a politically sensitive crop, targeted steps are usually taken to keep its retail price at an affordable level for the domestic consumers. Therefore, potato export was, in general, a crisis management tool during the years of oversupply. On the contrary, in the international markets exports can only be increased through building credibility and making long term contracts.

THE impact of extensive potato research and development in India during last seven decades had been phenomenal in all aspects of potato production. The crop has witnessed 9.19 times increase in area, 31.3 times increase in production and 3.4 times increase in productivity during 1949-50 to 2016-17. The area, yield and production in 1949-50 was 0.234 million ha, 6.59 t/ha and 1.54 million tonnes, respectively. By the end of XII plan period i.e. 2016-17, the country produced 48.61 million tonnes of potatoes from an area of 2.18 million ha with an average yield of 22.30 t/ha (NHB, 2016-17, final estimate). This production has been estimated to further rise to approximately 52 million tonnes as per the latest NHB report for 2018-19. As a consequence India became the second largest potato producer in the world. On the contrary, recurrent gluts in potato production have become a common event with the increase in potato production in the country. The prices crash drastically during harvesting months leading to panic sale by the farmers, thereby, incurring huge monetary losses. Lack of proper marketing channels, insufficient/ expensive cold storage facilities and low domestic utilization are some of the factors that precipitate glut situation. Moreover, the potential for exporting seed, table potatoes and processed products has hardly been explored in India. In true sense our country is not yet prepared to absorb excess potato production. Issues related to promotion of utilization, storage, marketing, processing and export need urgent attention for easing recurrence of gluts in potato production.

Recently, the Department of Commerce under Ministry of Commerce and Industry, Government of India, has formulated the Agriculture Export Policy with the objectives of: (i) doubling agricultural exports from present ~US$ 30+ Billion to ~US$ 60+ Billion by 2022 and reaching US$ 100 Billion in the next few years thereafter, with a stable trade policy regime, (ii) diversifying our export basket, destinations and boosting high value and value added agricultural exports including focus on perishables, (iii) promoting novel, indigenous, organic, ethnic, traditional and non-traditional agri products exports, (iv) providing an institutional mechanism for pursuing

Crop

Graded tubers

Packaging

Heap storage

market access, tackling barriers and deal with sanitary and phytosanitary issues, (v) striving to double India's share in world agri exports by integrating with global value chain at the earliest, and (vi) enabling farmers to get benefit of export opportunities in overseas market. Potato has been identified as a potential commodity for export in the "Agriculture Export Policy" and the following states with cluster of districts have been identified for export promotion.

State	Districts
Uttar Pradesh	Agra, Farukkabad
Punjab	Jalandhar, Hoshiarpur, Kapurthala, Navashehar
Gujarat	Banaskantha, SabarKantha
Madhya Pradesh	Indore, Gwalior

The clusters have been identified based on the existing production contributing to exports, exporters operations, scalability of operations, size of export market / India's share, awareness about SPS requirements, and potential for increase in export in short term. The list of clusters is tentative and can be expanded, provided the conditions for formation of cluster are met. The State Governments should evolve and put in place institutional mechanism for effective involvement and engagement of small and medium farmers for entire value chain as group enterprise(s) within cluster of villages at the block level. Exporting horticultural products requires significant volumes of high quality produce of the same variety with standard parameters matching import demands. Small landholding pattern and low farmer awareness in India has often meant limited volumes of different varieties of multiple crops with little or no standardization. Export oriented cluster development across states will be key to ensuring surplus produce with standard physical and quality parameters which meet export demands. The success of such a scheme will depend on State Government infrastructure. It is, therefore, critical that the Government of India encourage and incentivize the State Governments by strengthening State infrastructure to (i) identify suitable production clusters, (ii) conduct farmer registrations, (iii) digitization of land records, and (iv) promote Farmer Producer Organizations (FPO). ICAR-Central Potato Research Institute being the premier Research and Development organization on potato is facilitating the state governments in identification of potato export clusters. Keeping the overall requirement of promoting potato export and the level of preparedness of the country for the same we recently undertook an exercise to analyse the strength, weakness, opportunity, and threats for activity and the same is briefly presented below.

Diffused light store

Strengths

Diverse agro-climatic conditions and seasonal advantage: About 90% of the Indian potatoes are produced in winters, when no fresh potatoes are available in northern hemisphere. Besides, due to diverse agro-climatic conditions available at different places, India can produce potatoes for all purposes throughout the year.

