Price : ₹50
www.icar.org.in
ISO 9001:2015 Organization

INDIAN Horticulture

July-August 2026

98th ICAR Foundation Day Special Issue on

Health and Nutrition








HEALTHY FARMS • HEALTHY FOOD • HEALTHY INDIA

SEHAT

Science Excellence for Health through Agricultural Transformation

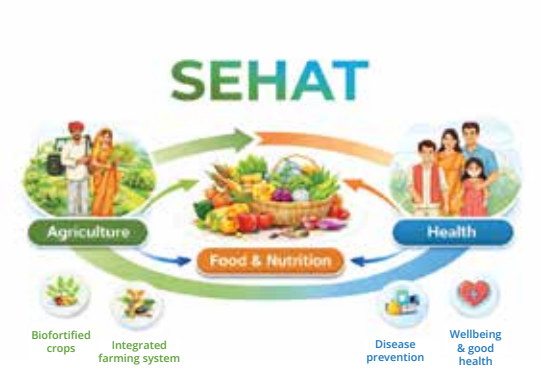
Why SEHAT?

India's farms do more than produce food — they shape the nation's health

- SEHAT is a visionary national mission that brings together Agriculture, Nutrition and Health to build a healthier India.
- Led jointly by the Indian Council of Agricultural Research (ICAR) and the Indian Council of Medical Research (ICMR).
- The mission connects the journey from:

Farm → Food → Nutrition → Health

- The mission promotes scientific solutions that improve dietary quality, strengthen immunity, reduce disease risks and support sustainable livelihoods.



Our Vision

To make agriculture a powerful driver of preventive and promotive healthcare through science-led integration of agriculture, nutrition and health research.

What SEHAT Focuses On

Nutrient-Rich Agriculture
Promoting biofortified crops, healthy livestock and nutrient-rich fish products.

Better Nutrition
Encouraging diverse, safe and balanced diets for all age groups.

Farmer Well-being
Reducing occupational risks and improving safety for agricultural workers.

Healthier Communities
Developing food-based solutions to tackle:

- Malnutrition
- Obesity
- Diabetes
- Hypertension
- Micronutrient deficiencies.

Together, ICAR & ICMR Aim to Build A National Research Ecosystem Linking Agriculture with Human Health

Key Action Areas

Biofortification & Nutri-Foods
Iron-rich, zinc-rich and vitamin-enriched crops for better nutrition.

Integrated Farming Systems
Combining crops, livestock, fisheries and horticulture for healthier households and stable incomes.

Occupational Health & Safety
Promoting safe farming practices, reduced pesticide exposure and climate-resilient agriculture.

Agri-Nutrition for Lifestyle Diseases
Developing functional foods and low-GI products for diabetes and heart health.

One Health Approach
Connecting human, animal and environmental health for stronger disease preparedness.

Expected Impact

SEHAT aims to create a healthier future by:

- Improving nutrition and dietary quality
- Reducing hidden hunger and micronutrient deficiencies
- Supporting prevention of non-communicable diseases
- Strengthening food and nutrition security
- Enhancing farmer health and safety
- Building resilient and sustainable food systems
- Enabling science-based policy decisions.

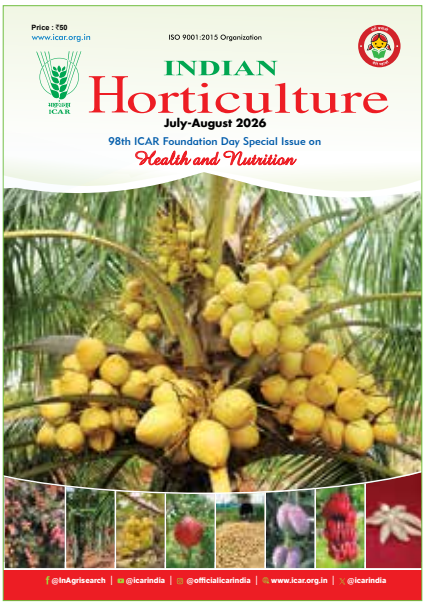
For more information:

Dr Mangi Lal Jat
Secretary, Department of Agricultural Research and Education (DARE) &
Director General, Indian Council of Agricultural Research (ICAR)
dg.icar@nic.in
☎ 011-23382626, 011-23386711
Krishi Bhawan, New Delhi 110001, India

Dr Rajiv Bahl
Secretary, Department of Health Research (DHR) &
Director General, Indian Council of Medical Research (ICMR)
secy-dg@icmr.gov.in ☎ 011-26588204, 011-26588662
V. Ramalingaswami Bhawan, P.O. Box No. 4911,
Ansari Nagar, New Delhi 110029, India

A Joint National Mission of

Indian Council of Agricultural Research (ICAR) &
Indian Council of Medical Research (ICMR)



Cover : Health and Nutrition
Courtesy : Punit Bhasin, ICAR-DKMA

Editorial Contact:
Telephone: 011-2584 2787/606
Fax: 011-2584 2787
E-mail: editor.indianhorticulture@gmail.com

Business, Subscription and Advertisement Contact:
Incharge, Business Unit
Indian Council of Agricultural Research
Krishi Anusandhan Bhavan, Pusa
New Delhi 110012
Telephone: 011-2584 3657
E-mail: businessuniticar@gmail.com

Price :	Single Copy	₹50,	US $30
	Special issue	₹200	
	Annual Subscription		
	1 Year	₹250,	US $60
	3 Years	₹700,	US $150

ISO 9001:2015 Organization

भाकृअनुप
ICAR

INDIAN Horticulture

July-August 2026

Published bimonthly, Vol. 71, No. 4

CONTENTS

From Food Security to Nutritional Wellness

The July–August 2026 issue of Indian Horticulture is a special edition on "**Health and Nutrition**", commemorating the **98th Foundation Day** of the Indian Council of Agricultural Research (ICAR). The issue underscores how India's extraordinary horticultural diversity constitutes a rich repository of biofunctional compounds capable of addressing contemporary nutritional and public health challenges. As the nation progressively shifts from the singular goal of calorie sufficiency to the broader objective of nutritional security and preventive healthcare, horticulture is emerging as a cornerstone of this transformation. In this context, Mission SEHAT (Science Excellence for Health through Agricultural Transformation), a pioneering initiative jointly launched by ICAR and Indian Council of Medical Research (ICMR), forges a vital connection between agriculture, nutrition, and human health. Anchored in the timeless Indian dietary philosophy of *Hitbhuk* (eating what is wholesome), *Mitbhuk* (eating in moderation), and *Ritubhuk* (eating according to the seasons), Indian horticulture is evolving beyond a production-centric enterprise into a strategic instrument for promoting lifelong health and well-being.

This issue explores how several minor and underutilized horticultural crops, including rambutan, avocado, mangosteen, sohiong, and others, are gaining prominence for their exceptional nutritional attributes and their potential to combat hidden hunger while simultaneously enhancing farmers' livelihoods through crop diversification and value addition. It also highlights the therapeutic potential of cultivated fruits as functional foods: pomegranate is renowned for its potent antioxidant and anti-inflammatory phytochemicals, litchi serves as an important source of essential vitamins and micronutrients, while grapes offer a diverse spectrum of health-promoting bioactive compounds. In addition, advances in potato biofortification, climate-resilient dragon fruit cultivation, indigenous superfoods such as *makhana*, and the nutritional promise of edible flowers collectively illustrate how horticultural innovation can strengthen regional food and nutrition security while expanding the diversity of health-enhancing diets.

Realizing the vision of Mission SEHAT demands that agriculture transcend primary production and embrace post-harvest innovation, value addition, and the principles of the circular bioeconomy. Accordingly, this issue presents insights into post-harvest processing of coconut, whole-plant utilization of moringa, advanced probiotic fermentation of fruits and vegetables to improve nutrient bioavailability, and innovative approaches for converting processing residues from major horticultural crops such as banana, citrus, and mango into high-value nutraceuticals and other bioactive products. It further examines the resilience and nutritional significance of tropical tuber crops, demonstrating how sustainable production systems and resource-efficient processing can contribute to future food and health security while fostering a paradigm shift towards food as a vehicle for preventive healthcare.

The pathway to a healthier India lies in diversifying agricultural production through resilient, nutrient-dense indigenous crops, fostering value-added horticultural products, and integrating biodiversity with nutrition-sensitive agriculture. By strategically linking farm-level biodiversity to national health outcomes, Indian horticulture has the potential to redefine the country's food systems and emerge as a powerful catalyst for nutritional well-being, environmental sustainability, and inclusive agricultural prosperity.

AAgrawal

(Anuradha Agrawal)

Sanjay Kumar Singh,
Prakash Chandra Tripathi*,
Vishaw Bandhu Patel and
Sudhakar Pandey

Minor Horticultural Crops for Nutritional Security

Minor horticultural crops play an important role in improving nutritional security, livelihood sustainability and agricultural diversification in India. These crops are rich sources of essential nutrients, vitamins, minerals, fats and bioactive compounds. Nuts are rich in protein and fats while fruits are excellent sources of vitamin C whereas leafy vegetables are rich in iron, calcium and vitamins. These crops help address micronutrient deficiencies such as anaemia, vitamin A deficiency and protein malnutrition, particularly among rural populations. Research and development efforts by ICAR institutes and agricultural universities have led to the identification of improved varieties and production technologies. Several progressive farmers have successfully adopted crops. Minor horticultural crops offer significant potential for enhancing nutritional security, income generation, crop diversification and climate resilience. However, greater research, promotion and market development are required to mainstream these crops and maximise their benefits.

Keywords: Crop diversification; Income generation; Minor horticultural crops; Nutritional security

INDIA has a rich and diverse heritage of biodiversity, encompassing a wide spectrum of habitats, from tropical rainforests to alpine vegetation and from temperate forests to coastal wetlands. Many horticultural crop species have originated in the Indian subcontinent. In addition to native minor horticultural crops like Jackfruit, Bael, Amla, Ber, Khejri, Jamun, Tamarind, Mahua, Phalsa, Lasora, Karonda, Pilu, Bilimbi, Kokum, Gooseberry, Snake gourd, Pointed gourd, Spiny gourd, Chayote, Legumes, Amaranth, Chenopodium, *etc.* , numerous minor horticultural crops such as Rambutan, Mangosteen, Longan, Avocado, Water apple, Hog plum, Macadamia nut, Kiwifruit, Longsat, Durian, Passion fruit, Dragon fruit, Pulasan, Star fruit, Kale, Asparagus, Small cucumber, Cruciferous vegetables, *etc.* were introduced during the last few centuries to India from South America, Africa, Europe and Southeast Asian countries and many of them have now adapted to Indian conditions (Table 1). 'Underutilised minor horticultural crops,' 'future horticultural crops,' 'aspirational horticultural crops' or 'opportunity crops' refers to the crops that may have high value but are not widely cultivated. Most minor horticultural crops are grown in small quantities around homes or collected from forests, but recently, commercial cultivation of some of these crops has also begun. Native minor and exotic horticultural crops have several distinctive characteristics, including ease of cultivation, stress tolerance and resilience to climate change compared to major horticultural crops. Furthermore, these crops are exceptionally rich in many essential nutrients (beneficial phytochemicals) and have medicinal and health-promoting properties. Their consumption can also contribute significantly to meeting the food and nutritional needs of rural populations, which can play a vital role in ensuring food and livelihood security for poor communities. Since ancient times, many such crops have been collected from forests and used in Ayurvedic and indigenous medicines.

Rambutan – *Arka Coorg Arun*

Avocado – *Arka Supreme*

Dragon Fruit (Kamalam)

Table 1. Minor horticultural crops of different agro climatic zones

Agro-climatic zones	Fruit crops	Vegetables	Flowers
Northern Temperate Region	Wood apple, Mahua, Bhotia almond, Sweet pangri, Chiura, Wild apricot, Black hisalu, Yellow hisalu, Blueberry, Kafal, Sea buckthorn, hazelnut *etc.*	Amaranth, Minor leafy vegetables, Gethi, minor cucurbit vegetables, Bathua, Lai saag, Satavari, Ligude, Keruwa, Lotus stem, *etc.*	Rhododendron, Wild lily, Piyoli, *etc.*
North Eastern Hilly Region	Passion fruit, Blood fruit, Burmese grape, Wild pear, Quince, Kachai lemon, Cardamom lemon, Minor citrus species, blood fruit *etc.*	Amaranth, Poi saag, Water spinach, Lai saag, minor leafy vegetables, Yam, Chayote, Lotus stem, *etc.*	Lotus, Orchid, *etc.*
Central Subtropical Region	Bael, Chironji, Khirni, Mahua, Jamun, Kendu, Bael, Karonda, Phalsa, Amla, Toddy palm *etc.*	Amaranth, Poi saag, Lai saag, Water spinach, minor leafy vegetables, Yam, minor cucurbit vegetables, Tree bean, Water chestnut, *etc.*	Lotus, Orchid, *etc.*
North-Eastern Subtropical Region	Mahua, Karonda, Passion fruit, Badhal, Jackfruit, Rose apple, Chalta, *etc.*	Amaranth, Poi, Water spinach, Lai saag, minor leafy vegetables, Aerial yam, Cucumbers, Beans, Kundru, Water chestnut, *etc.*	Lotus, Orchid, *etc.*
North-Western Subtropical Region	Phalsa, Date palm, Ber, Custard apple, Tamarind, Loquat, Lasora, Ker	Amaranth, minor leafy vegetables, Yam, Cucumber, *etc.*	Celosia, Zinnia, *etc.*
Arid and Hot Region	Bael, Chironji, Khirni, Mahua, Jamun, Kendu, Kaith, Custard apple, Karonda, *etc.*	Amaranth, minor leafy vegetables, Aerial yam, cucumber, Basella, Water spinach, legumes, *etc.*	Gomphrena, Portulaca, *etc.*
Semi-arid and hot regions	Bael, Chironji, Khirni, Mahua, Jamun, Kaith, Custard apple, Tamarind, *etc.*	Minor leafy vegetables, mustard greens, *etc.*	Celosia, Zinnia, *etc.*
Mid-tropical region	Mahua, Falsa, Khirni, Custard apple, Amla, Bael, Karonda, Jamun, Kaith, Kamalam, Kedu, Karonda, Tamarind, *etc.*	Amaranth, minor leafy vegetables, Aerial yam, Cucumber, Curry leaves, *etc.*	Gaillardia, Portulaca, *etc.*
Southern tropical climate zone	Custard apple, Amla, Bael, Karonda, Jamun, Kaith, Barbados cherry, Bilimbi, Hog plum, Rose apple, Carambola, Karonda, Suriname cherry, Tamarind, Macadamia nut, Kamalam, Hanuman Phal, Jackfruit, *etc.*	Amaranth, minor leafy vegetables, Aerial yam, Cucumber, Drumstick, *etc.*	Lotus, Orchid, *etc.*
Coastal tropical humid region	Avocado, Rambutan, Mangosteen, Kokum, Passion fruit, Malayan apple, other minor Garcinia, Bilimbi, Breadfruit, Hog plum, Barbados cherry, Rose apple, Carambola, Karonda, Suriname cherry, White sapota, Macadamia nut, Kamalam, Hanuman Phal, Jackfruit, Badhal, *etc.*	Minor leafy vegetables, Yam, Cucumber, Kakrol, Chathail, minor legumes, Drumstick, Curry leaves, *etc.*	Lotus, orchid Heliconia, torch lily, ornamental ginger varieties, *etc.*

Table 2. Key nutrients for human and their deficiencies

Vitamin/mineral/ nutrient	Symptoms of severe deficiency	Issues
Protein-energy	Weak immune system, stunting	Less availability, deficiency more common in vegetarian diet
Vitamin A/pro-vitamin A/ carotenoids	Vision impairment	Bioavailability is low due to interaction with phytates
Vitamin B complex	Neurological disorders, weak immune system	Needs to be consumed frequently as body doesn't build up a store. Vitamin B12 does not occur in plant-based foods
Zinc	Weak immune system, stunting	Bioavailability low from most staple grains; phytate can reduce bioavailability
Iron	Weak immune system, impaired mental development	Bioavailability is low due to interaction with phytates

Nutritional value: The consumption and access to different types of micronutrient-rich fruits and vegetables in adequate quantities is crucial for increasing the nutritional security. The lack of resources for producing and purchasing higher quality foods can sometimes present a barrier to achieving greater dietary diversity, especially in the case of poor populations. With the importance of fruits for dietary quality being increasingly recognized, innovative approaches are being made to increase their production and consumption in poorer regions of the world. Efforts are also underway to help such communities identify, domesticate and cultivate traditional and wild micronutrient-rich foods as a simple and affordable means of satisfying micronutrient needs. The strategy to eradicate these disorders is to promote a general increase in fruit and vegetable consumption and an intelligent diversification of the diet (Table 2).

Although most of the horticultural crops are low in protein but some underutilised fruits and nuts such as Macadamia nut, Chronji, Indian almond, Pine nut, minor legumes are rich sources of protein while Bael (*Aegle marmelos*), Bread fruit (*Artocarpus altilis*), Jack fruit (*Artocarpus heterophyllus*), Gular (*Ficus glomorta*), Phog (*Callgonum polygonoides*) and many root crops, contain

Table 3. Minor horticultural crops with higher nutrient content

Nutrients	Fruit crops	Vegetables	Flowers
Protein	Sea buckthorn, Chironji, Indian almond, Pine nut, Mahua Kernel	Malabar spinach, Pot Casia, Drumstick leaves, Agathi leaves, Kantha leaves, Kantha leave, Thai eggplant, Indian yam, Five leaf yam	Vegetable fern
Carbohydrate	Bael, Mahua, Custard apple, Khirani, Tamarind, Phog, Durian, Egg fruit, Ker ripe, Bread Fruit, Jackfruit, Tedu, Tamarind, Jherberi, Chest nut, Gular	Spiny bitter gourd, Thai eggplant, Indian yam, Five leaf yam, Kakrol	Kachnar flower, Kamal kakri
Fat	Avocado pulp, Mahua seeds, Pilu seeds, Kokum seeds, Chiura, Indian almond, Hazelnut	Himalayan mayflower, Agathi leaves	-
Vitamin A	Eggfruit, Capegooseberry, Khirani, Persimmon, Mahua, Phalsa, Surinam cherry, Barbados gooseberry, Sea buckthorn, Ker, Blood fruit	Basella leaves, Polpala, Pot Casia, Red amaranth, Drumstick leaves, Agathi	Kachnar flower, Sanai Flower, Wild plantain flower, Vegetable fern, Yellow Gulmohar
Vitamin B1	Chironji, Pine nut, Indian almond	Basella leaves, Polpala, Pot Casia, Red amaranth, Drumstick leaves, Agathi	Kachnar flower, Sanai Flower, Wild plantain flower, Vegetable fern
Vitamin B2	Bael, Wood apple pulp, Mahua flower, Chironji seed	Basella leaves, Polpala, Pot Casia, Red amaranth, Drumstick leaves, Agathi	Kachnar flower, Sanai Flower, Wild plantain flower, Vegetable fern
Vitamin B3	Bael, Soursop, Macadamia nut, Passion fruit, Pine nut, Egg fruit, Tamarind, Mahua flower	Basella leaves, Polpala, Pot Casia, Red amaranth, Drumstick leaves, Agathi	Kachnar flower, Sanai Flower, Wild plantain flower, Vegetable fern, Yellow Gulmohar
Vitamin C	Aonla, Sea buckthorn, Barbados cherry, Jaboticaba, Camu-camu	Malabar spinach, Basella leaves, Polpala, Pot Casia, Red amaranth, Agathi leaves, Kantha leaves	Vegetable fern, Banana flower
Calcium	Chironji seed, Ker, Governor's plum, Phalsa, Mahua flower, Indian Almond, Pilu	Malabar spinach, Basella leaves, Polpala, Pot Casia, Red amaranth, Kantha leaves, Agathi leaves, Anantmul, Kakrol	Vegetable fern
Potassium	Durian, Longan, Phalsa, Bael, Soursop, Jackfruit, Macadamia nut	Malabar spinach, Basella leaves, Red amaranth, Drumstick leaves, Agathi leaves, Kantha leaves	Vegetable fern, Yellow Gulmohar, Plantain flower
Zinc	Durian, Mangosteen, Carambola, Wood apple, Jackfruit	Malabar spinach, Red amaranth, Pot cassia, Kantha leaves, Lesua	Vegetable fern
Iron	Chronji, Ker, Gular, Macadamia nut, Mahua flower, Mahua Fruit, Khejri, Pilu, Jherberi	Malabar spinach, Basella leaves, Pot Casia, Red amaranth, Indian yam, Five leaf yam	-
Magnesium	Durian, Longan, Carambola, Barbados cherry	Malabar spinach, Basella leaves, Red amaranth	-

higher amount of carbohydrates. Most of the nuts as well as pulpy fruits such as Avocado, Mahua seeds *etc.* are rich in fats whereas minor legumes, cucurbits and leafy vegetables such as Amaranth, Basella, Agathi, Indian Yam, Drumstick, Thai egg fruits, Spiny bitter gourd, Kakrol, Teasel gourd, Ivy gourd, Tree bean, Parkia bean, *etc.* are rich in vitamins and minerals (Table 3).

Anti-nutrition factors: The minor fruits and vegetable not only contain nutritionally important bio compounds but are also sources of other phyto-compounds which at certain critical levels have significant anti-nutritional effects. These anti-nutrient factors may reduce nutrient bioavailability by binding the nutrient in a form that is not recognised by the uptake systems on the surface of intestinal cells, rendering the nutrient insoluble and thus unavailable for absorption or competing for the same uptake system. These compounds include oxalate, phytate, saponins and nitrate, cyanide *etc.* These antinutrient

Macadamia nut

Mangoteen

Kokum

Longan - *Gandaki Longan-1*

Malabar Tamarind

Custard Apple - *Arka sahan*

compound can be reduced by soaking, boiling and fermentation.