Strong R&D infrastructure support: Potato research and development is backed by ICAR-CPRI and team of regional level scientists through AICRP network, who can be used effectively for the betterment of the potato industry.

Strong seed production programme: The country has a well-established national seed production programme for producing disease free seed of potato varieties. Besides,

Bags

Chips

Hi-tech seed production and Aeroponics have further added to this advantage.

Surplus production: Due to development of improved varieties and technologies, the potato production is touching 52 million tonnes in the country and this huge production is not readily absorbed in the country. The surplus can be easily exported at low prices.

Ease of organic production: Still being a developing country, use of chemicals at several regions especially hilly areas, is minimal. This can serve as a strength for organic potato production in several pockets of the country, which may capture the organic market of the globe.

Weaknesses

Inadequate and unreliable certification system: The existent seed quality monitoring and certification system is grossly inadequate to cater to the international requirement of either seed potato or table potato. There is a need to restructure and strengthen the system as a backup for encouraging potato export.

Insufficient Infrastructure: Infrastructure support for reduced cost of transportation to ports, cold chain facility, modern handling, grading, packaging line, modern transportation racks etc. are quite insufficient for promoting the potato exports in the country.

Lack of warehousing facilities near ports: There is lack of warehousing/ cold storage facilities on exporting ports and being semi-perishable commodity, there are chances of losing potatoes at our ports itself.

No brand value of Indian potatoes: Since very low volume of Indian potatoes are being exported, it has not been able to create a brand in world trade.

Opportunities

Private participation in quality seed production: Several private agencies are now producing quality potato seed using Indian varieties. This may result in production of potatoes meeting export norms for table as well as processing potatoes.

Growing processing sector: Out of the total potato production, about 8% is being utilized for processing in India. Since demand for processed potatoes is increasing faster than the fresh potatoes, there are opportunities for exporting frozen and processed products.

Emergence of contract farming: With the popularization of contract farming, exporters can have the desired material as per their requirement exploiting the contract farming approach.

Demand of fresh potatoes in northern hemisphere: When 90% of the fresh harvest is done during winters in the country, there is shortage of fresh potatoes in the Eastern Europe, North Africa and Middle East. This may serve as an opportunity for export of raw fresh potatoes to these zones.

Growing demand for organic produce: Worldover, there is increasing demand for organically produced food including potatoes and India has the capability for producing organic potatoes, which can be exported in this sector.

Popularity of Indian varieties in specific countries: Some of the Indian varieties are in demand in Afghanistan, Nepal, Bhutan, Bangladesh, Sri Lanka, Philippines, Madagascar, Mauritius, Bolivia and Vietnam. Such varieties may be promoted for exporting to these countries.

Threats

Climate change: Mostly potatoes are grown in sub-tropical climates in the country, with the expected change in climate particularly increase in temperature, potato production is expected to hamper badly. This may not result in availability of surplus potatoes for export.

Worsening natural resources: Industrialization and real state growth is depleting the natural resources in form of cultivable land and water. With further development in these sectors, there will be shortage of farm area and irrigation water for raising potato crop.

High post-harvest losses: At present, post-harvest losses to the tune of about 16% are faced in potato crop due to high moisture varieties and poor infrastructure for handling, transportation and storage. This may further aggravate on exporting potatoes to long distances.

Indiscriminate use of chemicals: There is no check on the use of chemicals for disease and pest management, resulting in excessive use of pesticides and other agricultural chemicals while raising potato crop. Due to stringent quarantine requirements of the importing countries, the potato exports may not be acceptable by them.

Aggressive trade policies of other exporters: In the present era of globalized economy, all countries are linked with each other and the world market is becoming highly competitive and trade regulations are becoming stringent. Our global competitiveness in terms of quality and cost of produce is still not well calculated and some of the other countries are aggressive in promoting their agricultural exports.

Based on the above analysis some relevant issues have been highlighted below which may encourage export of potatoes from the country.

Policy issues

- A single window system for potato export should be developed, where stakeholder can get all information related to potato. Constitution of *Potato Export Promotion Council* may solve the problem.
- Export incentives should be designed in consultation with the established potato exporters.
- Potato varieties with export value, even if not of Indian origin and available in public domain, may be registered and allowed in seed chain.
- Seed producing areas in Punjab, western Uttar Pradesh, Madhya Pradesh, Rajasthan should be given special/ industrial status for export purpose.
  National certification system for seed potato produced using tissue culture raised plants/minitubers as basic material should be formalized immediately.