Research and Promotion: Several minor horticultural crops have been identified that have the potential to achieve significant increases in productivity and thus substantially improve national nutritional security at the local and regional levels. The last three decades have witnessed a diversification of research interests in minor horticultural crops. Several important programs have been launched to promote minor horticultural crops for agricultural systems as alternative crops or as sources of new products. Several ICAR institutes and State Agricultural Universities are working on the research and development aspects of these crops. Workshops, field days, seminars, crop fairs and variety shows help in promoting these crops. IIHR, Bengaluru, Central Horticultural Experiment Station, Chettalli, Central Horticultural Experiment Station, Bhubaneswar and Central Horticultural Experiment Station, Godhra have played a significant role in the research and extension of these crops.

ICAR- IIHR, Bengaluru has developed *Arka Sahan* variety of Custard apple; *Arka Ananta* and *Arka Chandra* varieties of Pomelo; *Jamun J-1* of Jamun; *Arka Suguna, Arka Samraksha, Arka Varna* and *Arka Arunima* in Amaranth, Central Horticultural Experiment Station, Chettalli released *Arka Supreme* and *Arka Coorg Ravi* of Avocado, *Arka Coorg Arun* and *Arka Coorg Peetabh* of Rambutan and *CHESM-1* variety of Malayan apple and identified improved accessions of Kokum, Karonda, Tree gooseberry, Hanuman phal and Pomelo. Central Horticultural Experiment Station, Bhubaneswar developed *Arka Bharat* of Teasel gourd, *Arka Neelachal Shanti* of Spine gourd and *Arka Neelachal Kunkhi* of Ivy gourd. ICAR-Central Institute of Arid Horticulture, Bikaner has developed varieties of Bael (*Goma Yashi, Thar Divya, Thar Neelkanth, Thar Srishti*), Jamun (*Goma Priyanka, Thar Kranti*) and Phalsa (*Thar Pragati*), Chironji (*Thar Priya*) and Mahua (*Thar Madhu*), Khejari (*Thar Shobha*), Kachari (*Thar Kasturi*), Matheera (*Thar Manak, Thar Madhur*) and Snapmelon (*Thar Mahak*). ICAR- IIVR, Varanasi has released Amaranth varieties *Kashi Chaulai-1*, *Kashi Suhaavani* and varieties of Basella (poi), Chenopod (bathua), Spinach beet (palak) and Water spinach (karamua sag). BSKVV, Dapoli developed *Konkan amrut* and *Konkan Hatis* varieties of Kokum, *Konkam Bahaduli* of Jamun, several farmers' varieties such as *Siddu*, *Shankara*, *Agrahara* in Jackfruit, *Niranthara* (Round the Year) in Jamun and *Lakshmana* in Tamarind have also been registered. In addition, propagation, production and post-harvest management techniques have also been developed. A large number of plants are being propagated and made available to farmers to facilitate the widespread adoption of these crops. Several private nurseries are also playing a significant role in the multiplication and supply of planting material for these crops. There are many success stories of farmers who have cultivated these crops successfully and earned substantial profits.

Success stories: Several progressive farmers have adopted these crops over the past decade and are reaping substantial profits.

- Mr. Jacob Puttur, from Karnataka, diversified into Rambutan cultivation in an area suitable for Arecanut, Black pepper, Rubber, Banana and other crops. With confidence and strategic management practices, he earned higher prices by selling Rambutan fruits through his own farm outlet. His Rambutan orchard has become a center of attraction for all growers in the region.
- Mr. Renny Jacob, from Kanjirappally, a chartered accountant and plantation owner, replaced Rubber

Spine Gourd - *Arka Neelachal Shanti*

Tissel gourd - *Arka Bharat*

Kundaru - *Arka Neelachal Kunkhi*

Kachri - *Thar Kasturi*

Khejri - *Thar Shobha*

Matheera variety - *Thar Madhur*

trees with Rambutan in 2008 and now harvests 12 tonnes of rambutan annually, with a market value exceeding ₹16 lakhs.

- Mr. Ahmed Kutty, from Kozhikode, Kerala earned good profits by taking interest in Mangosteen cultivation on his land.
- Mr. M K Marlin from Pariyaram village in Chalakudy town, Thrissur, Kerala, engaged in Mangosteen cultivation and marketing. Pariyaram village produces Mangosteen worth more than ₹1 crore every year.
- In Theni district of Tamil Nadu, Mr. R Ramesh, along with his friends, started the Srivaikai Passion Fruit Association. They have cultivated Passion fruit on 150 acres of land in different areas and are exploring market and processing opportunities in Madurai and Chennai.
- Mr. Joseph Louis Kavalam, a retired soldier from Kottayam, Kerala has made his life 'sweet' by cultivating Passion fruit on his 5-acre land. He gets more than 200 kg of fruit daily, which is sold in the market at ₹80/kg (farm gate price).
- Mr. Veerarasu, a progressive farmer from Thandikudi village in Dindigul district of Tamil Nadu, planted 800 Avocado trees in his Coffee plantation in 2002 to provide shade for his coffee plants. He recognised the potential of this crop and is personally promoting it. Now, there are many avocado growers in the Lower Palani Hills of Dindigul district. It is estimated that there are 1.2 million avocado trees there, generating an annual turnover of ₹12–15 crore.
- Mr. Jagadish Giri, a software professional from Bengaluru, planted around 1,000 Dragon fruit plants on his Doddaballapur farm in 2018. Currently, he earns ₹100–150/kilogram of dragon fruit. He sells the fruit in malls and shops in Bengaluru and emphasises that farmers should not depend on a single market, as this makes them vulnerable to market fluctuations.
- Mr. Milind Kulkarni from Deogaon Rangari village of Aurangabad district, Maharashtra has got good dividends and has become an inspiration to many by cultivating Teasel gourd var. *Arka Bharath*. He harvested around 1.5 tonnes of fruits and got income of ₹2,10,000 from 0.17 acre in a span of 6 months.
- Mr. Shankar Murthy, a B.Com. graduate from Kuppalli village, Shivamogga district, Karnataka has started commercial cultivation of Teasel gourd and harvested nearly 3,000 kg and sold at ₹150-200/kg.
- Mr. Venkatesh from Kushal Nagara, Kodagu district having 300 Teasel gourd var. *Arka Bharath* plants obtained 750 kg and realised a gross income of ₹80,000 from 0.25 acre land from teasel gourd cultivation.

The cultivation of minor horticultural crops has yielded good profits for some farmers, but these successes are limited to certain areas. For their widespread adoption and dissemination, integrated management of genetic resources and extensive identification of nutrient-rich germplasm in high-yielding indigenous and minor exotic horticultural crops is necessary. The valuation of minor horticultural crops and nutrient-rich by-products by the food processing industry needs to create new opportunities for their use in functional foods and therapeutic food formulations. The production and trade of minor horticultural crops, exotic fruits and vegetables are gaining global importance. The cultivation of these horticultural crops offers several benefits. Promoting indigenous horticultural species in different agro-climatic and agro-ecological regions will increase the cultivation, value and utilisation of native crops. However, extensive research is needed to bring nutrient-rich crops into the mainstream and maximise nutritional value without compromising sensory appeal.

SUMMARY

Minor horticultural crops are gaining popularity due to their disease tolerance and health benefits. These crops have tremendous potential in crop diversification. Some of them also hold great promise for the pharmaceutical and processing industries. The area under cultivation and the production of these crops is increasing rapidly. There have been several success stories involving these crops over the past decade. Currently, market prices are high and farmers are earning good profits. As more farmers are getting attracted towards these crops, it is expected that more produce will enter the market in the future. Some work has been done on identifying superior genotypes of these crops, but very limited research has been conducted on their production techniques and post-harvest management. More attention needs to be given to these aspects to sustain the profitability of these crops.

For further correspondence, contact:
Dr. Prakash Chandra Tripathi, Principal Scientist, Horticultural Sciences Division, Indian Council of Agricultural Research, Krishi Anusandhan Bhavan-II, Pusa Campus, New Delhi 110 012, India. Email: prakaashtripathii2000@yahoo.co.in

Suresh Kumar P*, Birundha M,
Shiva K N and Pramod Shelake

Nutraceuticals and Circular Bioeconomy from Banana

Banana, one of the world's most consumed fruits, offers immense potential for a circular bioeconomy through innovative value addition. Starch-rich cultivars and export-reject bananas are being transformed into low-fat chips, high resistant starch flour, modified starches provides low glycaemic, ready-to-cook foods and functional instant powders that support food security, improve satiety and promote gut health. Ripe banana powder, puree, non-starch polysaccharides, clarified fortified juices, wine and vinegar add versatility in the banana based products basket. Banana biomass, including leaves, flower, rhizome, peel and pseudo-stem residues, has also been utilized for producing xylitol-based low GI sugar free confectioneries, diabetic-friendly syrups and nutraceutical products. Encapsulation technologies using banana starch have enabled controlled delivery of probiotics and bio-actives such as β-carotene, laminarin and fish oil, enhancing stability and bioavailability for functional foods. Central core stem juice fortified with minerals like iron and vitamins demonstrates the potential of underutilized biomass for nutritionally enriched beverages with entrepreneurship opportunities. Beyond food applications, banana biomass has been converted into hydrogels, bioplastics, intelligent packaging materials, thermoplastic cutlery, fibre composites and biodegradable alternatives. Peel derived pectin, anthocyanin from flower, cellulose from pseudostem, mid rib, dietary fibre from scutcher and rhizome-based products, further support a zero-waste framework, highlighting banana as a sustainable resource for food, nutraceutical, biomedical and eco-friendly industrial applications.

Keywords: Banana; Bio-processing innovations; Functional food; Nutraceuticals

BANANA is one of the most important fruit crops in the world, with an annual global production exceeding 155 million tonnes cultivated across more than 130 countries. It ranks among the top staple and commercial fruit crops due to its year-round availability, affordability and nutritional significance. India is the world's largest producer of banana, contributing nearly 20% of global production with an annual output of about 39 million tonnes from approximately 0.9 million hectares. Beyond internationally traded *Grand Naine*, India houses more than 20 traditional as well commercial banana varieties specific to different states. GI tag has also been obtained for varieties like *Kamalapur Red Banana*, *Matti*, *Virupakshi*, *Sirumalai*, *Nanjangud Rasabale*, *Myndoli banana* and *Chengalikodan Nendran*.

Beyond its economic importance, banana cultivation supports the livelihood of millions of farmers, traders, processors and workers involved in the supply chain. Banana is considered a highly nutritious fruit containing about 20–25% carbohydrates, 2–3% dietary fibre and significant levels of potassium (350–400 mg/100 g), vitamin B_6, vitamin C, magnesium and natural antioxidants. Green bananas contain 40–60% resistant starch on a dry weight basis, making them highly valuable for the development of low glycaemic index and gut-friendly functional foods. Resistant starch acts as a prebiotic, improves colonic health, enhances satiety and helps regulate blood glucose levels, thereby supporting the management of diabetes, obesity and cardiovascular disorders. Banana flowers, peels and pseudo-stems are also rich in fibre, phenolics and bioactive compounds with antioxidant and therapeutic properties.

Banana processing industries convert fresh fruits into chips, puree, flour, powder, beverages, bakery products, pasta, extruded snacks and baby foods. Green banana flour and banana starch have gained major attention as functional ingredients because of their high resistant starch and dietary fibre content. The global functional food market is expanding rapidly and is projected to exceed $500 billion in the coming years, creating significant opportunities for banana-based nutraceuticals and health-oriented products. Banana-derived resistant starch, pectin, dietary fibre and bioactive compounds are increasingly incorporated into diabetic-friendly foods,

synbiotic formulations and nutraceutical supplements. Encapsulation technologies utilizing banana starch have improved the stability and controlled release of probiotics, fish oil, β-carotene and other sensitive bioactives, thereby enhancing their bioavailability and shelf life.

Tertiary processing and circular bioeconomy approaches have further widened the utilization potential of banana biomass. Nearly 60–70% of the banana plant biomass, including pseudo-stems, peels, leaves, rhizomes and flowers, remains underutilized after harvest. These residues are now being converted into pectin, dietary fibre, natural sweeteners such as xylitol, biodegradable packaging materials, starch-based bioplastics, fibre composites and functional beverages. Banana pseudo-stem alone can generate nearly 60–80 tonnes of biomass per hectare, representing a substantial resource for value addition and rural entrepreneurship. The complete valorization of banana biomass demonstrates a sustainable circular bioeconomy model where food, nutrition, functional ingredients, nutraceuticals and eco-friendly biomaterials are produced simultaneously while minimizing waste generation. Such integrated approaches not only improve economic returns and nutritional security but also contribute toward environmental sustainability and sustainable agro-industrial development.

Green banana-based functional foods and nutraceuticals: The simplest and most direct form of banana value addition involves the preparation of low-fat chips, resistant starch-enriched flours, fortified pasta and extruded powders. Banana processing has expanded far beyond traditional products such as chips, dried slices, intermediate moisture foods, leather, pickles and other products. Bananas are increasingly utilized for the production of flour, starch, ready cook foods like pasta, noodles, bakery products, breakfast mixes, instant beverage powders and functional snack foods. Banana flour and starch are gaining importance as functional ingredients because they can improve the nutritional quality of conventional foods while also enhancing texture and stability during processing.

Unripe bananas are particularly valued because they contain high amounts of resistant starch, which behaves similarly to dietary fiber. Foods prepared using unripe banana flour are associated with slower digestion, improved satiety and better blood sugar management. As a result, banana flour is being incorporated into diabetic-friendly foods, gluten free products and weight-management formulations. The functional properties of banana flour are strongly influenced by the stage of maturity and processing methods used. Unripe banana flour generally exhibits higher water absorption, swelling capacity and lower digestibility, making it suitable for health-oriented products. Processing methods such as freeze drying, spray drying, blast freezing, ultrasonication, are being used to improve shelf life, texture and stability while retaining nutritional quality. These techniques also help preserve resistant starch content and improve the suitability of banana ingredients for industrial food applications. A major opportunity in banana value-addition lies in the utilization of rejected and surplus fruits. Large quantities of bananas are discarded during grading and export due to cosmetic defects, bruises or size variations, despite being nutritionally sound. These rejected fruits can be converted into starch, flour and processed food ingredients, thereby reducing postharvest losses and improving resource utilization.

Green processing approaches such as enzymatic treatment, ultrasonication, heat-moisture treatment and retrogradation are gaining attention because they improve starch functionality without relying heavily on chemicals. These methods enhance solubility, cooking stability and resistant starch formation while supporting cleaner and more sustainable processing systems. Such innovations are creating new opportunities for the development of health-promoting foods and nutraceutical ingredients from banana resources. The nutritional significance of banana starch modifications lies in their impact on glycemic response, satiety and gut health. Resistant starch fractions, whether produced through chemical or enzymatic routes, consistently reduce the hydrolysis index and estimated glycemic index of banana starch. Phosphorylated starch demonstrated the highest prebiotic activity score, promoting the growth of probiotics like *Lactobacillus acidophilus* and related strains. Fermentation of these starches in the colon leads to the production of short-chain fatty acids, which contribute to improved colonic health, modulation of lipid metabolism and appetite regulation. These attributes highlight the dual functionality of modified banana starch as both a technological ingredient and a nutraceutical component.

Ripe and over ripe banana for nutri-beverages: In contrast, ripe banana powder contains more natural sugars, making it more suitable for sweet confectionary products such as cakes, cookies, muffins and desserts where flavor and sweetness are important. Foam mat drying transforms ripe banana pulp into stable banana powder using natural foaming agents, preserving important nutrients and probiotic properties. This powder can further be incorporated into biscuits and bakery products to improve dietary fibre content and functional quality. Dehydrated banana slices serve as lightweight, shelf-stable snacks; these serve as instant energy-rich snacks and can be conveniently used by military personnel, trekkers, athletes, travellers and school children due to their lightweight nature, portability and long storage stability. They can also be incorporated into breakfast cereals, bakery products, trail mixes and nutrition bars. Intermediate moisture foods like jam utilises ripe banana pulp to produce naturally sweet spreads with desirable flavour and texture characteristics and offers possibility of synbiotic food formulations. Banana ice cream developed from ripe banana pulp offers a naturally flavoured frozen dessert with enhanced creaminess and nutritional quality, while banana cake provides a soft-textured bakery product enriched with natural sweetness, minerals and dietary fibre. Conversion of ripe bananas into instant powder offers an effective strategy for utilizing surplus fruits and developing stable value-added products. Banana flour processed using twin-screw extrusion technology has improved solubility, dispersibility and rapid reconstitution properties as compared to conventional flour. The developed instant powder are suitable for applications in

beverage mixes, soups, porridges, bakery premixes, infant foods and nutraceutical products. Clarified banana juice prepared through enzymatic treatment helps to remove turbidity and viscosity caused by pectin and starch, resulting in a clear, appealing beverage with improved storage stability. This clarified juice also serves as an important base material for fermented products such as banana wine and vinegar. Functional beverages such as basil seed suspended banana juice combine the mineral-rich properties of banana, creating refreshing health-oriented drinks. Enzymatic clarification and controlled microbial fermentation improve flavour, aroma and storage stability while generating commercially valuable fermented products. Fermentation technologies further expand banana utilization through the production of banana wine and vinegar.

Secondary agriculture and bio-processing innovations

Xylitol: Low sugar alternatives from banana biomass: The global demand for natural sweeteners has accelerated due to rising concerns over obesity, diabetes and the adverse effects of artificial sweeteners such as aspartame and sucralose. Within this context, xylitol, a sugar alcohol with sweetness comparable to sucrose but only 2.4 kcal/g and a glycemic index between 7 and 13, has gained considerable commercial and therapeutic interest. Xylitol is particularly attractive because it provides sweetness similar to sugar while containing fewer calories and produces a much lower impact on blood sugar levels. It is also known for its dental health benefits, as it does not contribute to tooth decay. Banana pseudostem scutcher biomass, a residue generated during banana fiber extraction, is rich in hemicellulose-derived sugars and serves as a promising substrate for xylitol production using naturally occurring yeast strains like *Candida tropicalis* isolated from banana waste. Banana-derived xylitol can be used in sugar-free candies, chewing gums, gummies, syrups and diabetic-friendly food products due to its low glycemic response and pleasant sweetness profile.

Green and ripe bananas as sources of nutraceutical, synbiotic and functional food products

Encapsulation and smart release systems: Another emerging area in banana secondary processing is the development of encapsulation systems for protecting and delivering sensitive nutrients and bioactive compounds. Banana starch is particularly suitable for this purpose because of its film-forming ability and high amylose content. It can act as a natural carrier material that protects functional ingredients from degradation during processing, storage and digestion. Banana starch, when combined with plant proteins such as faba bean protein, can effectively encapsulate compounds like fish oil, antioxidants, probiotics and dietary fibers. Advanced techniques such as ultrasound-assisted encapsulation have improved the stability and retention of these compounds, achieving high encapsulation efficiencies and better protection against oxidation. Such systems help preserve sensitive ingredients and allow their gradual release in the digestive system, improving their nutritional effectiveness. Banana starch based encapsulation systems are also being explored for probiotic and syn-biotic food products. In these formulations, probiotics are delivered together with banana resistant starch, which acts as a prebiotic and supports beneficial gut bacteria. These technologies have been tested in fortified beverages and smoothies, where they improved protein content, antioxidant stability and overall nutritional quality.

Central core stem: Beyond therapeutic for precise delivery systems: Banana central core stem juice is rapidly emerging as a promising functional beverage in the expanding nutraceutical market, which is projected to reach nearly $18 billion by 2028. Although nearly 5–6 tons of banana pseudostem biomass are discarded after harvest, this underutilized material is exceptionally rich in dietary fibre, minerals, antioxidants and bioactive compounds. Traditionally recognized for its refreshing taste, detoxifying nature and kidney health benefits, banana stem juice also possesses antioxidant and anti-inflammatory properties. Remarkably, nearly 20,000 litres of juice can be extracted from one hectare of banana stem, creating entrepreneurship opportunities worth approximately ₹20 lakhs, while even partial utilization of available biomass could support a nutraceutical economy.

To enhance consumer appeal and health benefits, banana stem juice has been developed into several innovative functional products. Zero-calorie sweeteners such as stevia and sucralose have been incorporated to create low-calorie beverages suitable for health-conscious consumers. Flavoured variants enriched with ginger, mint, jamun, guava and grapes further improve taste, colour, antioxidant activity and vitamin content. Advanced encapsulation and smart delivery systems using modified banana starch have enabled the fortification of stem juice with iron and folic acid. The optimized pectin-modified starch encapsulation system achieved excellent encapsulation efficiency and nutrient retention, supporting the development of stable fortified functional beverages. Beyond beverages, banana stem juice has also been utilized in probiotic gummies, jellies and pudding systems containing encapsulated *Lactiplantibacillus plantarum*. Modified banana starches such as hydroxyphosphorylated and oxidized starch improve probiotic survival, texture and storage stability.

Peel-derived biomaterials and functional foods: Banana peel, which accounts for nearly one-third of the total fruit weight, is a valuable byproduct with multiple avenues for valorization. Among these, pectin extraction has received considerable attention due to the peel's relatively high yield. Banana peel powder, rich in dietary fibre has been successfully used as a fortifying ingredient in bakery products such as muffins, where partial substitution of wheat flour enhances dietary fiber, phenolic compounds and antioxidant activity. This dual valorization pathway reinforces the role of banana peel as a versatile biomass stream contributing both to sustainable biomaterial development and to the growing market for healthier, value-added foods.

Other high value products using banana biomass: Banana flowers and rhizomes, which are often discarded after harvest, contain significant levels of phenolics, flavonoids and minerals. These biomasses have been processed into traditional pickles and snacks, which are now entering nutraceutical markets as antioxidant-rich functional foods. These biomasses have the potential of reducing oxidative stress, supporting cardiovascular health and improving lactation. Banana biomasses such as peel, pseudostem, leaves, rachis, rhizome and fruit waste are emerging as promising and economical feedstocks for the production of valuable platform chemicals. Rich in cellulose, hemicellulose, starch, sugars and lignin, these agro-residues can be efficiently converted into high-value bio-based compounds including sorbitol, acetic acid, levulinic acid, furfural, hydroxymethylfurfural (HMF), xylitol, lactic acid, bioethanol, succinic acid and other furfural derivatives through biochemical and thermochemical processes. Since banana cultivation generates enormous quantities of low-cost biomass residues annually, their utilization provides one of the cheapest and most sustainable raw material sources for producing industrially important chemicals and advanced bioproducts.

Other innovative applications: Banana starch and processing residues are increasingly recognized as sustainable biomaterials with applications extending beyond conventional food uses. Modified banana starch, produced through physical, chemical or enzymatic treatments, exhibits improved stability, texture and digestibility, making it suitable for nutraceuticals, functional foods, edible coatings, biodegradable films and eco-friendly packaging systems. Owing to its high amylose content and excellent film-forming properties, banana starch can be blended with polymers such as polyvinyl alcohol or carboxymethyl cellulose to develop bioplastics with enhanced mechanical strength and barrier characteristics. Incorporation of anthocyanins extracted from banana flower bracts further enables the production of intelligent packaging materials capable of detecting food spoilage through *p*H-responsive color changes along with antimicrobial protection against common foodborne pathogens. Simultaneously, cellulose isolated from banana pseudostem has emerged as a valuable resource for biodegradable composites and hydrogel fabrication because of its hydrophilicity, porosity, biocompatibility and favorable tensile properties. These cellulose-based hydrogels support controlled release of bioactive compounds and show potential in wound dressings, oral delivery systems and tissue regeneration scaffolds. Banana

Banana biomass for valorisation and the circular economy

Potential applications of other banana biomass

Material applications from banana biomass

pseudostem fibers and processed banana leaves are also increasingly utilized in biodegradable household products, disposable tableware, packaging materials and lightweight composite structures as environmentally sustainable alternatives to synthetic and petroleum-based materials.

Entrepreneurship and market perspectives: The successful translation of these secondary processing innovations into viable enterprises hinges on techno-economic feasibility, consumer acceptance and regulatory compliance. Banana biomass valorization presents unique entrepreneurial opportunities for farmer-producer organizations, start-ups and SMEs. The establishment of decentralized biorefineries capable of producing xylitol, encapsulated nutraceuticals and fortified juices would not only diversify income streams but also reduce waste disposal burdens. Market demand for natural sweeteners, functional beverages and nutraceutical delivery systems is expanding rapidly, with consumer preference shifting toward clean-label, plant-based and sustainable solutions. Banana-derived products, by virtue of their low glycemic index, bioactive enrichment and eco-friendly origin, are well-positioned to capture this demand. Furthermore, partnerships with the food, pharmaceutical and nutraceutical sectors can facilitate scaling, while intellectual property protection and technology licensing can create additional commercialization pathways. Farmer-producer organizations and small enterprises can establish decentralized biorefineries that handle fruit rejects, peel drying, pseudostem fibre extraction and leaf-based product processing. Such clusters have the potential to diversify rural income streams, create employment for women and youth and foster rural industrialization in a sustainable manner.

SUMMARY

Banana exemplifies the transformation of a staple tropical crop into a model system for advancing nutraceuticals and circular bioeconomy. From resistant starch enriched flours and functional bakery products to peel-derived pectin, pseudostem-based hydrogels, intelligent packaging films and xylitol bioprocessing, every component of the plant demonstrates potential for high-value applications. This zero-waste approach underscores how banana biomass streams can be strategically integrated to enhance nutrition, reduce environmental burdens and generate sustainable livelihood opportunities. The convergence of science and technology has been central to this progress. Advances in starch modification, encapsulation platforms and digital traceability tools illustrate how fundamental research can be translated into tangible innovations. At the same time, entrepreneurship and decentralized biorefineries offer practical pathways for scaling these innovations, ensuring that smallholders, rural enterprises and start-ups become key beneficiaries of the banana-based bioeconomy. Looking ahead, banana provides a replicable blueprint for sustainable agri-food systems: A crop that addresses nutrition security, drives material innovation and supports environmental stewardship. By continuing to integrate multidisciplinary research with entrepreneurship and policy support, banana biomass valorization can evolve into a globally relevant pathway towards healthier diets, greener industries and resilient farming communities.

For further Correspondence, Contact,
Dr. Suresh Kumar P, Division of Crop Production and Post-Harvest Technology, ICAR-National Research Centre for Banana, Tamil Nadu- 620102, India. Email: psureshars@gmail.com

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.

Akath Singh*, Karma Beer, A K Gupta,
N Samarendra Singh and T Damodaran

Circular Bio-economy Approach for Zero-Waste Processing and Value Addition in Mango

Mango, being a climacteric fruit, undergoes rapid physiological and biochemical changes after harvest, leading to accelerated deterioration and significant post-harvest losses. These losses contribute to substantial economic setbacks due to inadequate storage facilities, limited processing infrastructure and inefficiencies across the supply chain. A circular bio-economy approach provides a sustainable pathway for addressing these challenges through zero-waste processing and inclusive mango utilization. By integrating shelf-life extension strategies, value addition and valorization of mango peel, pulp and seed kernel into nutraceuticals and functional products, this approach minimizes waste, enhances resource-use efficiency, increases farmer income, promotes environmental sustainability and strengthens inclusive agri-food systems.

Keywords: Circular bio-economy; Mango; Mango kernel butter; Zero-waste processing

INDIA, the native home of mango, is the world's largest producer, contributing nearly 22.84 million tonnes annually. Despite this substantial production, considerable post-harvest losses occur across the value chain, from harvesting and transportation to storage, processing, and retail distribution. Mango post-harvest losses are estimated at approximately 3.19 million tonnes, representing nearly 14% of total production, with an associated economic loss of around ₹478.5 crore annually. In major mango-producing states such as Uttar Pradesh, which contributes nearly 4.8 million tonnes annually, post-harvest deterioration and inadequate processing infrastructure leads to estimated losses of approximately ₹101 crore. These significant quantitative and economic losses underscore the pressing need for sustainable post-harvest management strategies and resource-efficient utilization of mango produce. A circular

Circular bioeconomy for a sustainable, profitable & climate-resilient mango value chain

bio-economy approach offers a sustainable pathway for transforming mango production systems from a linear 'produce–consume–discard' model into an integrated, zero-waste framework. This approach emphasizes maximizing resource efficiency through shelf-life extension, innovative processing, value addition, and complete utilization of mango components, including pulp, peel, and seed kernel. By-products generated during processing, often considered waste, can be valorized into nutraceuticals, functional ingredients, bioactive compounds, dietary fibre, pectin, seed oil, and natural antioxidants, thereby converting waste into wealth. Such an integrated approach not only minimizes post-harvest and processing losses but also strengthens environmental sustainability, improves nutritional security, enhances industrial opportunities, and increases farmer income through diversified value chains. Ultimately, the adoption of circular bio-economy principles in mango processing can contribute significantly to inclusive growth, sustainable agri-food systems and zero-waste horticulture in India.

Innovative approaches for extended shelf life and export quality: Shelf-life extension technologies are critical for reducing postharvest losses and maintaining the market quality of fresh fruits during storage, transportation, and marketing. Mango, being a climacteric and highly perishable fruit, undergoes rapid ripening, moisture loss, physiological deterioration, and microbial infection after harvest, limiting its marketability, particularly for distant and export markets. Advanced postharvest interventions such as pre-cooling, edible coatings, modified atmosphere packaging (MAP), controlled atmosphere storage, cold chain management, and ethylene regulation have significantly improved fruit storability by slowing respiration, reducing transpiration, delaying ripening, and minimizing spoilage while preserving firmness, flavour, and nutritional quality. Technologies developed at ICAR-Central Institute for Subtropical Horticulture have demonstrated considerable success in extending the storage life of commercially important mango cultivars. Shelf life has been enhanced up to 22 days in *Dashehari*, 20 days in *Langra*, 30 days in *Chausa*, 32 days in *Kesar*, and 40 days in *Banganapalli*, enabling improved market access and long-distance transport. Among these innovations dipping fruits for 7-10 minutes in CISH METWASH, a secondary metabolite–based organic formulation, effectively controls postharvest diseases and regulates ethylene production during transit and storage. As a result, significant extension in mango shelf life can be achieved while maintaining fruit quality and market acceptability. Another significant innovation, CISH-Fruit Wash, addresses black spots and sooty mould problems common in *Chausa* and *Langra* mangoes, particularly in major production belts of Uttar Pradesh. The technology removes nearly 80–85% of surface blemishes and improves visual appeal and export acceptability. Collectively, these interventions reduce postharvest losses, strengthen export competitiveness and improve returns to farmers and supply-chain stakeholders. In addition to these, anti-ripening compounds and ethylene management systems are increasingly used in postharvest handling to regulate fruit ripening. CISH anti ripeners I and CISH anti ripeners II function by controlling ethylene biosynthesis and absorbing excess ethylene gas during storage and transportation. Ethylene absorbents and inhibitors delay senescence, maintain fruit firmness, preserve physicochemical quality and extend storage life. Such technologies are highly beneficial during domestic supply chains where fruits are exposed to extended transit durations and variable environmental conditions. Overall, shelf-life extension technologies are essential tools for reducing postharvest losses, improving fruit quality, enhancing export competitiveness and strengthening the economy.

Integrated mango processing for value realization: Mango processing plays a central role in the circular bio-economy framework by enabling efficient utilization of seasonal produce, reducing post-harvest losses, and creating diversified market opportunities. Given the highly perishable nature of mango and its seasonal glut during peak harvest, integrated processing approaches provide an effective pathway for converting fresh fruits into stable, marketable, and high-value products. Such approaches not only enhance product availability beyond the harvesting season but also facilitate value realization through diversified processed products. Integration of modern processing technologies has facilitated the development of shelf-stable, nutritious, and export-oriented products, while utilization of processing residues further supports waste minimization and resource valorization under a circular bio-economy approach.

Primary processing

Mango Pulp: Mango pulp processing is one of the most important value-addition strategies for efficient utilization of surplus and seasonal mango produce. Fully

Premium grade mango post-harvest packaging

Sweetened dashehari mango pulp designed for bakery applications

Freeze dried mango pulp powder and dehydrated cubes

mature and ripe fruits are selected, washed, graded, and peeled before estining and pulping. The extracted pulp is refined to remove fibres and impurities, followed by pasteurization to ensure microbial safety and extended shelf life. Processed pulp is packed aseptically for year-round use. Mango pulp serves as a key raw material for secondary products like juices, nectars, beverages, jams, fruit bars, dairy products, confectioneries and export-oriented processed foods, thereby enhancing value realization and reducing post-harvest losses.

Mango pulp powder and cubes: Mango pulp powder is a high-value product developed through low-temperature dehydration that preserves the fruit's natural colour, flavour, aroma, nutrients and bioactive compounds. In this process, mango pulp is frozen and moisture is removed through sublimation under vacuum, minimizing thermal degradation and maintaining product quality using freeze driers. The resulting powder possesses excellent solubility, extended shelf life and high retention of nutrients and flavour compounds. Freeze-dried mango powder can be used in beverages, bakery products, dairy formulations, confectionery, infant foods, nutraceuticals and instant mixes, offering significant opportunities for product diversification and export-oriented value addition.

Secondary processing

Value added products from pulp: Mango pulp serves as an important raw material for manufacturing a wide range of processed foods, including ready-to-serve (RTS) beverages, fruit bars, dehydrated products, and functional snacks. Mango RTS beverages are prepared by blending mango pulp with sugar syrup, citric acid, and water, followed by pasteurization and hygienic bottling to ensure product safety and stability. These beverages are widely accepted due to their refreshing taste, nutritional value, and storage stability of up to six months.

Mango-based nutri bars and fruit bars represent another promising avenue for value addition, offering convenient, ready-to-eat products rich in carbohydrates, dietary fibre, vitamins, and antioxidants. Blended formulations such as mango-jamun fruit bars further enhance nutritional quality through higher vitamin C and antioxidant content, making them attractive to children and health-conscious consumers. In addition, advanced dehydration technologies, including freeze drying, vacuum drying and osmotic dehydration, have enabled the production of premium products such as dried mango slices, mango chips, dehydrated cubes and freeze-dried snacks. Freeze drying, in particular, retains natural colour, flavour, aroma, and nutrients, thereby increasing product quality, shelf life, and suitability for premium and export markets.

High-value products from premature dropped mango fruits: Prematurely dropped fruits of Mango, which are usually unripe and considered waste, can be efficiently utilized to produce several high-value products due to their rich content of organic acids, starch, pectin and bioactive compounds. Instead of being discarded, these immature mangoes can be processed into a variety of food, industrial and nutraceutical products. One of the most common uses is the preparation of pickles and chutneys, as unripe mangoes have a sour taste and firm texture that are ideal for traditional food products. They are also widely used for making amchur (dried mango powder), which serves as a natural souring agent in culinary applications. Unripe mangoes can also be processed into beverages such as panna, a refreshing drink known for its cooling properties and high vitamin content. Due to their high starch content, these fruits can be utilized for starch extraction, which has applications in food processing and textile industries. Furthermore, they contain significant amounts of phenolic compounds and antioxidants, which can be extracted for use in nutraceuticals and functional foods. In addition, premature mango fruits can be used for vinegar and fermentation products, where their natural sugars and acids support microbial fermentation. Thus, the utilization of prematurely dropped mango fruits not only helps in reducing agricultural waste but also creates

Value-added products from dropped mango

Various value-added mango products

Mangiferin extracted from mango leaves

opportunities for value addition, income generation and sustainable resource management.

Leaf-derived mangiferin for nutraceutical enhancement: Mango orchards generate a substantial quantity of pruning residues and biomass during annual canopy management and orchard maintenance practices. However, mango leaves are rich sources of several bioactive compounds including mangiferin, polyphenols, flavonoids and other phytochemicals possessing strong antioxidant, antimicrobial, and anti-inflammatory properties. Mango leaf biomass can serve as an important raw material for the extraction of mangiferin, a naturally occurring xanthonoid compound well known for its antioxidant, antimicrobial, anti-inflammatory, antidiabetic and therapeutic properties. Sustainable utilization of mango pruning residues through mangiferin extraction offers an efficient approach for converting low-value orchard waste into high-value bioactive ingredients. Such utilization supports the principles of circular bioeconomy

Mangiferin-enriched bael and guava squash

by promoting resource efficiency, waste minimization, and value addition to agricultural biomass. To improve stability, bioavailability, and incorporation into food systems, mangiferin can be effectively microencapsulated using suitable encapsulating agents under controlled processing conditions. Microencapsulation protects the sensitive bioactive compound from degradation caused by environmental factors such as light, oxygen, temperature and moisture while enhancing its controlled release and functional efficiency in food applications.

Using this approach, mangiferin-enriched functional squash has been developed utilizing Guava and Bael fruit pulp as the base material. Microencapsulated mangiferin extracted from mango leaves was incorporated into the squash formulation to enhance its nutraceutical and antioxidant properties. The incorporation of mangiferin significantly improved the functional quality of the beverage by increasing its bioactive content and potential health-promoting benefits. Such circular economy approaches contribute towards sustainable horticulture, biomass valorization, waste reduction and development of eco-friendly agri-food systems.

Valorization of mango by-products

Mango processing generates large amounts of by-products such as peel, seed kernel, and stone, which can be converted into useful, high-value products instead of being wasted. Extraction of value-added products from mango by-products is an important aspect of food processing and waste utilization, particularly in a major mango-producing country like India. During the processing of Mango, a significant portion of the fruit, nearly 35–45% is discarded as waste in the form of peel and seed. These by-products, however, are rich in valuable compounds and can be converted into economically useful products. Mango peel, which constitutes about 15–20% of the fruit, is a rich source of pectin, dietary fiber, antioxidants, and natural pigments. Pectin extracted from mango peel is widely used as a gelling agent in the preparation of jams and jellies. The extraction process generally involves drying the peel, grinding it into powder, followed by acid extraction, filtration, and precipitation. Additionally, mango peel can be processed into dietary fiber powder, which is used in bakery products and health supplements due to its high nutritional value. The presence of bioactive compounds like carotenoids and polyphenols also makes it suitable for the extraction of natural colorants and antioxidants, which are useful in food and cosmetic industries. Various extraction techniques are employed to obtain these value-added products, including drying to reduce moisture content, solvent extraction for oils and bioactive compounds, steam distillation for essential oils, acid extraction for pectin, and mechanical pressing for oil recovery. The utilization of mango by-products not only helps in reducing environmental pollution caused by agro-waste but also provides additional income opportunities for farmers and entrepreneurs.

Table. Value addition of mango waste

Waste portion	Waste (%)	Nature of waste	Value added products
Mango peels	12-15	Peel and pulp	Pectin, Alcohol, Cattle feed, Compost
Mango pulper waste	5-10	Fibre	Wine, Vinegar, Juice
Mango Kernels	15-20	Hull & Kernel	Fat, Tannins, Starch

Extraction of butter from mango kernel: The mango seed, constituting approximately 20–25% of the fruit, contains a nutritionally and industrially valuable kernel. This kernel can be processed to extract mango kernel oil, commonly referred to as mango butter, which exhibits physicochemical properties comparable to cocoa

Mango butter

butter. Owing to its excellent emollient and stability characteristics, mango butter is extensively utilized in confectionery applications as well as in cosmetic formulations, including soaps, creams, and lotions. In addition to oil extraction, the kernel can be dried and milled into flour, serving as a gluten-free ingredient for various food products and as a supplementary component in animal feed. The kernel is also a potential source of starch, which can be isolated and employed as a thickening and binding agent in both food and textile industries. Furthermore, mango seed kernels contain appreciable amounts of tannins, which find applications in leather processing and certain pharmaceutical formulations.

Mango kernel butter can be efficiently extracted using the solvent extraction method with a Soxhlet apparatus. Standardized extraction conditions indicate that an optimum temperature of approximately 65°C yields high-quality butter. For a 20 g kernel sample, a minimum solvent volume of about 230 ml and extraction duration of 4 hours were found to be adequate. Under these conditions, the recovery of mango kernel butter was approximately 12%. The extracted butter also demonstrated significant bioactive potential, with total phenolic content measured at 135.6 mg/100 ml, indicating its antioxidant value and suitability for functional applications.

Compost, animal feed and bioenergy from mango processing waste: Following the extraction of bioactive compounds, nutrients and starch the residual mango by-products can be efficiently utilized for composting, animal feed and bioenergy production, ensuring complete resource recovery and minimizing waste. One of the most common methods is composting, in which mango peels, seeds, and pulp waste are biologically decomposed to produce nutrient-rich organic fertilizers that enhance soil fertility and reduce reliance on chemical fertilizers. Another important utilization is as animal feed, where mango by-products, especially pulp residues and seed kernels, provide a good source of fiber, carbohydrates, and bioactive compounds, making them a low-cost and nutritious feed option for livestock and poultry. Furthermore, mango processing waste can be used for bioenergy production through anaerobic digestion, where microorganisms break down organic matter to produce biogas that can be used for heat and electricity generation. The leftover digestate from this process can also serve as an organic fertilizer, making it a sustainable and efficient waste-to-energy solution.

SUMMARY

Zero waste approach enables complete utilization of mango resources through integrated strategies encompassing GAPs, shelf-life extension, value-added processing, bioactive extraction, and waste valorization. By transforming by-products into nutraceuticals, functional foods, compost and bioenergy, minimizes losses, enhances resource efficiency, and generates additional income. Ultimately, the adoption of circular bio-economy principles in mango processing can contribute significantly to inclusive growth and sustainable agri-food systems.

For further correspondence, contact,
Dr. Akath Singh, Principal Scientist & Head, Division of Post Harvest Management, ICAR-Central Institute for Subtropical Horticulture, Rehmankhera, P.O. Kakori, Lucknow 226 101, Uttar Pradesh, India. Email: akath2005@yahoo.co.in

Namrata A Giri,
Nilesh N Gaikwad and
R A Marathe*

Pomegranate *(Punica granatum)*: A Powerhouse of Health and Nutrition

Transforming India's arid regions, the pomegranate has emerged as a cornerstone of the *'Viksit Bharat'* vision. This resilient superfood drives rural prosperity by yielding high returns per acre, encouraging youth to embrace modern agribusiness. Nationally, booming exports of premium varieties like *'Bhagwa'* strengthen India's global trade footprints, while advanced processing units foster lucrative rural entrepreneurship. By seamlessly blending water-efficient, climate-smart cultivation with robust value-addition industries, pomegranate farming secures both nutritional health and economic resilience. It stands as a definitive, highly scalable blueprint for sustainable agricultural innovation and nationwide development.