Infrastructure

- There is need to establish a link between producers, cold store owners, processing industry, exporters and departments of state/central governments to promote export of potato from India. For this purpose a platform like "*PotatoNet*" may be created for the benefit of potato farmers and other stakeholders.
- In India, most of potato exports take place from western coast. However, due to difficulty in getting shipping space from this coast, we should exploit the potential of east coast which is highly convenient for exporting potatoes to Sri Lanka and South East Asian countries like Malaysia, Vietnam, Thailand, Singapore etc.
- Warehousing/cold storage facilities should be established on important exporting ports, so that potatoes can be transported after harvest from designated potato producing areas to port for storage and further shipping as per requirement of importing countries.
- Use of modern handling, grading, packaging line for high grade export quality potato should be encouraged giving policy support (may be from NHB).
- Storage boxes or imported modern racks are needed for long distance transport from states like Punjab (subsidy from NHB).
- Linkage in domestic inter-state markets needs to be strengthened to enhance domestic consumption.

Sanitary and phytosanitary issue

- Phyto-sanitary certification process should be revamped to include requirements of more countries and to make the process quicker and effective.
- Area free from quarantine diseases (particularly brown rot) needs to be identified and maintained for export purpose.

R&D issue

- Easy detection of quarantine diseases need to be developed scientifically as X-ray is being used for detection of spongy tissues in mango. Validation of X-ray facility for detection of brown rot should be taken up on urgent basis.
- Training on storage and packaging aspects may be arranged for stakeholders.

General issues

- India has huge surplus of potatoes, however, meagre quantity (0.7%) is exported. Therefore, ways and means for exporting table potatoes, seed potatoes and processed potato products to the potential importing countries needs to be worked out and a moderate export target (may be 5% of production) may be fixed for next five years.
- Regular and a minimum fixed quantum of export of potatoes to established markets needs to be maintained in steady manner to become a credential player in global export market. For that country should start long term potato export contacts and meet export obligations religiously.
- The requirements of destination countries should be taken into account for export of table, seed and processed potatoes. It may be listed and made available to exporters and producers.
- Varietal catalogue with detailed information on the pattern of foreign countries may be published.
- Potato Export group may be created on WhatsApp to create prompt link between the stakeholders. The group should meet regularly, i.e. at least thrice in a year to monitor the progress of activities related to potato export.

India has the natural advantage of exporting fresh table potatoes from January to June when supply from European countries dwindles. It can also supply fresh potatoes round the year because India has diverse agro-climates and potato is grown throughout the year in one or the other part of the country. Potato has a good future in India under the changed scenario of global economy. Globalisation has resulted in many developing countries becoming much more integrated into the international potato trade. With the phasing out of quantitative restrictions on agricultural commodities, the import and export of potato would be based on the differences in price and production cost between the importing and exporting countries involved. Due to low production cost in the country as a result of the availability of cheap labour, India will have competitive advantage in the international potato trade. By adopting some of the major recommendations on policy change and Infrastructural development, a boon in potato export might be realised in coming times.

For further interaction, please write to:
Dr S K Chakrabarti (Director), ICAR-Central Potato Research Institute, Shimla 171 001, Himachal Pradesh, India. E-mail: director.cpri@icar.gov.in

V K Dua, Paresh Chaukhande, Jagdev Sharma and Pooja Mankar

Impact of climate change on potato cultivation: A global perspective

Potato is the third most important food crop in terms of production, and it has invaluable significance for the diets and livelihoods of millions of people worldwide. Food and agriculture organization (FAO) has declared potato as a wholesome food. International Food Policy Research Institute (IFPRI) reported that major food source in the world (wheat, rice, corn, and potatoes) will steadily decrease up to 2050. Climate change has effected potato production globally. Future potato yields are likely to be affected by anthropogenic climate change as well as direct effects of emissions such as carbon dioxide (CO_2) fertilization. Hence, it becomes imperative to study climate change impacts on potato with adaptive strategies and intervention to curtail impact for next generations as well as to feed a burgeoning world population.

EFFECTS of climate change in the agriculture sector are distributed unevenly across the globe. This sector is contributing to climate change not only by anthropogenic emissions of greenhouse gases but also by conversion of non-agricultural land mainly forests into agricultural land. According to the Intergovernmental Panel on Climate Change (IPCC), Working Group III report, agriculture, forestry, and land-use changes contributed to 25% of global annual emissions.

Potato is a valuable food commodity from the nutritional and economic perspective that feeds more than a billion people worldwide. The leading continents in potato production are Asia (42.5%) and Europe (38.8%) which are dominating the world potato markets. Potato is well suited to cold climate. It is widely cultivated in temperate, subtropical, and cool tropical regions, as monocrop, in crop rotation or multiple cropping systems. In subtropical climate, potato is well adjusted in a range of cropping systems. In temperate zones, cold temperatures confine potato production to one growing season per year as a monoculture. In northern Europe and North America, potato production is generally carried out with intensive farming practices such as high rates of fertilization, pesticide use, and necessary irrigation. In some areas of the Peruvian highlands, the temperature during February drop down to –30°C, causing significant yield losses while in some regions, drought hampers potato yield. The past projections and historical trends estimated that growth rates in potato production in developing countries for the period 1993–2020 are between 2.02–2.71%. The potato production will be directly affected by climate change, while there would be several indirect effects on various facets of supply, storage, utilization, and acreage of the crop in future climate scenarios.

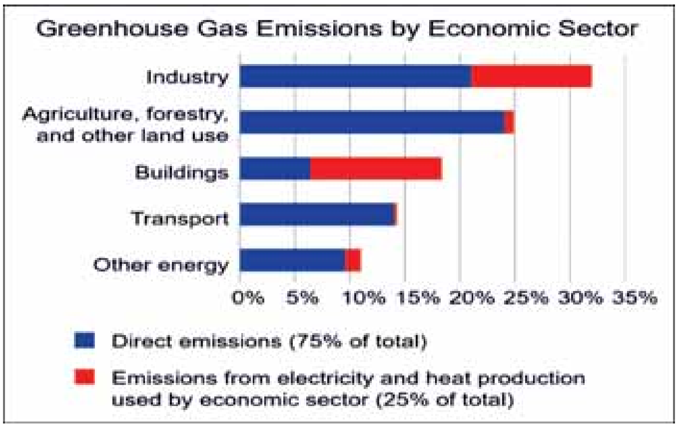
OTC (Open top chamber)

Impact of climate change on potato

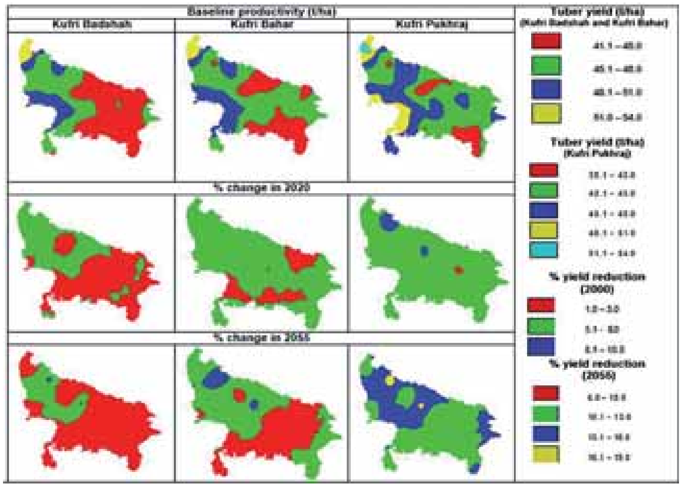
Potato crop cycle is sensitive to changes in temperature and humidity, which ultimately have direct and indirect effects on its productivity. The first notable expression of climate change relates to higher temperatures. Apart from temperature, disease, and pest build-up, under elevated temperature and CO_2 can significantly affect potato production globally.

Rise in temperature

Increase in temperature has most likely adverse effects on potato yield as it affects the growth and development of potato. For several countries (especially in tropics and subtropics) up to 20–30% yield declines are expected. The temperature during night plays a crucial influence on starch deposition in potato tubers. Night temperatures above 22°C severely hamper tuber development. The highest tuber yield of potato is obtained under short-day (12 hr photoperiod) condition at 20°C. The higher temperature throughout the season resulted in a shorter growth cycle in the Netherlands.



Contribution of GHGs by various sectors



A study reported that, due to rise in temperature, 16–22% of all wild potato species are on the verge of extinction by the year 2055. It is an alarming situation, as wild relatives are crucial gene pools for breeding new varieties. Hijmans (2003) predicted that without adaptation, most of the leading potato-producing countries of the world would suffer losses in potential yield. Results (for selected countries) showed that potential potato yield could be severely affected if no adaptation to variation is allowed (19-32%) whereas with adaptation the potential yield decreases (2–24%), but more significant differences between regions exist. Here, adaptation is defined as changes in the month of planting or the maturity class of cultivar. Simulation studies carried out in India indicate that rise in temperature will result in a change in potato productivity in selected parts of Bihar, Madhya Pradesh and West Bengal under future climate scenarios of 2020 over the baseline scenario, whereas some parts of Punjab will get advantage in terms of high potato yield due to temperature rise in 2020.