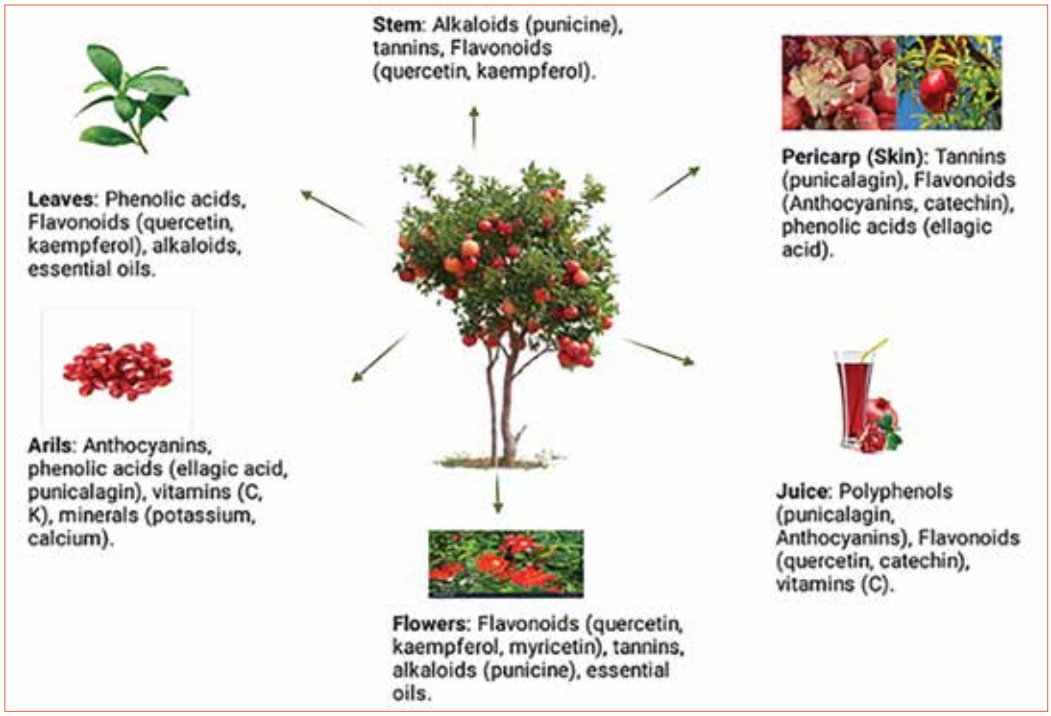
Keywords: Health and Nutrition; Nutritional quality; Nutritive value; Value added products

INDIA is one of the largest producers of pomegranates globally, particularly in states like Maharashtra, Karnataka, Gujarat, and Andhra Pradesh. The crop is well-suited to arid and semi-arid climates, and its cultivation can help improve the economic status of farmers in these regions. India exports a substantial quantity of pomegranates to international markets, including the Middle East, Europe, and the United States. This trade brings in foreign exchange and strengthens India's position in global agriculture market. Pomegranate is widely recognized as a superfruit and more in demand by consumers due to its exceptional nutritional profile and diverse health benefits. It is rich in vitamins (C, K), dietary fiber, and essential minerals, along with a high concentration of bioactive compounds such as polyphenols, flavonoids, anthocyanins, and ellagitannins. These compounds exhibit strong antioxidant activity, helping to neutralize free radicals and reduce oxidative stress in the body. Pomegranates are processed for utilization in the food, pharmaceutical and cosmetic products. The growth of the agro-processing industry creates opportunities for value-added products, enhancing the income for producers and contributing to India's manufacturing sector. Pomegranate farming supports a large workforce, providing employment not just in cultivation but also in processing, packaging, and transportation.

Nutritional quality of pomegranate: The pomegranate fruit is composed of approximately 50% edible part constituting of arils and 50% non-edible peel on a fresh weight basis. Within the arils, seeds are found and represent between 4-10% of the total fruit weight. The pomegranate juice made from arils contain 85% water, 10% total sugars (mainly fructose and glucose), and 1.5% pectin, organic acids (ascorbic, citric and malic) and bioactive compounds such as phenolic compounds and flavonoids mainly anthocyanins. Arils also provide 12% of the daily value (DV) for vitamin C and 16% for vitamin-K per 100 g serving. The red color of arils and juice can be attributed to anthocyanins, such as delphinidin, cyanidin, and pelargonidin glycosides.

Pomegranate peel, accounting about 50% of the whole fruit, is the non-edible fraction comprised mainly of several bioactive compounds such as hydrolysable tannins (pedunculagin, punicalin, punicalagin and ellagic and gallic acids), flavonoids (catechins, anthocyanins, and other complex flavonoids), complex polysaccharides and minerals (phosphorus, magnesium, calcium, potassium and nitrogen). The primary polyphenols in peel are gallic acid (14.14%), proto catechuic acid (14.51%), chlorogenic acid (2.35%), vanillic acid (3.851 %), coumarin (3.53%), caffeic acid (2.74%), oleuropein (0.59%), ferulic acid (1.85%), quercetin (0.94%), and caffeine (6.42%). Pomegranate peel is known for high antioxidant activity and anti-microbial properties.

Pomegranate seeds are important co-product of the pomegranate juice processing industry. Seeds contain a significant amount of lipid, protein, sugars, dietary fiber and essential minerals. In addition to this, the pomegranate seeds contain nutraceuticals, such as sterols, γ-tocopherol, hydroxyl benzoic, punicic acid, and phenyl aliphatic glycosides such as phenethyl rutinoside; besides the contents of most minerals excluding vitamin K are higher in seeds than in arils. The soft seeded varieties of pomegranate contain seed oil up to 25-26% (V/W), which is mainly rich in conjugated linolenic acid (70%). Seeds contain punicic, palmitic, stearic, oleic,and linoleic acids. Seed oil is also a rich source of a steroidal estrogen,



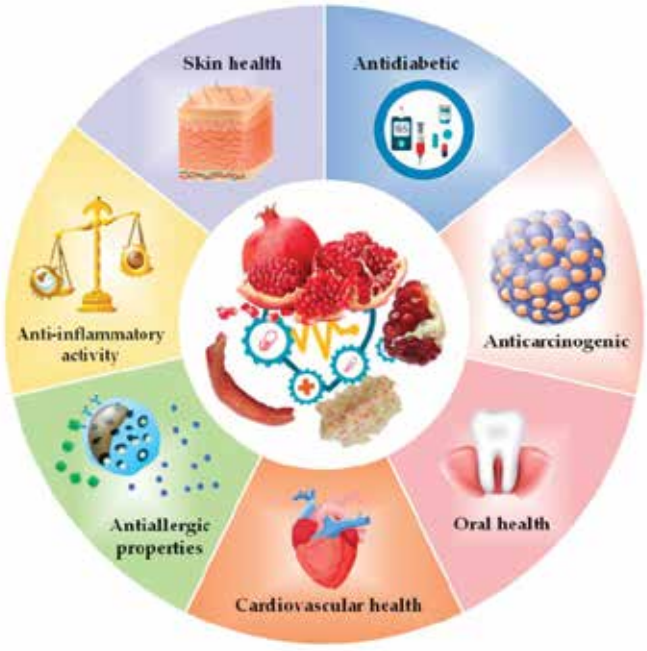
Phytochemical distribution in different parts of the pomegranate (Source: Saeed *et al.,* 2025)

estrone, and contains γ-tocopherol, a rare and potent form of vitamin E and the phytosterols: β-sitosterol, stigmasterol, and campesterol.

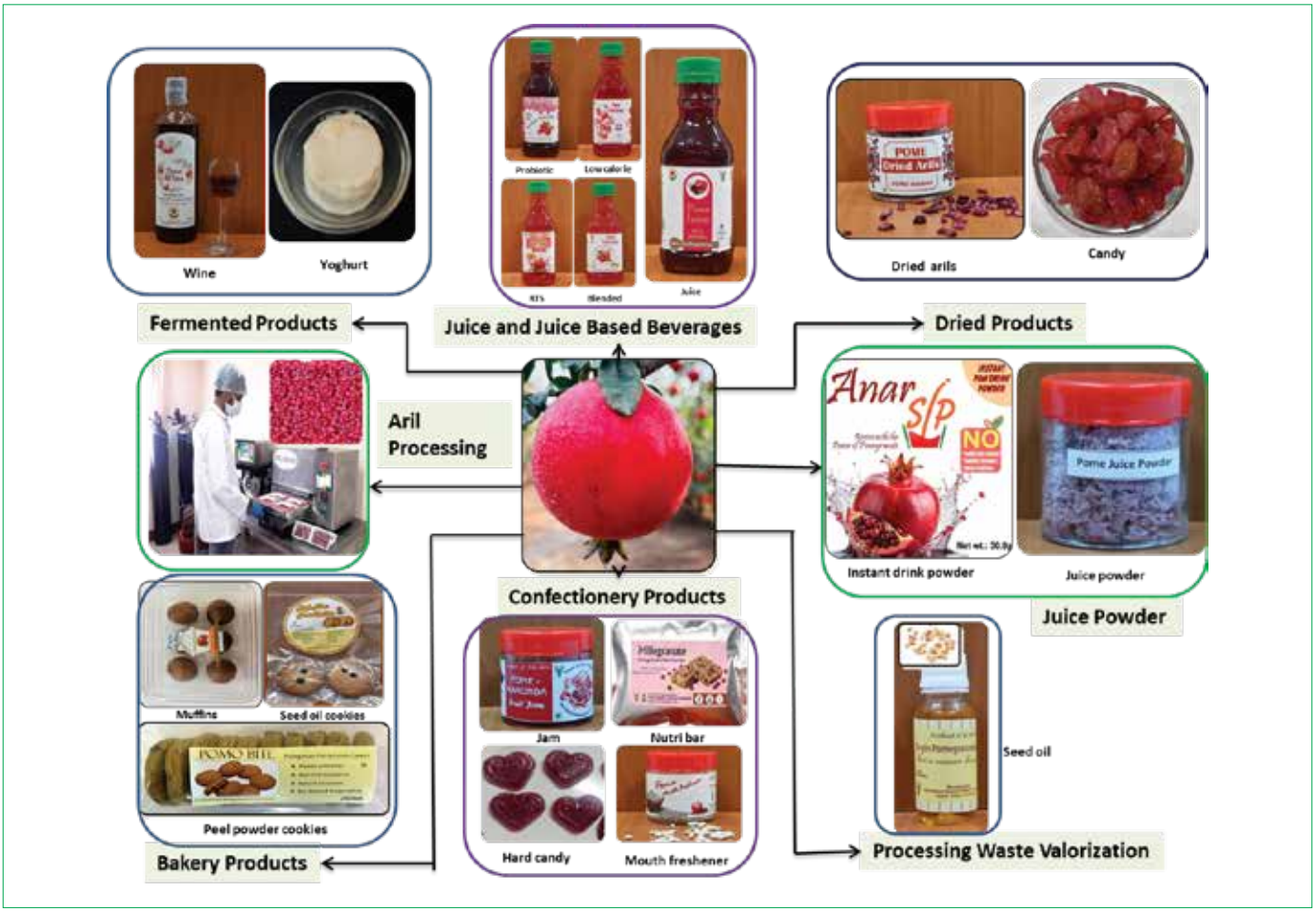
Pomegranate flowers contain a variety of secondary metabolites such as polyphenols with strong antioxidant activity. It contains mainly ellagic acid, anthocyanins, triterpenes, oleanolic acid, ursolic acid, and gallic acid.

Nutritive value of pomegranate fruit (values per 100g edible portion): The edible portion (100 g) of pomegranate provides approximately 65–78 kcal of energy, 15.4–19.6 g carbohydrates (including about 14.5 g natural sugars), 3.4–5.1 g dietary fiber, and 5.3–16 mg ascorbic acid (vitamin C). It also contains essential minerals such as calcium (3–12 mg), phosphorus (8–37 mg), iron (0.3–1.8 mg), potassium (133–259 mg), magnesium (4–44 mg), and sulphur (~12 mg). Pomegranate is a moderate-energy fruit, making it suitable for a balanced diet without excessive calorie intake. The carbohydrates and natural sugars provide quick energy, while the relatively high dietary fiber content supports digestion, improves gut health, and helps regulate blood sugar levels. The presence of ascorbic acid (vitamin C) enhances immune function, aids in collagen synthesis, and acts as an antioxidant to combat oxidative stress. Among minerals, potassium plays a crucial role in maintaining heart health and regulating blood pressure, while magnesium supports enzyme activity and muscle function. Calcium and phosphorus contribute to bone strength, and iron is essential for hemoglobin formation and prevention of anemia. Additionally, trace elements like sulphur are involved in protein synthesis and detoxification processes in the body.

Therapeutic benefits of pomegranate: Regular consumption of pomegranate has been shown to provide significant cardiovascular protection by lowering systolic blood pressure, improving endothelial function, inhibiting LDL oxidation, and reducing atherosclerotic plaque formation. In terms of anti-diabetic activity, pomegranate aids in regulating blood glucose levels, enhancing insulin sensitivity, and modulating carbohydrate metabolism enzymes. The fruit also exhibits promising anti-cancer properties, as its polyphenols can inhibit cancer cell proliferation, induce apoptosis, and suppress tumor growth in cancers such as prostate, breast, and colon. Its anti-inflammatory action involves down regulation of pro-inflammatory cytokines and enzymes like COX and NF-κB, making it beneficial in managing chronic inflammatory conditions including arthritis and metabolic disorders. Furthermore, pomegranate demonstrates potent antimicrobial activity against a wide range of bacterial and fungal pathogens, supporting its use in food preservation and therapeutic formulations. Emerging studies also highlight its neuro-protective effects, where it helps reduce oxidative damage in neural tissues, potentially lowering the risk of neurodegenerative diseases like Alzheimer's. Additionally, its polyphenols act as prebiotics, improving gut microbiota composition and enhancing digestive health. Altogether, these diverse biological activities make pomegranate a powerful natural therapeutic agent with applications in functional foods, nutraceuticals, and preventive healthcare systems.



Therapeutic benefits of pomegranate (Source: Das *et al.,* 2021)



Value added products from pomegranate developed by ICAR-NRCP, Solapur

Value added products from pomegranate: Pomegranate offers immense potential for processing and development of value-added and functional food products. The arils, seeds, and peel can be efficiently utilized to minimize postharvest losses and enhance profitability. A wide range of products has been developed by NRCP, Solapur including minimally processed fresh arils, pomegranate juice, Ready-To-Serve (RTS) beverages, probiotic pomegranate drinks, Pome-lime-ginger RTS beverages, and low-calorie pomegranate drinks. Additionally, fermented products such as pomegranate wine, and processed items like jam, squash, dried arils, anardana, and juice powder are gaining popularity. The seeds can be used for pomegranate seed oil extraction and development of innovative products like seed-based mouth fresheners and nutribars. Furthermore, pomegranate peel, a major by-product, can be valorized into peel powder-fortified muffins, peel extract-enriched soy yoghurt, and other functional foods due to its high polyphenol content. Thus, pomegranate serves as a versatile raw material in horticultural processing, supporting the development of diverse, health-oriented value-added products.

ICAR-NRCP, Solapur has developed and patented an advanced process for extraction of pomegranate seed oil that ensures maximum retention of its valuable nutrients and bioactive compounds. Building on this innovation, the institute has also developed gel capsules of pomegranate seed oil, providing a convenient nutraceutical form for human consumption. Furthermore, encapsulation of the oil using spray drying technology has been standardized to enhance its stability, protect sensitive bioactives from oxidation, improve shelf life, and facilitate its incorporation into functional food formulations. The utility of this technology is significant in both nutraceutical and functional food sectors. The encapsulated forms (gel capsules and spray-dried powder) enable controlled dosage, ease of handling, and improved bioavailability, while also allowing its use as an ingredient in health supplements, fortified foods, beverages, and cosmetic formulations.

SUMMARY

Putting all the aspects in a nutshell, the pomegranate has all the potential to contribute in 'Viksit Bharat' by improving agriculture, boosting economic growth, promoting health and nutrition, sustainable livelihood, and supporting rural development. Through strategic focus and innovation, the cultivation and processing of pomegranates can play a key role in India's journey toward becoming a developed nation.

For futher correspondence, contact:
Dr. R A Marathe, Director, ICAR-National Research Centre on Pomegranate, NH-65, Solapur-Pune Highway, Kegaon, Solapur 413 255, Maharashtra, India. Email: ramarathe28@gmail.com

Dinesh Kumar[1]*, M S Ladaniya[2], Anamika Thakur[1] and V Bansode[2]

Value Addition in Citrus and Valorisation of Waste for Secondary Agriculture and Profit Optimization

Citrus fruits are among the most important horticultural commodities worldwide because of their nutritional, medicinal, and industrial significance. India is a leading producer of mandarin, sweet orange, lemon, and acid lime; however, substantial post-harvest losses occur due to inadequate storage, limited processing infrastructure, and poor value-addition practices. Citrus fruits are highly valued because of their refreshing flavour, rich nutritional composition, antioxidant properties, and therapeutic importance. They are important sources of vitamin C, flavonoids, carotenoids, sugars, dietary fiber, organic acids, and several bioactive compounds that contribute to human health. Citrus fruits are highly suitable for secondary agriculture because nearly every component of the fruit can be converted into value-added products. Approximately 40–45% of citrus fruits are utilized for juice extraction, while the remaining 55% is generated as waste in the form of peel, pulp, pomace, and seeds. Traditionally, these by-products were discarded, causing environmental pollution and economic losses.

Keywords: Citrus fruits; Citrus value chain; Profit optimization; Secondary agriculture

IN recent years, citrus waste valorization has emerged as an important component of secondary agriculture and circular bioeconomy models, focusing on the conversion of processing residues into high-value products. Advanced green extraction technologies such as microwave-assisted extraction, ultrasound-assisted extraction, supercritical fluid extraction, membrane filtration, and freeze drying have significantly improved recovery efficiency, product quality, and environmental sustainability. Research findings from the ICAR-Central Citrus Research Institute have further highlighted the potential of immature dropped citrus fruits as rich sources of hesperidin and diosmin for nutraceutical applications.

Secondary agriculture and citrus value chain: Secondary agriculture plays an important role in strengthening the agricultural economy by transforming raw produce into processed and industrial products. Value addition increases the commercial value of citrus fruits by converting them into ready-to-serve beverages, concentrates, candies, essential oils, pectin, nutraceuticals, and functional foods. Such activities also promote export opportunities and sustainable utilization of agricultural waste.Despite the immense potential of citrus processing, several challenges continue to affect the growth of the sector. In addition, extraction technologies for high-value compounds are not widely available, and a large quantity of citrus waste remains underutilized.

Fizzy Citrus drink

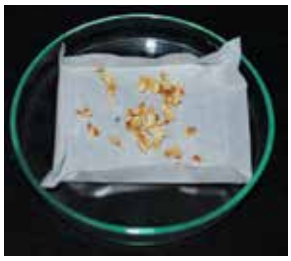
Nutritional and functional importance of citrus: Citrus fruits are rich sources of bioactive compounds with nutritional and therapeutic importance. They contain vitamin C, flavonoids, carotenoids, limonoids, terpenes, pectin, dietary fiber, sugars, and organic acids. These compounds contribute significantly to antioxidant activity, immune enhancement, cardiovascular protection, antimicrobial action, and prevention of chronic diseases. More than 500 natural compounds have been identified in citrus fruits, including flavonoids, carotenoids, coumarins, volatile compounds, limonoids, and phenolic substances.

In India, citrus fruits have conventionally been processed into common food products like squashes, jams, and jellies. These products are still very popular because people are familiar with them, they are easy to make, and they are widely accepted by consumers. Ready-to-serve (RTS) drinks made from mandarin orange or acid lime juice are among the most common citrus products available in the market. People like them because they are refreshing and rich in vitamin C. Citrus squashes made from sweet orange or lime juice concentrates are also widely consumed, especially during the summer season. Marmalade, a thick spread made from citrus juice and peel (mainly orange), is commonly eaten as a breakfast spread in urban areas. Jams and jellies prepared from lemon,


Lemon Squash


Orange Squash

Mandarin (Peel) Marmalade


Orange Seeds

Extracted Limonin

lime, or orange are also popular because of their good taste and texture, especially among young consumers. Apart from these, citrus syrups and candied peels are also becoming popular. These are made by treating citrus peels with sugar after removing their bitterness. They are now being used in bakery products, ice creams, and traditional sweets. These traditional citrus products form the foundation of India's citrus processing industry and provide a good base for developing new and innovative products in the future.

Citrus processing and value addition

Citrus processing is an important component of secondary agriculture because it increases shelf life, improves marketability, and enables diversification of products. A wide range of citrus-based products are produced by processing industries. Citrus beverages include juices, ready-to-serve drinks, and carbonated beverages. Citrus concentrates prepared through evaporation and membrane technologies have long shelf life and high export potential. Citrus peel powder and dried slices are used as dehydrated products, while peel oils, pectin, limonin, and dietary fiber serve as industrial ingredients and nutraceuticals.


Fizzy drink (Mandarin)

Fizzy citrus drinks: Carbonated citrus beverages have gained popularity because of their refreshing taste and commercial appeal. Lime and mandarin fizzy drinks are prepared through juice extraction, chilling, carbonation, bottling, and sealing operations.

Citrus juice concentrates: Citrus juice concentrates are important industrial products because of their long shelf life, ease of transportation, and export potential. Traditionally, juice concentrates were prepared through flash evaporation and freeze drying. However, modern membrane technologies such as ultrafiltration, reverse osmosis, and osmotic distillation have become increasingly popular because they preserve flavour, aroma, and nutritional quality better than conventional thermal methods. Using these technologies, juice concentrates of Khasi mandarin, Kachai lemon, Nagpur mandarin, and Sweet orange were developed with total soluble solids ranging between 51–52.5°Brix.


Orange Juice Concentrate

Citrus waste utilization: Citrus processing industries generate large quantities of peel, pomace, pulp, and seeds, which can be effectively utilized for development of value-added products. Citrus waste is a rich source of pectin, flavonoids, essential oils, limonoids, dietary fiber, and seed oil.


Citrus Peel Pectin

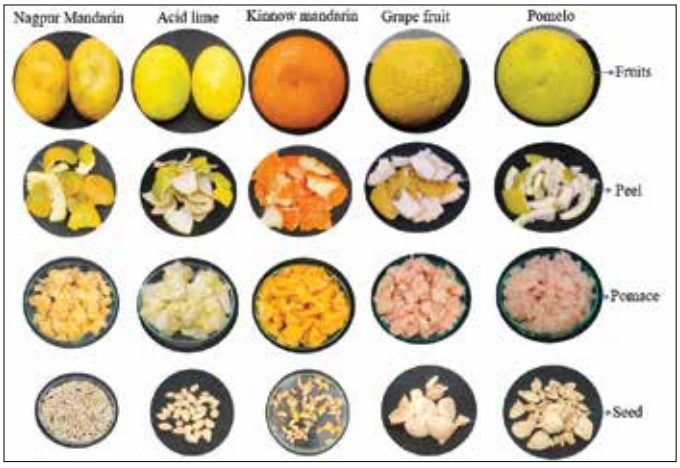
Pectin extracted from citrus peel is widely used in jam, jelly, confectionery, and pharmaceutical industries because of its gelling properties. Pectin extracted from Khasi mandarin peel exhibited higher methoxyl content and jelly grade compared to Kachai lemon peel.

Cold Press Oil

Hydrodistilled Oil

Citrus peel oil contains valuable aromatic compounds such as limonene, pinene, sabinene, terpineol, and ocimene, which are extensively used in food, cosmetic, fragrance, and pharmaceutical industries.

In recent years, citrus waste valorisation has gained attention as a sustainable strategy for waste management



and resource recovery. Citrus residues are now recognized as valuable biomass containing industrially important compounds such as pectin, limonene, flavonoids, and antioxidants. These compounds have applications in food, pharmaceutical, cosmetic, and nutraceutical industries. Despite growing research interest, several gaps remain in the effective utilization of citrus waste. Most studies focus on the extraction of individual compounds rather than integrated valorisation approaches capable of utilizing the entire biomass.

Citrus processing waste (Peel, pomace and seeds)

Characterization of citrus waste: The characterization of citrus waste directly influences processing decisions and product development strategies. High pectin content supports its utilization in food stabilizers and edible films, while elevated sugar content favors bioethanol production through fermentation. Waste rich in essential oils is suitable for extraction of flavoring agents and antimicrobial compounds. Similarly, high cellulose and hemicellulose content can support biogas, compost, or biochar production. Thus, detailed characterization enables efficient selection of extraction technologies and enhances economic feasibility in integrated biorefinery systems.

Farmers upliftment through citrus waste utilization

Citrus waste valorization can have a meaningful impact on farmers and the broader economy by converting an underused agricultural byproduct into a source of additional income, employment, and industrial raw material. In citrus-growing regions, peels, pulp, seeds, and pomace are often discarded after juice extraction or market processing, creating disposal costs and environmental burdens. By developing collection, processing, and extraction systems for these residues, farmers and local processors can benefit from an added revenue stream through the sale of waste biomass to food, nutraceutical, cosmetic, and bioenergy industries.

At the macroeconomic level, citrus waste valorization supports import substitution and industrial innovation by providing domestic sources of pectin, essential oils, antioxidants, dietary fiber, and biodegradable materials. These value-added products can reduce dependence on imported inputs and improve the competitiveness of food and packaging industries. The approach also contributes to waste minimization, lower pollution, and more efficient resource use, which reduces environmental management costs for municipalities and processors.

Environmental and social implications

Citrus waste valorisation provides important environmental benefits by reducing agro-industrial waste and promoting sustainable resource utilization. The valorisation of citrus waste also contributes to social and economic development, particularly in rural and citrus-producing regions. Processing industries based on citrus waste can generate employment opportunities in collection, transportation, extraction, and product manufacturing sectors. Technology transfer and adoption of sustainable processing methods can further strengthen agro-based economies and encourage industrial innovation.

Citrus flavonoids and nutraceuticals

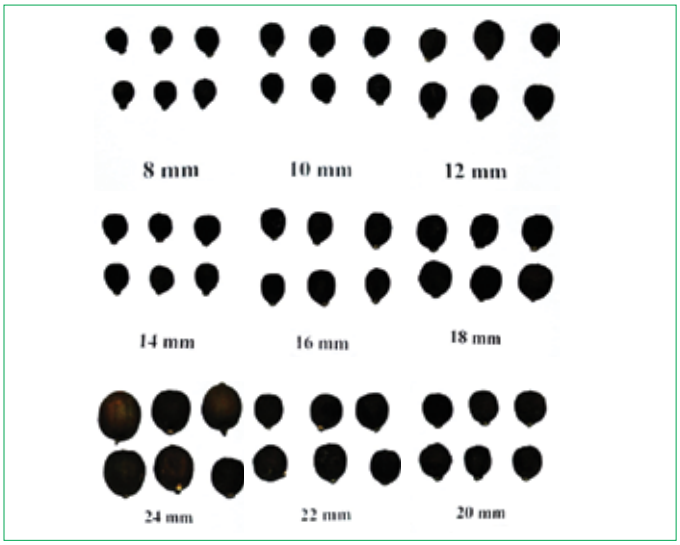
The global nutraceutical market has expanded rapidly due to increasing consumer awareness regarding health-promoting foods and natural bioactive compounds. Citrus fruits and their by-products are important sources of nutraceutical ingredients such as flavonoids, vitamin C, and dietary fiber. India's nutraceutical market has also shown remarkable growth and is projected to reach nearly $18 billion by 2026. Commercial citrus nutraceuticals include vitamin C supplements, citrus fiber, citrus extracts, and bioflavonoid preparations rich in hesperidin and naringin. These products are widely used in pharmaceuticals, dietary supplements, and functional foods.

Research findings on citrus dropped fruits

Immature dropped fruits generated during citrus cultivation are generally discarded as waste. However, recent studies conducted at ICAR-Central Citrus Research Institute revealed that these fruits contain high concentrations of flavonoids such as hesperidin, narirutin, diosmin, didymin, and neoponcirin. The results demonstrated that immature Nagpur mandarin fruits

Table. Flavonoid content of immature Nagpur mandarin fruits

Sr. No	Sample Size (mm)	Hesperidin (%)	Narirutin/ Isonariging (%)	Diosmin (%)	Didymin Neoponcirin (%)
1	8	24.30	0.143	0.28	0.281
2	10	26.63	0.118	0.17	0.331
3	12	28.74	0.134	0.18	0.384
4	14	27.67	0.147	0.13	0.354
5	16	21.03	0.212	0.14	0.459
6	18	15.49	0.098	0.07	0.369
7	20	11.47	0.191	0.07	0.685
8	22	8.095	0.26	0.0	0.417
9	24	7.777	0.325	0.0	0.342



Immature Dropped Fruits of Nagpur Mandarin

contain very high levels of hesperidin, particularly at smaller fruit sizes.

Future Scope of Citrus Value Addition

The future of citrus value addition lies in the development of innovative functional foods, nutraceuticals, and eco-friendly processing technologies. Increasing research attention is being directed toward development of probiotic citrus beverages, fortified juices, citrus peel-based nutritional bars, antimicrobial compounds for packaging applications, and extraction of bioactive compounds. Advances in membrane technology, green extraction methods, biotechnology, and waste-to-wealth approaches are expected to further enhance the profitability and sustainability of citrus processing industries. Utilization of citrus by-products for development of high-value ingredients will not only reduce environmental pollution but also create additional employment opportunities and support sustainable agro-industrial growth.

SUMMARY

Citrus value addition plays a significant role in strengthening secondary agriculture and improving farmer income. Processing technologies enable diversification of citrus products into beverages, concentrates, confectionery products, nutraceuticals, and industrial ingredients. Efficient utilization of citrus waste provides opportunities for extraction of pectin, flavonoids, limonoids, dietary fiber, and essential oils. Research findings indicate that immature dropped fruits are promising sources of valuable flavonoids such as hesperidin and diosmin. The expanding nutraceutical market further increases the commercial importance of citrus bioactive compounds. Promotion of agro-processing industries, technological innovations, and sustainable waste utilization strategies can transform the citrus sector into a profitable and environmentally sustainable agro-industrial system.

For further correspondence, contact:
[1]Dr. Dinesh Kumar, Head, Food Science and Post Harvest Technology, ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India. Email: dineshscn@gmail.com; [2]ICAR-Central Citrus Research Institute, Amravati Road, Nagpur 440 033, Maharashtra, India.

Subhra Saikat Roy*,
Venkatraman Bansode and Dilip Ghosh

Citrus-Based Functional Foods and Beverages

Recent innovations in citrus-based functional beverages, fortified confectionery, fibre-enriched snacks, and peel-derived nutraceutical ingredients demonstrate how horticultural science can directly contribute to preventive healthcare. Not-from-concentrate citrus drinks enhance hydration and antioxidant intake, while vitamin C-fortified gummies and jelly bites provide child-friendly immune nutrition. Pomace-based cubes and cookies improve fibre intake and metabolic moderation, and peel-derived pectin and essential oils extend applications into functional food formulation and natural preservation. These products demonstrate how citrus bio-resources can address nutritional gaps while promoting sustainability, circular bioeconomy principles, and reduction of post-harvest losses. Citrus value-addition thus represents a powerful convergence of horticulture, nutrition science, preventive healthcare, and green enterprise development.

Keywords: Bioactives; Bioeconomy; Citrus; Functional foods and beverages; Health benefits; Human nutrition

Nutrition today extends beyond the provision of calories; it encompasses immune resilience, metabolic stability, gut health, and long-term disease prevention. In this context, citrus fruits occupy a strategic position because of their dense concentration of essential nutrients and bioactive compounds. India, being world's third largest producer of citrus fruits such as mandarin, sweet orange, acid lime, lemon, pomelo, and many underutilized citrus species grown across diverse agro-climatic zones possesses enormous potential not only for fresh consumption but also for functional food development.

Citrus fruits are uniquely positioned at the interface of horticulture and health. Their characteristic composition of vitamin C, flavonoids, limonoids, carotenoids, dietary fibre, organic acids, pectin, and essential oils offer multiple physiological benefits. With increasing consumer awareness regarding immunity, oxidative stress, and lifestyle disorders, citrus-based functional foods and beverages provide a practical and culturally acceptable route to integrate preventive nutrition into daily diets. Recent developments demonstrate how scientific value-addition can convert perishable citrus fruits and their by-products into nutritionally enriched, shelf-stable, and health-oriented products.

Citrus as a functional food matrix

The health potential of citrus lies in its complex phytochemical architecture. The health benefits of important phytochemicals are outlined below.

Citrus Flavonoids: Flavonoids are a major class of polyphenolic compounds in citrus, responsible for flavour attributes and a wide range of bioactivities. Flavonoid profiles vary by cultivar, maturity stage, agro-climatic conditions, and post-harvest handling. The primary flavonoids in citrus are flavanones, which exist mainly as glycosides (bound to a sugar molecule). Hesperidin and narirutin are the most abundant flavanones in oranges and mandarins, including Indian varieties like mandarins (Nagpur, Khasi and Kinnow) and sweet oranges. Hesperidin is particularly concentrated in the albedo and peel. Naringin, a flavanone, is responsible for the characteristic bitter taste. It is a key bioactive in Indian pomelo varieties. Eriocitrin, predominantly found in lemons and limes, is a key flavonoid in Indian acid lime and lemon. Polymethoxyflavones (PMFs) are unique class of flavonoids, including nobiletin and tangeretin, is almost exclusively found in citrus. They are highly concentrated in the peel of mandarins and sweet oranges. PMFs are highly bioavailable and possess potent anti-inflammatory properties. Besides, many other flavonoids like hesperetin (aglycone of hespiridin), naringenin (aglycone of naringin), diosmin and rutin, etc. are also found in different types of citrus fruits.

The health benefits of citrus flavonoids are supported by evidence from different levels of scientific research. Flavonoids are powerful antioxidants and contribute to redox homeostasis through scavenging reactive oxygen species and upregulate body's endogenous antioxidant and enzymes (SOD, catalase, glutathione peroxidase), thereby protecting cells from oxidative damage. They also exhibit significant anti-inflammatory effects by modulating transcription factors such as NF-κB and reducing the production of pro-inflammatory cytokines (e.g., TNF-α, IL-6). In the context of cardiometabolic health, these

mechanisms translate into tangible benefits. Human observational studies have shown that regular consumption of orange juice can help reduce systolic and diastolic blood pressure and improve endothelial function. Clinical trials have demonstrated that flavonoid-enriched supplements or juices can improve lipid profiles (lowering LDL-cholesterol). Citrus flavonoids also known for reducing inflammation markers, and enhance glycaemic control in individuals with obesity or prediabetes. Flavonoids modulate carbohydrate metabolism by influencing glucose transporters, improving insulin sensitivity and reducing postprandial glucose spikes.

Beyond their well-recognized free radical scavenging, anti-inflammatory, anti-hyperglycaemic and cardiometabolic effects, citrus flavonoids exhibit several distinct and clinically relevant bioactivities. Hesperidin, hesperetin and eriocitrin, for instance, have demonstrated promising neuroprotective potential by attenuating oxidative stress in neural tissues and modulating redox-sensitive pathways implicated in neurodegeneration. Diosmin is widely employed in the management of chronic venous insufficiency, varicose veins, and hemorrhoids; it enhances lymphatic drainage, improves capillary resistance, and confers protective effects on the vascular endothelium. Naringenin, narirutin and eriocitrin have shown hepatoprotective properties, particularly through regulation of lipid metabolism and mitigation of hepatic steatosis. Rutin, likewise, contributes to vascular health by strengthening capillaries and reducing vascular fragility.

Vitamin C: Citrus fruits are well-known for their rich vitamin C content. Vitamin C acts as a potent water-soluble antioxidant, cofactor in collagen synthesis and immune-supportive micronutrient. Importantly, synergistic interactions between vitamin C and flavonoids may enhance overall antioxidant capacity.

Limonoids: Limonoids such as limonin and nomilin are highly oxygenated triterpenoids found in seeds and peel. Limonoids showed promising anti-inflammatory activity, chemopreventive potential and detoxification enzymes modulation activity.

Carotenoids: Citrus carotenoids (e.g. β-cryptoxanthin and β-carotene) are precursors to vitamin A, act as antioxidants and support immune function. Mandarins and sweet oranges are important dietary sources.

Phenolic acids: Compounds like ferulic acid and caffeic acid are also present in citrus, contributing to the overall antioxidant capacity of the fruit. Mandarin peel has been identified as a good source of ferulic acid.

Organic acids: Citrus fruits are rich in organic acids, primarily citric acid, along with malic acid. Citric acid acts as a natural antioxidant and chelating agent, helping in detoxification and improving mineral absorption. Malic acid supports energy production in the body through its role in the Krebs cycle.

Citrus pectin: Citrus peel is an exceptionally rich source of pectin, a complex structural polysaccharide that functions as a soluble dietary fibre. Pectin can constitute 20-30% of the peel's dry weight. It consists of homogalacturonan and rhamnogalacturonan regions, and its gelling properties and functional behaviour depend on the degree of esterification (DE). Pectins are classified as high-methoxyl (DE > 50%) or low-methoxyl (DE < 50%), suiting them for different applications.

Citrus pectin is not digested in the upper gastrointestinal tract. Upon reaching the colon, it undergoes fermentation by colonic microbiota, producing short-chain fatty acids (SCFAs), including butyrate, propionate and acetate. These SCFAs are vital for colon cell health and contribute to maintenance of colonic epithelial integrity, modulation of systemic inflammation and metabolic regulation. Thus, pectin acts as a prebiotic, promoting the growth of beneficial gut bacteria. This modulation of the gut microbiome is a cornerstone of pectin's health benefits.

Furthermore, its ability to form a gel-like matrix in the gut helps in cholesterol control by binding to bile acids and promoting their excretion, and in glycaemic control by slowing down glucose absorption. Given that India imports a substantial amount of pectin, developing a domestic industry based on valorizing citrus peel waste aligns perfectly with national goals of 'Make in India' and promoting a zero-waste circular economy.

Essential oils: Extracted from the flavedo, citrus essential oils are complex mixtures of volatile compounds, with limonene often being the major component. The composition can vary significantly between species. Citrus essential oils are widely used in the food, cosmetic, and pharmaceutical industries for their aromatic and antimicrobial properties.

However, it is crucial to note that these bioactives support health as part of a balanced diet and are not treatments for disease. When these bioactive components are preserved and strategically incorporated into food formulations, citrus transcends its role as a simple fruit and becomes a functional food platform capable of delivering multiple health benefits simultaneously.

A glimpse of citrus-based functional foods and beverages

Delivering essential nutrients and bioactives through commonly consumed foods and beverages increases compliance and long-term dietary integration compared to standalone supplements. Hence, citrus-based functional foods and beverages represent a food-first nutritional strategy that integrates immunity, hydration, gut health, and sustainability.

Functional citrus beverages: The development of not-from-concentrate (NFC) citrus beverages represents a significant advancement in retaining natural nutrients and sensory authenticity. Acid lime-based functional energy drinks formulated with real juice provide not only rapid carbohydrate-derived energy but also natural vitamin C and flavonoids that help mitigate oxidative stress. Unlike conventional synthetic energy beverages, these formulations reduce reliance on artificial flavoring systems and emphasize clean-label nutrition. The inclusion of balanced functional ingredients and amino acids further supports sustained energy release, making such beverages relevant for physically active and health-conscious individuals.

Similarly, NFC acid lime sports drinks enriched with electrolytes support hydration and neuromuscular balance. During intense physical activity, the body loses sodium,

potassium, and fluids, and the isotonic nature of citrus-based hydration beverages facilitates rapid replenishment. The antioxidants help counter exercise-induced oxidative damage, while organic acids enhance palatability and fluid absorption. In tropical climates, where dehydration risk is high, such natural hydration solutions are particularly valuable.

Ready-to-serve (RTS) citrus beverages and fizzy citrus drinks offer healthier alternatives to conventional soft drinks. By incorporating authentic fruit juice and moderate sugar levels, these beverages deliver refreshment along with micronutrient contribution. Vitamin C content enhances daily intake, while the absence of artificial colors aligns with consumer demand for transparency and ingredient simplicity.

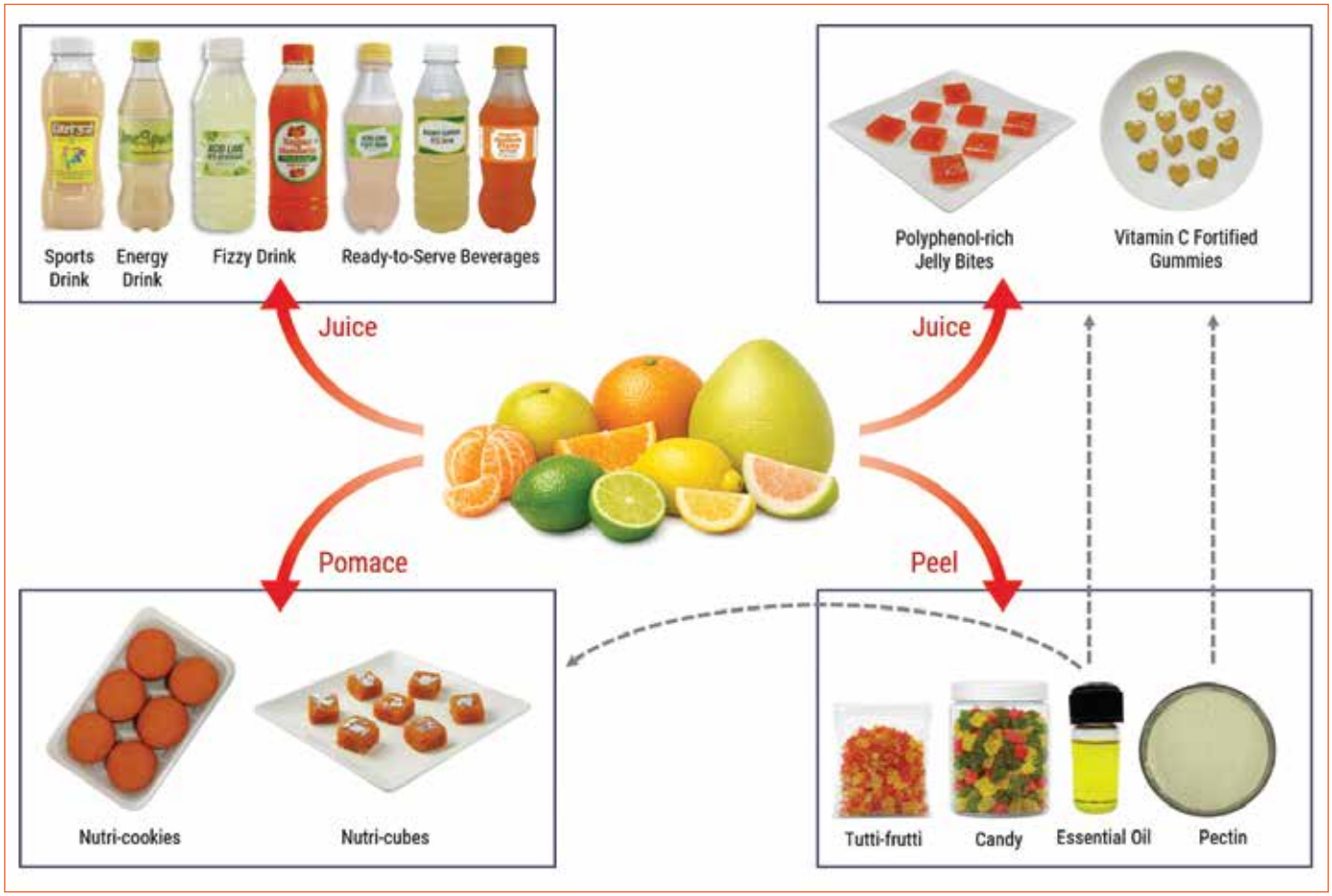
Functional confectioneries: One of the most innovative applications of citrus bioactives lies in functional confectionery. Vitamin C-fortified acid lime gummies and polyphenol-rich mandarin jelly bites transform immune-support nutrients into child-friendly formats. These products provide enhanced vitamin C levels (180-200 mg/100g) along with flavonoids (76-80 mg/100g), supporting immune resilience, antioxidant defense, and tissue repair. Since children often resist conventional supplementation, fortified citrus confectionery serves as an acceptable and enjoyable nutrient delivery vehicle.

The use of peel-derived pectin as a natural gelling agent further enhances the nutritional value by contributing soluble fibre. Clean-label formulations devoid of synthetic colors, flavors, and preservatives reinforce consumer confidence and promote healthier snacking habits. Such products demonstrate that indulgence and preventive nutrition can coexist within thoughtfully designed food systems.

Pomace-based functional foods: Citrus pomace, the nutrient-rich residue left after juice extraction, contains valuable fibre, residual vitamin C, flavonoids, and other phytochemicals. Transforming pomace into nutri-rich mandarin cubes represents an exemplary model of nutritional upcycling. These cubes exhibit enhanced protein, fibre, and antioxidant content compared to conventional sweets. The dietary fibres are known to supports digestive regularity, improves satiety, and moderates post-prandial glucose response. Sugar-free variants further extend their applicability to calorie-conscious and diabetic populations.