Higher yields due to higher CO_2 concentration

Effect of elevated CO_2 level in controlled experiments conducted in Open top chambers (OTC), free air carbon enrichment (FACE) and growth chambers suggest a positive effect on growth and yield of potato with only a few negative influences. Increase in tuber yield is estimated to be approximately 10% for every 100 ppm increase in CO_2 concentration. These positive effects are attributed to increased photosynthesis from 10 to 40%. Simulation analysis indicated that CO_2 levels of 700 ppm could increase tuber yield (20-30%) while FACE studies showed an increase in tuber yield by >40% at the rate of 10% per 100 ppm increase in CO_2. In potato, considerable response to rising atmospheric CO_2 is expected due to its large below ground sinks for carbon and efficient phloem loading mechanism. CO_2 concentration and assimilation are positively correlated in potato. Few adverse effects of elevated CO_2 concentration include a reduction in chlorophyll content in leaves, particularly during the later growing season after tuber initiation. Then in the season, leaf photosynthesis is also likely to decrease progressively in the higher CO_2 environment due to senescence. Leaf N concentration is reported to deplete faster in the leaves grown under elevated CO_2 environment, which further supports the conclusion that leaf senescence gets accelerated in the plants grown under high CO_2.

The combined effect of temperature change and increased CO_2 from simulation studies in India shows that, the productivity of potato cultivars will not be affected in 2020 over the baseline scenario, but might decline slightly in 2055 at Punjab, whereas in West Bengal and Bihar, the combined effect of temperature and increased CO_2 shows that potato productivity will decrease to a high level.

Impact of diseases and pests on potato

Many potato growing regions of the world will face an increase in temperature and precipitation which ultimately make warmer and wetter conditions, favourable for late blight (especially in temperate areas). Work in Finland has predicted that for each 1°C warming late blight would occur 4-7 days earlier, and the susceptibility period will be extended by 10-20 days. Late blight is also expected to expand into areas that have previously been relatively safe from this disease. According to an estimate, the yield loss would be 2 t/ha for each 1°C increase in temperature.

Further, fungicide applications (1-4) will be required to manage the disease, thereby increasing both farmer costs and environmental risk. Insects (aphids and whiteflies) are the vector of many viral and mycoplasmal diseases of potato. A 2°C rise in temperature in temperate climate zones could result in one to five additional life cycles of certain insects per season. Increase in temperature (2°C) may result in a shift of certain insects such as aphids, whiteflies, leafhoppers population which can bring an increase in the geographical area in the range of their infestation. Experiences from Peru (Canete Valley) revealed that whiteflies could develop resistance to pesticide and multiply fast at high temperature. The multiplication rate of most of the potato viruses is expected to rise with the increase in temperature. By the end of this century when average temperatures are expected to increase by about 3°C, there is a tremendous possibility of a widening of viral and mycoplasmal diseases. Studies carried out in Holland has revealed that during 12 years (1994-2008), new viral strains (PVYntn, PVYnw) have been detected and similar results also reported in India. Apart from these, heavy rains might lead to outbreaks of late blight disease and pests (armyworms and beetles), which can result in 2.4 to 2.7-fold increase in the use of pesticide by 2050.

Conclusion

Research and development in potato will always look forward to continuous contribution, given its high productivity per unit of land and time and value as both a staple and a cash crop, increasing stress tolerance has a great potential to contribute to food and income security, mitigate poverty and farmer's risk in minimizing vulnerable agricultural environments in the era of global climate change. Sustainable potato production under climate change scenario much depends on successful breeding of new varieties and adaptive crop management strategies. If researchers succeed in breeding more stress (drought, heat, salt, pests, etc.) resistant varieties that produce sufficient yields under climate change conditions (such as rise in temperature and CO_2 concentration and disease and pest outbreak, etc.) then the wholesome potatoes will keep continuing to be grown in many regions in future.