Mandarin pomace nutri-cookies, blended with millets or oats, provide a functional bakery alternative with improved fibre density and lower glycemic potential. While a large population is facing the dual burden of micronutrient deficiency and rising lifestyle disorders, fibre-enriched snacks represent a strategic intervention for promoting balanced dietary patterns. The subtle citrus notes from peel components enhance sensory appeal while delivering additional phytochemicals.

Peel-based innovations: Citrus peel, particularly pomelo albedo, is often discarded despite its high fibre and bioactive content. Converting pomelo peel albedo into candy and tutti-frutti-like products demonstrates how waste streams can be transformed into nutritionally superior



Citrus based functional foods and beverages

confectionery. These products retain dietary fibre and flavonoids, contributing to digestive health and antioxidant intake while reducing environmental waste and promoting a zero-waste citrus industry. Prepared with natural colors, these products are entirely free from synthetic additives, including preservatives. Nutritionally, these products offer superior nutritional value and enhanced sensory and textural appeal compared to conventional variants, making it a versatile ingredient for a wide range of applications from standalone healthy snacking to incorporation in different bakery formulations. Aligned with zero-waste principles and the circular economy, these products represent a sustainable, clean-label confectionery solution that appeals to modern consumers seeking both taste and health in their dietary choices.

Citrus-based functional processed products developed by ICAR-CCRI

A defining strength of citrus-based processed products lies in its zero-waste orientation. Juice is converted into functional beverages, pomace into fibre-rich snacks, peel into confectionery. This circular bioeconomy model maximizes nutrient recovery from each fruit, reduces post-harvest losses, and enhances economic sustainability. Nutrition security and environmental responsibility thus converge within citrus value chains. By increasing nutritional output per unit of harvested fruit, citrus processing innovations contribute to both health outcomes and citricultural resilience. This integrated approach supports farmers, processors, entrepreneurs, and consumers simultaneously.

SUMMARY

Citrus-based functional foods and beverages represent a powerful convergence of horticultural innovation, nutritional science, and sustainability. Rich in vitamin C, flavonoids, dietary fibre, and bioactive essential oils, citrus products support immunity, metabolic balance, cardiovascular wellness, and digestive health. Innovations such as NFC functional beverages, fortified gummies, pomace-based fibre snacks, peel-derived confectioneries demonstrate how science-backed value addition can transform perishable fruits into health-promoting, shelf-stable products and preventive nutrition solutions. Equally important, the upcycling of citrus by-products aligns health promotion with circular bioeconomy principles. In an era marked by lifestyle disorders and micronutrient gaps, citrus-based functional products offer an accessible, consumer-friendly, and sustainable pathway to improve public health and nutrition while strengthening India's horticultural sector. By integrating these innovations into mainstream food market, India can simultaneously enhance public health, reduce post-harvest losses, and strengthen its citrus value chain.

For further correspondence, contact,
Dr. Subhra Saikat Roy, Principal Scientist, ICAR-Central Citrus Research Institute, Amravati Road, Nagpur 440 033, Maharashtra, India. E-mail: subhra.roy@icar.org.in

G Byju

Tropical Tuber Crops: Future Foods for Nutrition, Health and Wellness

Transitioning from the 'food of the poor' to globally recognized future-smart foods, tropical tuber crops (TTCs) like cassava, sweet potato, and yams are reshaping Indian horticulture. Contributing over ₹130 billion annually, these climate-resilient powerhouses secure the livelihoods of 200 million people, including vital tribal and marginal farming communities. Breakthrough biofortified varieties such as beta-carotene-rich *Bhu Sona* and antioxidant-heavy *Bhu Krishna* are tackling hidden hunger head-on. By merging low-input, drought-tolerant cultivation with advanced processing for gluten-free, low-glycemic, and industrial bioeconomic applications, TTCs offer an indispensable blueprint for sustainable national health and climate-resilient agricultural growth.

Keywords: Cultivation practices; Mulching; Protected cultivation; Strawberry; Yield

Tropical tuber crops (TTCs) such as cassava, sweet potato, yams, elephant foot yam, taro and other aroids and a few other minor tubers have nourished millions of people across Asia, Africa and Latin America for centuries. Once regarded merely as 'food of the poor', these crops are now increasingly recognized as 'future-smart foods' because of their climate resilience, nutritional richness and immense potential for health-promoting food products. At a time when the world is grappling with climate change, food insecurity, hidden hunger and lifestyle diseases, tropical tuber crops are emerging as strategic crops for nutrition, health and sustainable agriculture.

Tropical tuber crops in India: Importance and future prospects: India cultivates tropical tuber crops in about 0.4 million hectares with an annual production of nearly 10 million tonnes and a market value exceeding ₹130 billion. Cassava, sweet potato elephant foot yam and yams are among the important carbohydrate-rich food crops of the country, supporting the food and livelihood security of nearly 200 million people, particularly smallholders,

Tropical Tuber Crops

tribal communities and marginal farmers. Globally too, cassava ranks among the five most important energy foods, underlining the strategic importance of tropical tubers in ensuring future food and nutritional security.

Tropical tuber crops are highly productive and resilient under adverse conditions. They thrive under marginal soils, tolerate drought and erratic rainfall, and produce substantial quantities of food with relatively low external inputs. Cassava, for instance, is highly efficient in converting solar energy and nutrients into energy-rich food. These crops are therefore increasingly viewed as climate-resilient alternatives to conventional cereals, especially under changing climatic scenarios. Their adaptability to diverse agro-ecological conditions also makes them ideal candidates for sustainable and low-input farming systems.

Bhu Sona, an orange fleshed sweet potato

SP-95/4, a promising orange fleshed sweet potato

Bhu Krishna, purple fleshed sweet potato

Bhu Arunima, purple fleshed sweet potato

'ICAR-CTCRI Jamuni', recently commercialised purple taro line

East Indian Arrowroot, Dongria Kondh Tribe, Niyamgiri hills, Odisha

Nutritional richness, nutraceutical value and health benefits: Apart from being excellent sources of energy, tropical tuber crops possess remarkable nutritional attributes. They are rich in carbohydrates, dietary fibre, vitamins, minerals and several bioactive compounds that contribute to better health and well-being. Sweet potato, particularly the orange-fleshed varieties, is an excellent source of β-carotene, a precursor of vitamin A. Vitamin A deficiency remains a major public health concern in many developing countries, especially among children and pregnant women. Promotion of orange-fleshed sweet potato can therefore significantly contribute towards combating hidden hunger and improving nutritional security.

Purple-fleshed sweet potato varieties contain anthocyanins, natural pigments known for their strong antioxidant properties. Anthocyanins help reduce oxidative stress, inflammation and cellular damage, thereby lowering the risk of chronic diseases such as cancer, cardiovascular disorders and diabetes. These varieties are increasingly attracting global attention as nutraceutical foods and natural sources of health-promoting compounds.

Cassava, though traditionally known as an energy food, is now recognized for its industrial and functional food potential. Cassava starch is highly digestible and widely used in food, pharmaceutical and industrial sectors. Resistant starch fractions present in cassava are particularly important because they function as prebiotics, improving gut health and supporting beneficial intestinal microorganisms. Resistant starch also helps regulate blood glucose levels, improves insulin sensitivity and contributes to better colon health.

Elephant foot yam is another highly nutritious tropical tuber crop that is gaining popularity as a functional food. It is rich in dietary fibre, potassium and several phenolic compounds. Consumption of elephant foot yam has been associated with improved digestive health, reduced cholesterol levels and better metabolic functions. Its low glycaemic index and high fibre content make it suitable for health-conscious consumers and diabetic patients.

Yams are rich in carbohydrates, minerals and bioactive compounds such as diosgenin, which possesses antioxidant, anti-inflammatory and therapeutic properties. Certain yam species are traditionally valued in indigenous medicine systems for their role in improving immunity and general health. Similarly, taro contains easily digestible starch with small granule size, making it suitable for infants, elderly people and individuals with digestive disorders. Taro is also a good source of potassium, magnesium and mucilage compounds beneficial for gut health.

Modern nutrition science increasingly recognizes tropical tuber crops as nutraceutical foods because they provide both nourishment and health protection. Their nutraceutical value arises from the presence of bioactive compounds such as carotenoids, anthocyanins, flavonoids, resistant starch, dietary fibre and polyphenols. These compounds contribute to lowering cholesterol, reducing oxidative stress, strengthening immunity and minimizing the risk of lifestyle diseases such as obesity, diabetes and cardiovascular disorders.

Biofortified varieties and value-added products: Recognizing the growing importance of nutrition-sensitive agriculture, ICAR-Central Tuber Crops Research Institute (ICAR-CTCRI) have developed several biofortified and climate-resilient varieties of tropical tuber crops. Important achievements include β-carotene-rich sweet potato varieties, anthocyanin-rich purple sweet potatoes, drought-tolerant cassava genotypes and nutrient-efficient varieties suitable for sustainable farming systems. Such varieties not only improve productivity and resilience but also help address micronutrient deficiencies.

Biofortification has immense relevance in India where deficiencies of vitamin A, iron and zinc continue to affect large sections of the population. Inclusion of biofortified sweet potato and yams in programmes such as PM-POSHAN, Integrated Child Development Services (ICDS) and other nutritional interventions can substantially improve dietary quality among vulnerable populations. Climate-resilient and nutrient-rich tuber crops can therefore play a major role in future nutrition and public health strategies.

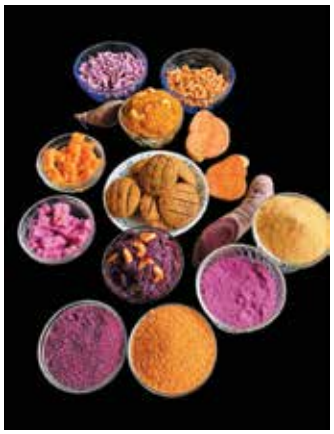
Another major strength of tropical tuber crops lies in their enormous potential for value addition and processing. ICAR-CTCRI has developed a wide range of technologies for producing snack foods, pasta, noodles, bakery products, nutribars, instant mixes, resistant starch, biodegradable packaging materials and functional foods from tropical tubers. These technologies are creating new opportunities for entrepreneurship, rural industrialization and employment generation.

Consumer demand for gluten-free, high-fibre and low glycaemic foods is steadily increasing across the world. Tropical tuber crops are naturally suited for the preparation of such products. Cassava flour and starch are increasingly used in gluten-free foods. Purple sweet potato-based beverages and bakery products are gaining popularity because of their antioxidant properties. Vacuum-fried chips, resistant starch formulations, health snacks and nutraceutical powders prepared from tuber crops are also emerging as important health-oriented products.

The industrial importance of tropical tuber crops is equally significant. Cassava starch finds application in textiles, paper, pharmaceuticals, adhesives, biodegradable plastics and bioethanol industries. The growing demand for eco-friendly and biodegradable materials is expected to further increase the relevance of tuber crops in the bioeconomy and circular economy sectors.

The future prospects of tropical tuber crops are therefore enormous. Climate change, increasing health consciousness, diversification of food habits and expansion of functional food markets are likely to drive their demand in the coming decades. Tropical tuber crops can contribute simultaneously to food security, nutritional security, climate resilience, sustainable livelihoods and industrial development.

Recognizing the strategic importance of these crops, a proposal for a 'National Mission on Tropical Tuber Crops (NMTC)' has been suggested to mainstream tropical tubers into India's food, nutrition and climate agendas. The proposed mission envisages strengthening certified seed systems, promoting decentralized processing units, supporting FPO-led value chains, encouraging biofortified varieties, integrating tuber crops into nutrition programmes and expanding entrepreneurship opportunities for rural youth and women. The mission also aims to link tropical tuber crops with schemes such as MIDH, PM-FME and PM-POSHAN so as to improve farmer income, reduce post-harvest losses and create sustainable livelihoods while enhancing nutritional security.



Value added commercialised food products from orange and purple fleshed sweet potato

'Tapioca Murukku', commercialised in K-Inam brand of Government of Kerala

'Taro chips', commercialised in K-Inam brand of Government of Kerala

'Tapioca Murukku', commercialised in K-Inam brand of Government of Kerala

However, realizing the full potential of these crops requires focused efforts in research, policy support and value-chain development. Expansion of quality planting material production, strengthening seed systems, promotion of biofortified varieties, development of processing industries, market linkages and consumer awareness are essential for accelerating growth in the sector. Greater integration of tropical tuber crops into public nutrition programmes, school feeding systems and health-oriented food policies will also help mainstream these crops into India's food and nutrition agenda.

SUMMARY

Over the past six decades, India has transformed tropical tuber crops from underutilized staples into scientifically advanced, nutritionally important and

economically valuable crops. Continued investments in science, innovation and entrepreneurship can further position tropical tuber crops as pillars of sustainable agriculture and healthy diets. In the years ahead, tropical tuber crops are poised to emerge not merely as alternative staples but as 'super foods' for the tropics – nourishing people, supporting farmers, promoting wellness and strengthening climate-resilient agriculture in an era of unprecedented global challenges.

For further correspondece, contact:
Dr. G Byju, Director, ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram 695 017, Kerala, India. Email: Byju.G@icar.org.in;director.ctcri@icar.org.in

R Dinesh[1], V Srinivasan[1]*,
Anees K[1], P P Shameena Begum[1]
and Sanjay Kumar Singh[2]

Harnessing Nutraceutical Potential and Market Opportunities of spice sector in India

India is redefining its historic legacy as the world's spice hub by pivoting from raw commodity exports to high-value, processed derivatives. Producing 12 million tonnes annually, the sector is undergoing a massive transformation driven by changing global consumer demands for wellness, sustainability, and quality assurance. The traditional export of ground powders is rapidly giving way to sophisticated, high-margin products like essential oils, oleoresins, nutraceuticals, and specialty ingredients. By blending innovation with advanced processing technology, India's spice value chain is unlocking immense economic wealth, ensuring global market premium pricing, and securing its position in modern agro-industrial development.

Keywords: Health and Nutrition; Nutraceutical Potential; Spices;Value addition

INDIA has been the world's spice hub for centuries. Today, the country produces approximately 12 million tonnes of spices annually on 4.69 million hectares, exporting around 1.8 million tonnes worth billions of rupees. However, India's spice sector is undergoing a significant transformation. The days of exporting raw spices and ground powders are gradually giving way to high-value processed products that command premium prices in global markets.

Modern consumers worldwide are no longer satisfied with spices as mere flavoring agents. They seek health benefits, guaranteed quality, consistent taste, and sustainable sourcing. This shift in consumer expectations is reshaping India's spice value chain from a commodity-based industry into a sophisticated, innovation-driven sector generating substantial wealth through value addition, particularly in oils, oleoresins, nutraceuticals, and specialty ingredients.

Understanding spice value addition in India

Value addition means transforming raw spices into refined, concentrated or processed products that fetch higher prices and serve diverse applications. The Indian spice sector's private industry is increasingly investing in advanced technologies to extract, concentrate, and process spice bioactives into premium products. This is happening across three major product categories:

- ***Oils and oleoresins:*** Concentrated extracts that preserve spice flavor and bioactive compounds in stable, shelf-stable forms.
- ***Nutraceuticals and health supplements:*** Spice-derived capsules, powders, and formulations targeting specific health benefits.
- ***Specialty ingredients:*** Flavoring compounds, natural colorants, and functional food ingredients for industrial applications.

The private sector boom: Oils and oleoresins leading the way

India's private spice processing industry has witnessed explosive growth in recent years, particularly in extracting and processing oils and oleoresins. These high-value products are the future of India's spice trade. Recent export data (2024-25) paints a clear picture of this transformation:

Leading value-added spice exports (2024-25): During 2024-25, India's spice exports achieved an all-time high, with total shipments valued at ₹39,99,448 lakh (₹17,99,267 tonnes), marking a 8.21% increase in value terms from 2023-24. Key value-added products like spice oils and oleoresins accounted for over ₹4,53,324 lakh in 2024-25, while chilli, turmeric, ginger and cumin constitute 41.54% of total export volume.

As processed oils and oleoresins command 3-5 times higher prices than raw spices, are shelf-stable without the need for extensive packaging, and can be directly used by food manufacturers, pharmaceutical companies, and

Top performing spice extracts in export during 2024-25

HS code	Commodity	Export (ton) 2024-25	Percentage growth
33019022	Chilli oleoresin	6015	18
33019014	Turmeric oleoresin	2129	-2
33012949	Turmeric oil	122.4	250
33019012	Ginger oleoresin	234	18
33012926	Ginger oil	39.06	8
33019024	Cumin oleoresin	138.2	43
33012945	Cumin oil	20.41	28

Source: Indiastat, 2025

cosmetic makers, the private firms are keen to invest in the spice extract based product.

Public sector interventions for spice value chain development

ICAR institutions, have significantly strengthened India's spice sector. ICAR-IISR has developed high-yielding varieties rich in bioactive compounds *viz.* curcumin, piperine, oleoresins, and essential oils, widely adopted by farmers and industries. Notable examples include IISR Prathibha turmeric, cultivated across India from Himachal Pradesh to Kanyakumari. The production technologies– micronutrient mixtures, crop management practices, plant protection formulations, and sustainable production methods have enhanced productivity and quality. Its research spans high-value varieties, post-harvest technologies, bioactives, and value-added product development. Several commercialized products demonstrate IISR's impact, most notably Golden Milk Mix through MILMA, which gained widespread acceptance during COVID-19. Currently, IISR is developing liquid oleoresin blends for culinary applications (Sambhar, rasam, paneer butter masala, tea mixes) to replace conventional powders, ensuring instant, uniform flavor, consistency, and quality in food preparation.

How India's spice value chain is evolving

Traditionally, India exported bulk quantities of raw, dried spices and simple ground powders. This commodity approach meant competing on volume and accepting low margins. Today's landscape is fundamentally different:

From bulk to extracts: Instead of exporting 1000 tonnes of raw turmeric, processors now extract and export concentrated turmeric oleoresin. The same bioactive compounds are preserved, but in a product 10 times more concentrated, requiring less storage space, no quarantine requirements, no microbial spoilage due to absence of moisture content and commanding premium prices.

From generic to specialized: Raw spice exports serve generic purposes. Value-added products serve specific industries. A pepper oleoresin supplier, for instance, can target meat processing units, spice blend manufacturers, or pharmaceutical companies, each willing to pay different premiums based on purity and specifications.

From domestic to global supply chains: Large multinational food, pharma, and cosmetic companies increasingly source oils and oleoresins from India rather than processing raw spices in-house. This has created a structured supply chain where quality, consistency, and documentation matter more than volume.

From seasonal to year-round production: Advanced extraction and processing technologies allow companies to process spices continuously, smoothing production cycles and ensuring consistent supply to global markets regardless of harvest seasons.

Technology advances and emerging trends in spice value-chains

To cope up with the changing scenario in the global market and ever changing consumer preferences the spice value chain systems has also emerged to shift its strategy to match the global need. This can be summerised as follows:

Adaptation in production

- Climate-smart production through GIS mapping and precision farming for optimized resource use under changing climatic conditions.
- Vertical farming, controlled-environment plant factories, and protected cultivation for consistent, pesticide-free spice production.
- Organic and residue-free spice certification meeting stringent international food safety standards and premium market requirements.

Adaptation in processing

- Nano-encapsulation and nano-formulation improve bioavailability and stability of spice compounds like curcumin to enable targeted delivery and enhanced therapeutic efficiency.
- Advanced extraction technologies including supercritical fluid extraction and nano-encapsulation to enhance bioavailability of spice compounds.
- Smart packaging solutions with extended shelf life, ensuring product stability and consumer appeal.
- Blockchain-enabled supply chain traceability providing end-to-end documentation from farm to consumer.
- Improved (greener) extraction and purification techniques enabling production of specialty oleoresins and bio-flavours allowing development of specialty ingredients for diverse industries.
- Artisanal and gourmet spice blends catering to ethnic cuisine markets and premium consumer segments globally.

Adaptation in quality evaluation

- AI-powered quality assessment using multispectral imaging and electronic nose systems for rapid adulteration detection and purity verification.
- DNA barcoding and molecular tools for scientific authentication of spices and their bioactive profiles.
- Development of non-invasive and greener methods for quality analysis in spices.
- Electronic nose (E-nose) systems and sensor-based technologies for contamination detection replacing laborious conventional methods.
- Real-time assessment of intrinsic quality and contamination levels to reduce export rejection rate.

Emerging market opportunities

Global markets for spice-derived products are expanding at 8-12% annually. Key growth areas include:

- ***Nutraceuticals and functional foods:*** Turmeric for joint health, black pepper for nutrient absorption, ginger for digestion
- ***Cosmeceuticals and skincare:*** Spice bioactives in face creams, serums, and anti-aging products
- ***Pharmaceutical applications:*** Curcumin formulations for inflammation, piperine for bioavailability enhancement
- ***Beverage industry:*** Health drinks, immunity boosters, and wellness teas incorporating spice extracts
- ***Meat and poultry processing:*** Natural antimicrobial

and antioxidant agents replacing synthetic additives

Future prospects and strategic interventions in spice value chains

In the near future, spices are expected to evolve beyond traditional culinary ingredients into multifunctional products with applications in health, wellness, pharmaceuticals, cosmetics, functional foods, and personalized nutrition, thereby creating new opportunities for innovation and global market expansion.

Increasing emphasis is also being placed on the "wealth from waste" approach, wherein spice by-products and processing residues are efficiently utilized for the production of value-added products such as bioactive extracts, natural colorants, essential oils, pectin, dietary fibre, biodegradable packaging materials, and other functional ingredients. Such approaches not only improve profitability but also promote sustainability and circular bio-economy concepts within the spice sector.

Oil pulling with Cardamom Oil blend

Golden milk with spice oleoresins

Garam Masala flavored oil

Nutmeg Oil

Clove oil

Cianamon Essential oil

Future development should focus on the establishment of rapid, reliable, non-invasive, greener and cost-effective technologies for quality assessment, adulteration detection, traceability, and food safety management. Simultaneously, consumer-oriented studies focusing on market trends, sensory preferences, clean-label products, and sustainable packaging solutions will be essential for improving the global acceptance and commercial success of spice products.

Geographic indications certificates issued for spices and spice products have not yet resulted in effective capture of premium markets. This needs special attention as their exploitation can generate significantly more foreign exchange. Another promising sector for development is spice-based aromatherapy. At present, the use of essential oils from spices in aromatherapy, despite their innate medicinal properties, remains limited. Low infrastructure requirements and the absence of strict regulations offer advantages for this sector, enabling high expansion potential.

SUMMARY

India stands at a pivotal moment in its spice sector history. The convergence of scientific research validating spice health benefits, technological advancements enabling efficient processing, supportive government policies, and rising global demand for natural and functional ingredients creates an unprecedented opportunity to transform spices from a commodity into premium, value-added products.

Institutional coordination and equitable benefit sharing among stakeholders will be critical for strengthening spice value chains. Mechanisms such as contract farming, farmer-producer organizations (FPOs), cooperatives, and public-private partnerships can improve aggregation, value addition, marketing efficiency, and financial access for spice farmers.

For India to become a global hub for processed spice products, stronger collaboration among public research institutions, universities, private industries, farmer organizations, and policymakers is essential. This collaboration will facilitate faster technology transfer, commercialization, and innovation in areas such as extraction technologies, flavor blending, industrial processing, and nutraceutical product development.

The private sector is already leading this transformation. Whether it is turmeric oleoresins commanding premium prices globally or artisanal spice blends finding niche markets, the evidence is clear: The future of India's spice sector lies not in exporting more raw spices, but in exporting fewer tonnes of higher-value products. This shift promises greater profitability, sustainability, and global competitiveness for all stakeholders in the Indian spice value chain.

For further correspondence, contact:
[1]Dr. V Srinivasan, Principal Scientist & Head, Division of Crop Production & Post Harvest Technology, ICAR- Indian Institute of Spices Research, Marikunnu, Calicut 673 012, Kerala, India. Email: srisoilv@gmail.com; [2]Deputy Director General, Horticultural Science, Division of Horticultural Science, Krishi Anusandhan Bhawan - II, Pusa, New Delhi 110012, India.

Mahendra Gunjal, Sharmistha Naik*, Sachin Ekatpure, Sujoy Saha and Kaushik Banerjee

Grapes: A Natural Pathway to Human Nutrition and Health

Grape is a low-calorie fruit that contains about 80-85% water, and has a low amount of fat present. It provides energy to the extent of 53-94 kcal/100 g. Grape contains carbohydrates, dietary fiber, protein, vitamins such as C, K, B-complex, β-carotene, and E, and important minerals including potassium, calcium, phosphorus, and magnesium. There are a lot of antioxidants in the skin and seeds of the fruit, especially polyphenols, e.g. resveratrol, anthocyanins, quercetin, and catechins. The antioxidants make the fruit even better for health. These compounds are linked to benefits including cardiovascular protection and blood vessel health, lowering inflammation, improving metabolism, protecting the brain, and boosting the immune system. Colored grape varieties usually have more antioxidant activities. Promoting functional foods made from grapes by utilizing the processing industry by-products helps in increasing farmers' income, and supports farming systems that focus on health-oriented food strategies. It also helps ensure nutritional security, increase farmers income, and supports sustainable farming systems that focus on health-oriented food strategies.

Keywords: Anthocyanins; Functional foods; Grape; Nutraceuticals; Polyphenols; Resveratrol

IN recent years, changes in eating habits and greater health awareness have lead consumers to prefer functional and nutrient-rich foods. In this context, grapes have become more popular because of their high polyphenol content and health benefits. The rising rates of lifestyle-related conditions, like heart disease, type 2 diabetes, and obesity, have increased the demand for foods that can help prevent or treat these issues. Grapes are good sources of carbohydrates including glucose and fructose, moderate amounts of dietary fiber and important micronutrients. It is well-known for having a lot of polyphenols, such as flavan-3-ols, anthocyanins, flavonols, stilbenes (resveratrol), and phenolic acids. These compounds have strong antioxidant effects and help control oxidative stress, keep blood vessels healthy, control fat metabolism, and lower inflammation.

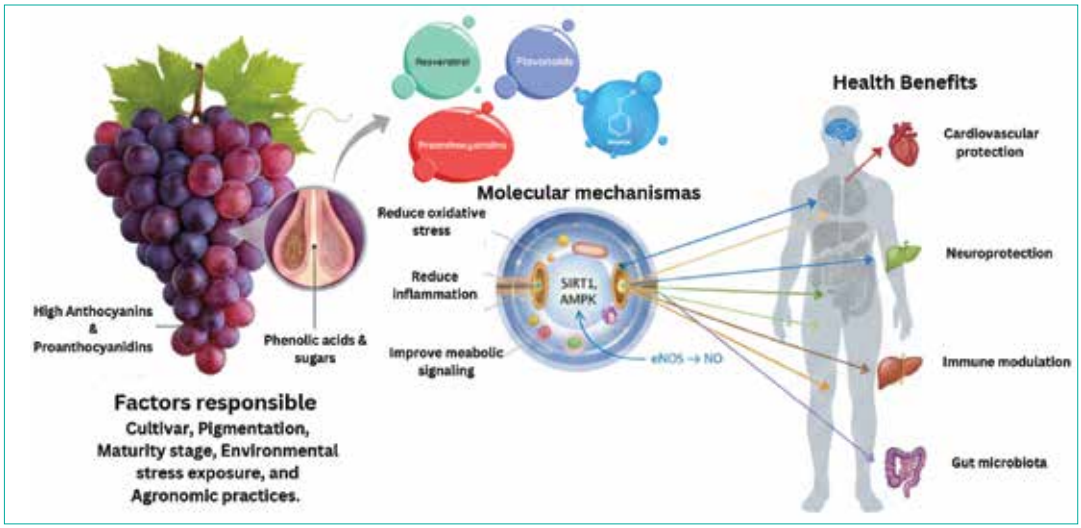
Consumption of grapes play a significant role in regulating biochemical processes, such as balancing oxidative stress, improving insulin sensitivity, supporting blood vessel function, and modulating gut bacteria. Grapes can be processed into a diverse range of products such as juice, wine, vinegar, concentrates, and grape-seed extracts, thereby contributing to nutritional security. In addition, the efficient utilization of by-products like pomace and seeds for extracting proanthocyanidins, dietary fiber, and seed oil not only minimizes waste but also enhances the availability of health-promoting compounds, supporting sustainable and nutrition-sensitive food systems.

Nutritional composition and health significance of grapes

Grape contains nutrients as well as other bioactive substances, and composition of these in berries depends on genetic differences, environmental factors, ripeness of the fruit, and farming practices. However, the basic nutritional profile remains the same across different grape products. The composition of the nutrients in the fruit indicates that it is not only a source of energy but also a functional food that can influence many physiological systems in the body (Figure 1). Fresh grape contains 80 to 85% water, and it is essential for hydrating the body and controlling temperature in the body. Fresh grapes provide approximately 224–395 kJ (53–94 kcal) per 100 grams. Carbohydrates constitute the major component of fresh grapes, ranging from 12 to 20 g/100 g. These carbohydrates are primarily present as simple sugars, which are rapidly absorbed in the intestine through glucose transporters. However, their impact on blood sugar levels is moderated by the dietary fiber content, which ranges from 1.15 to 1.64 g/100 g.

Although grapes contain relatively low protein levels (0.6–1.4 g/100 g), their amino acids contribute to various physiological functions in the body. The lipid content in the fruit pulp is also minimal (0.26–0.46 g/100 g); however, grape seeds are rich in essential fatty acids, including saturated, monounsaturated, and polyunsaturated forms. Among these, linoleic acid is a prominent polyunsaturated

fatty acid in grape seed oil. It plays important roles in eicosanoid synthesis, maintenance of membrane fluidity, and lipid signaling. Owing to these functional properties, grape seed lipids have attracted considerable interest for the development of health-promoting products.



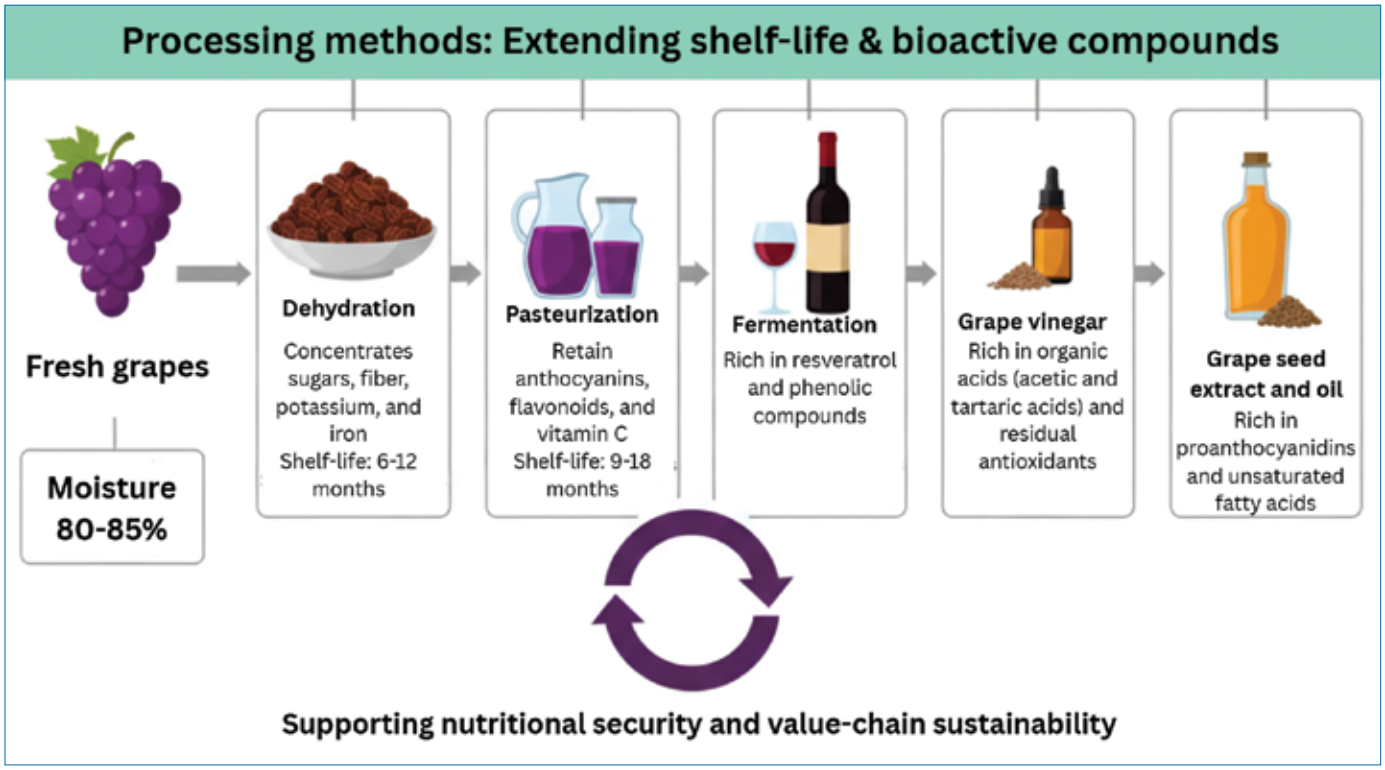
The bioactive compounds in grapes and their health benefits

The characteristic feature of grapes, nevertheless, is the varied polyphenolic structure. Polyphenols are secondary metabolites that have an aromatic ring structure with hydroxyl groups that can donate electrons in redox reactions. These molecules are found to be localized in the skin and seeds, along with minor amounts in the pulp. Their biosynthesis is known to be induced by environmental stress factors such as exposure to UV light and pathogens, as part of the protective response in the defense mechanisms of the plant. Of the polyphenols in grapes, resveratrol, a stilbene derivative, has been the focus of much scientific investigations. Resveratrol has been found to have significant antioxidant properties by quenching reactive oxygen species (ROS) and inducing the activity of endogenous antioxidant enzymes such as catalase and glutathione peroxidase. More importantly, it modulates cellular signaling cascades through sirtuin-1 (SIRT1) and AMP-activated protein kinase (AMPK) activation, which are important in the regulation of mitochondrial biogenesis, lipid metabolism, and insulin sensitivity. These polyphenols are important in cardioprotective, antidiabetic, neuroprotective, and anti-proliferative activities. It also enhances endothelial nitric oxide synthase (eNOS) activity, thereby increasing nitric oxide production and vasodilation. Moreover, it shows inhibitory properties against low-density lipoprotein (LDL) oxidation and platelet aggregation.

Flavonoids make up the major class of grape polyphenols and consist of flavonols, flavan-3-ols, and anthocyanins. Quercetin has anti-inflammatory properties and acts on the cyclooxygenase and lipoxygenase pathways and on NF-kB, which controls cytokine (small proteins that act as vital chemical messengers regulating immunity, inflammation, and hematopoiesis) production from immune cells. Catechins and epicatechins increase endothelial reactivity and decrease lipid peroxidation by increasing the bioavailability of nitric oxide. Anthocyanins, responsible for the red and purple color of grapes, have strong free radical scavenging activities and modulate signaling for apoptosis, angiogenesis, and inflammatory modulation. Epidemiological studies have shown anthocyanins to have cardiovascular and cognitive benefits by increasing cerebral perfusion.

Manjri Naveen

Among the bioactive compounds, grape seed has been reported to have high levels of proanthocyanidins, which are basically condensed tannins with high antioxidant activities. This oligomeric flavan-3-ol has been reported to have antioxidant properties,



Different processing methods for improving shelf-life and bioactive compounds

and potential to strengthen connective tissue and capillary integrity by inhibiting matrix metalloproteinases. The importance of grapes to the body's physiological functions can be attributed to the synergistic effect of these nutrients and bioactive compounds, rather than the bioactive compounds acting in isolation. These bioactive compounds have been reported to modulate transcription factors, nuclear receptors, and epigenetic mechanisms, which regulate genes responsible for oxidative stress response, inflammation, and metabolism.

In the gastrointestinal tract, grape polyphenols undergo bioconversion by microorganisms, which leads to the production of smaller bioavailable phenolic compounds. This interaction favors the growth of *Lactobacillus* and *Bifidobacterium*, while inhibiting pathogenic microorganisms. This increase in microbial diversity enhances nutrient uptake, intestinal integrity, and reduces systemic inflammation. Short-chain fatty acids, which are produced during metabolism of dietary fiber components of grape, also play a crucial role in managing the regulatory process of metabolic and immune homeostasis. The systemic contribution of grapes, as per the system biology approach, can be viewed as an integrated effect on different physiological domains. Cardiovascular protection is provided by potassium-mediated blood pressure control and polyphenol-mediated improvement of endothelial function. Regulation of metabolism is provided by a moderated glycaemic response, improvement of insulin sensitivity, and reduction of oxidative stress. The neuroprotective effect of grapes is provided by reduced inflammation of neurons and improvement of blood flow to the brain. The immune system is protected by vitamin C-mediated improvement of leukocyte function, while the stabilizing effect on connective tissue and skin is provided by proanthocyanidin-mediated preservation of collagen integrity.

Grapes provide a multidimensional health benefits that includes hydration, electrolyte balance, micronutrient supplementation, organic acid functionality, and phytochemical bioactivity, making it a nutritionally dense fruit with significant scientific validity for maintaining health, preventing diseases, and providing a basis for the use of grapes as a functional food for health-promoting diets.

Value-added products and nutritional enhancement

Grape is a seasonal fruit, and processing is essential to ensure its availability throughout the year while retaining all nutritional and functional properties. Value addition makes them more important for nutrition by making sure they are always available in different forms. Such processing not only extends shelf-life of the products but also helps concentrate nutrients and bioactive compounds, thereby enhancing their functional and commercial value. Furthermore, the development of grape-derived products allows for better utilization of the fruit, increased economic returns, and preservation of key phytochemicals with potential health benefits (Fig. 2).

Raisins are processed by dehydrating grapes, which reduces their moisture content to 15-18%. The process increases the energy value by concentrating natural sugars, fiber, potassium, and iron contents. Although drying might lose some potency of bioactive substances, the polyphenols usually retain their bioactivity. Grape juice, a ready-to-serve beverage, retains its bioactive components such as anthocyanins, flavonoids, and vitamin C during processing, provided the temperature is appropriately regulated during the process. Pasteurization of grape

Sharad Seedless

juice makes it safe for consumption while minimizing the loss of polyphenols. Apart from these, micronutrients such as iron and vitamin C can be added to enhance these benefits. Wine, especially red wine, is prepared by a process of fermentation, and through extended skin contact, the extraction of resveratrol and diverse phenolic compounds increases. Moderate wine consumption has been found to have beneficial effects on blood vessel function and oxidative stress levels. Vinegar made from grapes has organic acids such as acetic acid and tartaric acid, as well as the antioxidants that remain intact after processing. These have beneficial effects on digestion and blood sugar levels. Grape seed extract and oil are rich in proanthocyanidins and unsaturated fatty acids. Processing increases the products' shelf life and provides a market for these products, which has beneficial effects on nutrition and value chains

SUMMARY

Grapes have been recognized for their nutritional value, containing carbohydrates, essential vitamins and minerals, and various antioxidants including polyphenolic compounds, which play a crucial role in maintaining heart, and regulating metabolic, immune, and cell health. The bioactive components of grapes, including flavonoids and proanthocyanidins, have been reported to prevent diseases and reduce oxidative stress. The processed products derived from grapes, including raisins, juice, wine, vinegar, and grape seed extract, increase the shelf-life and enhance the nutritional value. Grapes, therefore, have been recognized for their nutritional and health benefits, along with their contribution to economic sustainability.

For further correspondence, contact:
Dr. Sharmistha Naik, Scientist, ICAR-National Research Centre for Grapes, Pune 412 307, Maharashtra, India. Email: naiksharmistha@gmail.com

Sunil Kumar*, Bikash Das, Abhay Kumar, Ankit Kumar, Ipsita Samal, Ashok Dhakad and Rohit Kumar

Litchi: A Nutrient-Rich Fruit for Better Health and Nutrition Security

Litchi (*Litchi chinensis* Sonn.), popularly known as the 'Queen of Fruits', is a nutrient-rich subtropical fruit with significant potential to enhance nutrition and health in India. It is normally consumed as fresh or processed and has become one of the most popular fruits because it has a delicious flavor, attractive color, and high nutritive value. Whole litchi fruits have been used not only as a food source but also for medicinal purposes. The health benefits of litchi have been attributed to its wide range of nutritional components, among which polysaccharides and polyphenols have been proven to possess various beneficial properties. Regular consumption of litchi supports immunity, cardiovascular health, digestion, and overall well-being. The fruit also plays an important role in addressing hidden hunger by improving dietary diversity and micronutrient intake. In addition, litchi by-products offer scope for nutraceutical and value-added applications. With its increasing availability and acceptance, litchi is emerging as a nutrition-smart fruit, contributing to improved public health and supporting nutrition-sensitive horticulture in India.

Keywords: Health benefits; Immunity booster; Litchi; Nutrition-smart fruit; Oligonol

HORTICULTURAL crops are now acknowledged as key drivers of nutritional security, particularly in developing countries like India where micronutrient deficiencies remain widespread. In this context, fruits serve not only as sources of income but also as essential components of a balanced and healthy diet. Litchi stands out as a promising fruit crop that combines taste with nutrition and health benefits. Its bright red skin, juicy translucent pulp, and distinct sweet flavour make it one of the most relished summer fruits in India. Beyond its sensory appeal, litchi is increasingly recognized as a nutrition-rich and health-promoting fruit, contributing significantly to improved dietary quality and well-being. India is the second-largest producer of litchi globally, with major cultivation concentrated in Bihar, followed by Jharkhand, Uttar Pradesh, and West Bengal. In recent years, driven by its remunerative returns and increasing demand, litchi cultivation is expanding into non-traditional regions such as Rajasthan, Himachal Pradesh, Madhya Pradesh, Punjab, as well as southern states and North Eastern India. This expansion is improving the availability of this nutrient-rich fruit and strengthening its role in nutrition-sensitive agriculture.

Nutritional richness: A natural source of energy and vital nutrients

Litchi is a refreshing summer fruit with high moisture content (about 80–82%), making it highly effective in

Attractive bunches of litchi cultivars '*Shahi*' and '*China*', highlighting their distinct colour

maintaining hydration during hot weather. The fruit pulp contains natural sugars such as glucose, fructose, and sucrose, which provide quick and easily digestible energy. One of the most important nutritional attributes of litchi is its high vitamin C content, which plays a crucial role in enhancing immunity and protecting the body against infections. The fruit also contains B-complex vitamins such as thiamine, riboflavin, and niacin, which are essential for metabolic functions. Litchi is a good source of minerals including potassium, magnesium, calcium, phosphorus, and iron. Additionally, the presence of dietary fiber contributes to improved digestion and gut health. Beyond basic nutrients, litchi is rich in bioactive compounds such as flavonoids, phenolic acids, and anthocyanins. A unique compound, oligonol, derived from litchi polyphenols, enhances its functional value.