For further interaction, please write to:
Dr V K Dua (Principal Scientist), ICAR-Central Potato Research Institute, Shimla 171001, Himachal Pradesh. E-mail: vkdua65@yahoo.com

Hort Fact Sheet

T. Janakiram

Potato at a Glance


Kufri Bahar

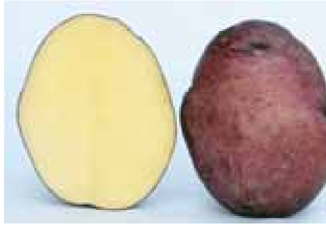

Potato field


Kufri Pukhraj


Padyhouse


Aeroponics


Biotechnology


Kufri Neelkanth

Potato : Potato is the third most important food crop in terms of human consumption after rice and wheat contributing to food and nutritional security in the world.

Botanical name : *Solanum tuberosum* L. (Family: Solanaceae)

Varieties : Zone-specific varieties and crop period of potato production

Zones	Crop Period	Varieties
North-Western hills	Summer (15^{th} April–October)	Kufri Jyoti, K. Himalini, K. Girdhari, K. Kanchan, K. Chandramukhi
North-Western plains	Autumn (1^{st} week October–Feb./March)	Kufri Jyoti, K. Chandramukhi, K. Badshah, K. Pukhraj, K. Surya, K. Khyati
North Central plains (MP)	Autumn (3^{rd} week October–Feb./March)	Kufri Jyoti, K. Chandramukhi, K. Sindhuri, K. Pukhraj, K. Lauvkar, K. Chipsona I , III & IV, K. Surya, K. Lalima
North Central plains (UP)	Autumn (2^{nd} week October–Feb./March)	K. Bahar, K. Sadabahar, K. Anand, K. Surya, K. Chipsona I, III & IV, K. Frysona, K. Gaurav, K. Badshah, K. Garima, K. Mohan
North-Eastern plains	Autumn (4^{th} week October–Feb./March)	K. Jyoti, K. Chandramukhi, K. Kanchan, K. Sindhuri, K. Lalima, K. Arun, K. Ashoka, K. Pukhraj, K. Surya, K. Chipsona I , III & IV


Chipsona


Chips

Propagation and economic part : Tuber (Vegetative)

Climate and soil requirement : Loamy and sandy loam soil, pH: 5.8-6.6, Optimum temperature: 18-22°C (< 20 °C night temp. for tuberization.

Planting : 30-35 g (tuber), 60 x 20 cm^2

Seed production : Conventional and aeroponic system; ICAR-CPRI, Shimla produces 3,000 tonnes of nucleus and breeder seeds annually.

Manure and Fertilizer : 20-25 t/ha FYM, 120-160 kg N/ha, 60-80 kg P/ha, 80-100 kg K/ha

Pest and diseases : Late blight, viruses, common scab, balck scurf, dry rot, soft rot, PCN, aphid, white fly, cut worm, potato tuber moth etc.

Harvesting : 90-100 days after planting.

Yield : 30-40 ton/hectare

Grading : Large (>60 mm or >150 g), Seed size (>30-55 mm or 25-125 g), Small (<30 mm or <25 g).

Seed Treatment : Dip/spray in 3% boric acid for 25-30 min.

Storage : 3-4°C with 85-90% RH (seed); 10-12°C with ≥ 90% RH (table and processing)

Value-added products : Chips, french fry, daliya, halwa, cookies, starch etc.


Kufri Jyoti


French Fries

For further details, please contact or write to:
Drs S K Chakrabarti, Rajesh K Singh, Jagesh K Tiwari, Tanuja Buckseth and **Brajesh Singh**
ICAR-Central Potato Research Institute, Shimla (HP)
Email: director.cpri@icar.gov.in

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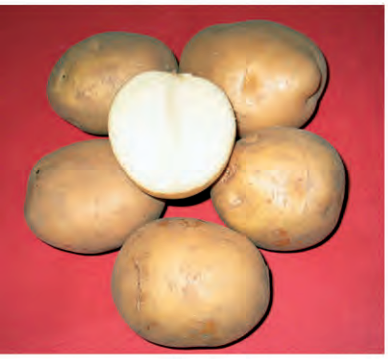
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Kufri Jyoti

French Fries

For further details, please contact or write to:
Drs S K Chakrabarti, Rajesh K Singh, Jagesh K Tiwari, Tanuja Buckseth and **Brajesh Singh**
ICAR-Central Potato Research Institute, Shimla (HP)
Email: director.cpri@icar.gov.in

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HANDBOOK OF HORTICULTURE

VOLUME 1 & 2

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HANDBOOK OF HORTICULTURE

Volume 1 & 2

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