Table 1. Nutritional composition of litchi per 100 g fresh fruit

Moisture	**71.11-84 g**	**Niacin (Vitamin B_3)**	**1.1 mg**
Carbohydrate	15-89 g	Ascorbic acid (Vitamin C)	15 – 60 mg
Protein	0.7-4.12 g	Calcium (Ca)	4 – 4.90 mg
Fat	0.1-3.75 g	Phosphorus (P)	25 – 35 mg
Fiber	1.3 g	Potassium (K)	140 – 180 mg
Thiamine (Vitamin B_1)	0.02 mg	Copper (Cu)	0.17 – 0.23 mg
Riboflavin (Vitamin B_2)	0.07 mg	Zinc (Zn)	0.16 – 0.28 mg

Health benefits: A functional fruit for modern lifestyles

Litchi, often regarded as a functional fruit, offers a wide range of health benefits due to its rich composition of nutrients and bioactive compounds. The fruit is an excellent source of vitamin C, which plays a vital role in strengthening the immune system and protecting the body against infections. Regular consumption of litchi helps enhance the body's natural defense mechanisms, making it particularly beneficial in maintaining overall health. In addition, litchi is rich in polyphenols and other antioxidants that help neutralize harmful free radicals in the body. This antioxidant activity reduces oxidative stress and protects cells from damage, thereby lowering the risk of chronic diseases. The presence of potassium and flavonoids further contributes to heart health by helping regulate blood pressure and improving overall cardiovascular function.

Litchi also exhibits anti-inflammatory properties, as its bioactive compounds help reduce inflammation associated with various lifestyle disorders. Compounds like oligonol have been reported to support metabolic health by aiding in the regulation of blood sugar levels and reducing fat accumulation. Moreover, the dietary fiber present in litchi promotes healthy digestion, supports gut function, and helps prevent constipation. The protective effects of litchi extend to vital organs as well. Its antioxidant constituents are known to support liver health and may play a role in reducing the risk of neurodegenerative disorders. Overall, these health-promoting properties highlight the importance of litchi in managing lifestyle-related conditions such as hypertension, diabetes, and cardiovascular diseases, making it a valuable addition to modern diets.

Role in combating hidden hunger

Micronutrient malnutrition, commonly termed 'hidden hunger', continues to pose a serious public health challenge in India, particularly among children, women, and other vulnerable groups. Despite adequate calorie intake, deficiencies of essential vitamins and minerals often lead to impaired immunity, poor growth, and increased susceptibility to diseases. In this context, litchi emerges as a valuable fruit with the potential to contribute meaningfully toward improving nutritional security. Litchi is a rich source of vitamin C, along with important minerals and bioactive compounds that support better nutrient absorption and overall metabolic functions. Regular inclusion of litchi in the diet can enhance dietary diversity, which is a key strategy in addressing micronutrient deficiencies. Its refreshing taste, appealing appearance, and ease of consumption make it especially suitable for promoting fruit intake among children.

Furthermore, incorporating litchi into daily diets–either as fresh fruit or in processed forms–can help bridge nutritional gaps in resource-limited settings. For women, particularly during pregnancy and lactation, improved intake of micronutrients through fruits like litchi can support better health outcomes. At the community level, promoting litchi cultivation and consumption can complement ongoing nutrition-sensitive horticulture initiatives aimed at combating malnutrition. Thus, litchi holds significant promise as a nutrition-smart fruit that not only enriches diets but also plays an important role in reducing hidden hunger and improving overall public health in India.

Functional and nutraceutical potential: Recent research has highlighted that not only the edible portion (aril) but also the by-products of litchi possess significant functional and nutraceutical value. The peel (pericarp) and seeds, which are often discarded as waste, are rich sources of bioactive compounds, particularly antioxidants such as polyphenols. These compounds have strong health-promoting properties and offer considerable scope for utilization in value-added applications. The antioxidant-rich litchi peel can be effectively utilized in the development of functional foods and nutraceutical products aimed at promoting health and preventing diseases. In addition, these bioactive constituents have potential use as natural preservatives, helping to improve the shelf life and safety of food products in an eco-friendly manner.

Processing and value addition further enhance the utility of litchi. Products such as juices, squashes, and dried litchi not only increase the availability of the fruit beyond its short harvesting season but also facilitate better nutritional utilization. Thus, litchi and its by-products present promising opportunities for developing health-oriented products while also contributing to waste reduction and sustainable horticulture.

Value-added litchi products developed by ICAR–National Research Centre on Litchi, demonstrating potential for enhanced nutrition, shelf life, and income generation

Enhancing nutritional quality through post-harvest management

Maintaining the nutritional quality of litchi after harvest is crucial, as the fruit is highly perishable and prone to rapid deterioration under ambient conditions. Improper handling can lead to significant losses in vitamin C, antioxidants, and overall fruit quality. Therefore, adoption of scientific post-harvest management practices is essential to preserve its nutritional integrity and market value. In this regard, ICAR-National Research Centre on Litchi has been playing a pivotal role in developing and disseminating improved post-harvest technologies for litchi. Improved storage and packaging practices, including the use of perforated packaging materials and modified atmosphere techniques, have also been promoted to reduce physiological losses and maintain fruit freshness. Such interventions are particularly important for distant marketing and export, where quality retention is a major concern.

Processing technologies further contribute to enhancing the availability and utilization of litchi. Techniques such as juice extraction, pulp preservation, dehydration, and preparation of products like squash and nectar not only extend shelf life but also ensure year-round accessibility of nutrients. The development of value-added products from litchi, has opened new avenues for reducing post-harvest losses and improving farmers' income. Overall, scientific post-harvest management, coupled with processing and value addition, plays a vital role in preserving the nutritional richness of litchi and strengthening its contribution to nutrition security and horticultural development in India.

Manual and mechanical peeling of litchi fruits for preparation of litchi-based rasgulla and value-added products, involving systematic separation of aril (pulp), with pericarp (peel) and seeds generated as processing by-products, indicating their potential for value-added utilization

Litchi honey: Where flavor meets health: Litchi honey is a premium, monofloral honey produced by bees that forage predominantly on the blossoms of litchi orchards during the flowering season. It is known for its light amber colour, delicate floral aroma, and pleasantly mild sweetness, making it highly preferred by consumers. Nutritionally, litchi honey is rich in natural sugars, enzymes, amino acids, vitamins, and antioxidants, which contribute to its health-promoting properties. Regular consumption is associated with improved digestion, enhanced immunity, and quick energy supply. It also exhibits antimicrobial and anti-inflammatory properties, making it useful in traditional remedies. From an economic perspective, litchi honey offers an excellent opportunity for integrating beekeeping with litchi cultivation, thereby enhancing pollination, improving fruit yield, and providing additional income to farmers.

SUMMARY

Litchi is a unique fruit that combines excellent taste with high nutritional and health value, making it highly relevant for modern diets. Rich in vitamins, minerals, and bioactive compounds, it supports immunity and helps address hidden hunger and nutritional security in India. Beyond nutrition, its potential in functional foods, nutraceuticals, and value-added products enhances utilization and reduces wastage. Scientific interventions by ICAR-National Research Centre on Litchi in post-harvest management and processing have further strengthened its importance as a high-value crop. With expanding cultivation and awareness, litchi is emerging as a nutrition-smart fruit contributing to both public health and farmers' livelihoods.

For further correspondence, contact:
Dr. Sunil Kumar, Scientist, ICAR-National Research Centre on Litchi, Mushahari, Muzaffarpur 842 002, Bihar, India. Email: mehtasunil98@gmail.com

Pratik Kumar Sinha, G Karunakaran*, C Kanupriya, Pushpa Chethan Kumar, Preethi P and C K Narayana

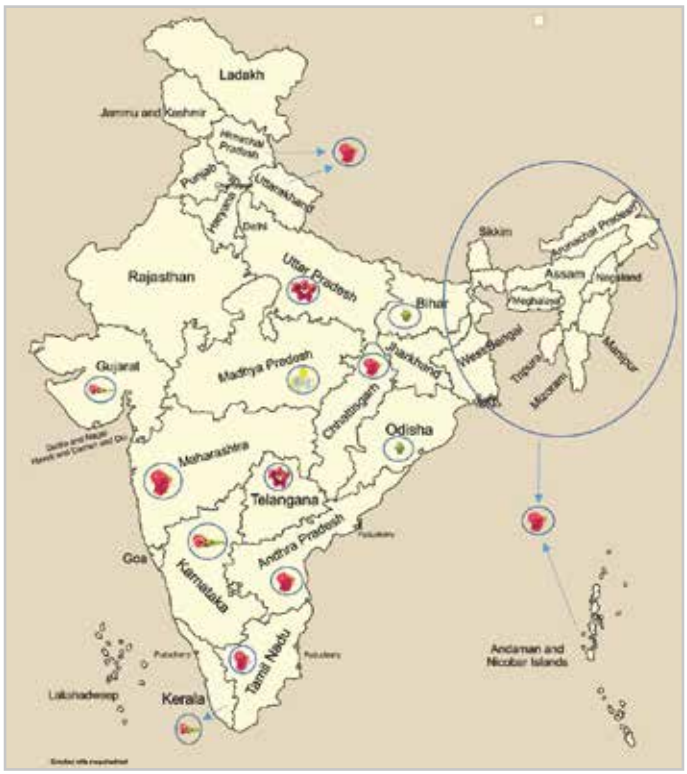
Dragon Fruit: A New-Age Fruit for Nutrition, Income and Sustainable Farming

Kamalam fruit is emerging as a high-value fruit crop in India owing to its richness in nutritional profile, adaptability to diverse agro-climatic conditions and increasing consumer demand. Rich in dietary fibre, minerals and antioxidants such as betalains, it is increasingly recognised as a health promoting fruit. The crop requires relatively low water, tolerates low fertile soils and bears early, making it suitable for sustainable horticulture. With increasing production, value addition has become mandatory to enhance market demand and farmer's income. Research-led innovations such as Kamalam RTS, a ready-to-serve beverage with natural colour and prolonged shelf life, and dragon fruit powder with extended storage stability and diverse food applications, demonstrate the crop's processing potential. Overall, dragon fruit offers great potential for nutrition security, entrepreneurship and profitable diversification of farming systems in India.

Keywords: Betalains; Dietary fibre; Nutraceutical value; Pitaya; Value-addition

DRAGON fruit (*Selenicereus spp*), popularly known as Pitaya, is a climbing or sprawling cactus belonging to the family Cactaceae. It is a perennial, fast-growing plant with succulent, greenish, angular stems that develop aerial roots, enabling it to cling on the poles or other supports. A distinctive feature of Dragon fruit is its Crassulacean Acid Metabolism (CAM) pathway, in which stomata opens at night, reducing water loss. This adaptation makes the crop well suited to dry and semi-arid regions with limited water availability.

Dragon fruit originated in the tropical rainforests of Mexico and Central America. From its centre of origin, it spread to South America and later to Southeast Asian countries such as Vietnam, Thailand, Malaysia, and Philippines, where it received commercial importance due to its attractive fruits and gained strong market demand. Vietnam became a major producer and exporter, significantly contributing to its global popularity. In India, Dragon fruit was introduced in the late 1990s and has gained rapid recognition since then its adaptability to diverse agro-climatic conditions, drought tolerance, suitability for problematic soils, and increasing consumer demand have supported the gradual expansion of cultivation across several states, establishing it as an emerging fruit crop of horticultural significance.



Major Dragon Fruit production zones and Emerging States in India

Dragon fruit (vernacularly called as Kamalam fruit) has emerged as a promising crop in India. Once limited to niche markets, now it is widely cultivated due to its great market value, adaptability to diverse agro-climatic conditions, and very less water requirement. Rich in dietary fibre, vitamins, minerals, and antioxidants, it appeals to health-conscious consumers.

Beyond nutrition, it offers vast potential for sustainable horticulture and income generation. It suits marginal farmers and supports value addition through processing of pulp, seeds, and peel. Thus,

kamalam fruit is emerging as a crop that can enhance nutrition security, farmer livelihoods, and sustainable agricultural development in India.

Nutraceutical value and health benefits: Dragon fruit, has established itself as a prominent tropical fruit owing to its balanced phytochemical profile and presence of health-promoting compounds. The fresh pulp contains about 82-85% moisture, making it light and easily digestible, while its less fat content and low energy value supports its adoption in health-oriented diets. The fruit provides moderate dietary fibre (0.8-1.0 g/100 g pulp), contributing to digestive health and glycemic control. It also supplies essential micronutrients, including vitamin C (6 mg/100 g) and important minerals such as potassium (120-200 mg/100 g), calcium (20-45 mg), magnesium (30-45 mg), phosphorus (20-35 mg), and iron (0.7-1.5 mg/100 g), enhancing its overall nutritional value.

Distinctive nutritional attribute of Dragon fruit is its richness in bioactive compounds, particularly betalains, phenolic compounds, and flavonoids, which together contribute to its strong antioxidant potential. Betalains, responsible for the characteristic red and pinkish red colour in red & purple fleshed Dragon fruit, are known for their antioxidant and anti-inflammatory potential. Phenolic content in Dragon fruit pulp has been reported to range between 25-55 mg GAE/100 g, while flavonoid content ranges from 15-35 mg CE/100 g. In addition, dragon fruit contains moderate levels of natural sugars (about 5-7 g/100 g pulp) and displays a low glycaemic index, making it suitable for diabetic and health-conscious consumers when consumed regularly. The collective presence of fibre, essential minerals, vitamin C, betalains, and antioxidants positions it as a nutritionally valuable fruit capable of supporting improved nutrition and overall health.

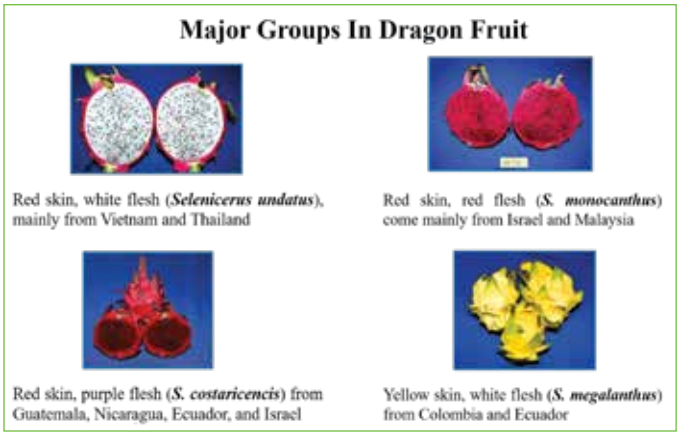
Important species and varieties under cultivation: Dragon fruit commercial cultivation worldwide is based on a only few species of the genus *Selenicereus* (formerly grouped under *Hylocereus*). The most widely grown species is *Selenicereus undatus*, which has a red or pink peel with white pulp. It is preferred for its wide adaptability, stable yield, and commercial success. The fruits are less sweet and suitable for fresh consumption as well as processing.

Red-fleshed types are mainly represented by *Selenicereus monacanthus* and *Selenicereus costaricensis*, producing red peel with red to reddish purple pulp. These types are gaining popularity because of their attractive colour and higher betalain content, contributing to higher antioxidant value and better market prices, particularly in urban and export markets. The yellow-skinned species, *Selenicereus megalanthus*, has limited occurrence in India because of slower growth and limited adaptability, although it has superior sweetness. In India, cultivation is largely focused on white- and red fleshed types, with growing interest in red- and purple-fleshed genotypes.

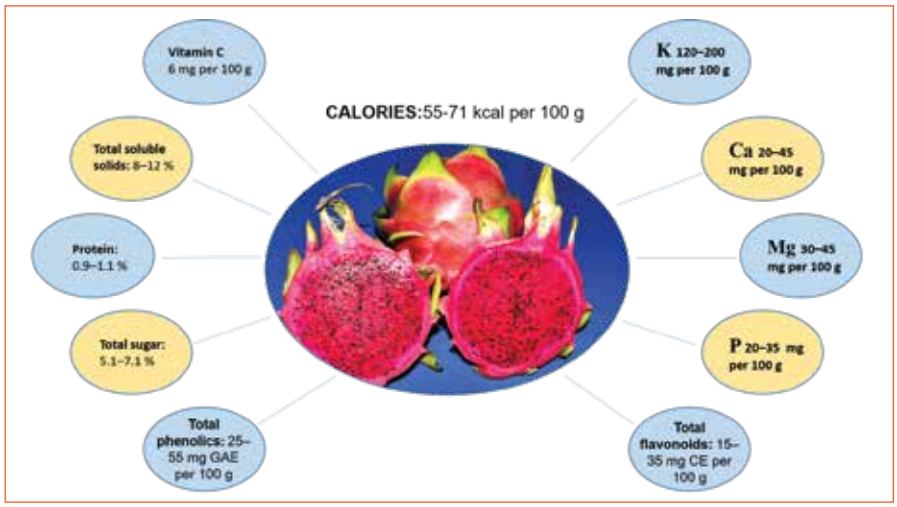
Several promising genotypes *CHES-D1*, *CHES-D2*, *CHES-D3*, *Hirehalli White*, and *CHES-DE* are under evaluation at the Centre of Excellence, Hirehalli, ICAR-Indian Institute of Horticultural Research. These are being analyzed for growth, yield, fruit quality, and adaptability, supporting the spread of region-specific, high-performing planting material in India.

Cultivation practices and agronomic advantages: Dragon fruit cultivation is rapidly increasing in India due to its adaptability to diverse agro-climatic conditions. It performs well in tropical and subtropical regions and tolerates drought better than many fruit crops. It thrives in well-drained soils and can be grown successfully on marginal or degraded lands, provided waterlogging is not a problem. The key agronomic advantage is its low water requirement. Because of its CAM pathway, the plant utilises water efficiently by reducing transpirational losses. This makes it suitable for drought prone areas. Drip irrigation is recommended to enhance water use efficiency, particularly during flowering and fruit development.

Plants are trained on concrete or wooden poles to promote vertical growth and facilitate better canopy management practices. Regular pruning improves light penetration, regulates vegetative growth, and enhances



Different Species of Dragon fruit



Nutritive value of Dragon fruit

flowering and yield. Removal of weak, diseased and overcrowded shoots ensures better plant health and productivity. Dragon fruit bears early, with flowering & fruiting starting 14–18 months after planting under good management. Multiple flowering flushes (generally 5-8, differ from species to species) enable staggered harvesting and continuous income. The crop has relatively low pest and disease incidence however in tropical region, ants and anthracnose are major problem. In addition to diseases fruit cracking is major physiological disorder. Proper management practices help in reducing these incidences.

Overall, drought tolerance, Minimal input requirement, early and extended bearing, and wide adaptability make Dragon fruit a suitable crop for farming system diversification and sustainable income generation in India.

Value addition and product diversification in dragon fruit: Production of dragon fruit is steadily increasing in India, creating a strong need for development of value-added products to enhance demand, stabilise prices and improve farmer income. Value addition not only strengthens market potential but also ensures better utilisation of surplus produce and reduces post-harvest losses. In response to growing consumer preference for convenient and health-oriented beverages, ready-to-serve (RTS) fruit drinks are securing popularity as healthier alternatives to carbonated beverages.

In this direction, ICAR–Indian Institute of Horticultural Research (IIHR), Bengaluru, has developed Arka Kamalam RTS, a ready-to-serve beverage from Dragon fruit. Preparation of dragon fruit RTS is technically challenging due to the mucilaginous nature of the pulp. A standardised method has been developed to obtain clear juice without seeds, resulting in an attractive beverage with a natural pink colour and characteristic flavour without the addition of synthetic colours or flavours. The RTS beverage has a shelf life of up to six months under optimum storage conditions and retains important phytochemical compounds such as ascorbic acid, total betalains and polyphenols known for their health-promoting properties.

Arka Kamalam RTS

In addition to beverages, Dragon fruit powder has been developed as a stable, value-added product with prolonged shelf life (approximately six months at room temperature and up to twelve months under refrigerated storage). The powder contains appreciable amounts of carbohydrates, dietary fibre and protein, along with significant levels of bioactive compounds such as anthocyanins (96 mg/100 g) and vitamin C (43 mg/100 g). It is also a source of essential minerals including calcium, potassium, magnesium, iron, zinc and manganese. Due to its intense natural pink colour and functional properties, Dragon fruit powder can be utilised as a natural food colourant and flavouring ingredient in bakery products, confectionery, milkshakes, ice cream and health formulations. The powder form facilitates easy transportation, storage and incorporation into various food matrices.

Dragon fruit powder

Processed products prepared from dragon fruit powder and pulp

Beyond edible applications, Dragon fruit fractions derived from the pulp and peel are now-a-days utilised in cosmetic products such as creams, soaps and lotions owing to their antioxidant-rich composition and skin-beneficial properties. Red- and purple-fleshed cultivars are highly suitable for such diversified processing due to their high pigment content, while the peel, often regarded as waste, can be effectively utilised for the extraction of natural pigments and antioxidants, thereby promoting sustainable processing and circular resource utilisation. Adoption of these value-added technologies by farmers, food processing industries, farmer-producer organisations (FPOs) and small-scale entrepreneurs can expand product portfolios, generate additional income and enhance the overall profitability and environmental stewardship of Dragon fruit cultivation in India.

SUMMARY

Dragon fruit has arisen as a promising fruit crop in India owing to its nutritional richness, adaptability to diverse agro-climatic conditions and increasing consumer demand. Its low water requirement, tolerance to problematic soils and early bearing habit make it suitable for sustainable and climate-resilient horticulture. Increasing awareness about functional foods has further enhanced the demand for red- and purple-fleshed types

rich in natural antioxidants. With expanding cultivation, emphasis on scientific production practices, quality planting material and market-driven approaches will be essential to realise the full potential of the crop. Value addition and diversification of products can further improve Revenue generation and reduce post-harvest losses. Overall, dragon fruit offers significant opportunities for enhancing nutrition security, strengthening farmer livelihoods and promoting sustainable diversification of farming systems in India.

For further correspondence, contact:
Dr. G Karunakaran, Principal Scientist, Division of Fruit Crops, ICAR-Indian Institute of Horticultural Research, Hesaraghatta Lake Post, Bengaluru 560 089, Karnataka, India. Email: avojack2023@gmail.com

Heiplanmi Rymbai*, H Talang, S Nandhakumar, M Bilshini Devi, V K Verma and T Ramesh

Advancement in Sohiong *(Prunus nepaulensis)* to improve nutrition and food systems in NEH, India

Sohiong (*Prunus nepaulensis* (Ser.) Steud.) is an important underutilised indigenous fruit species native to Northeast India. Fruits are a valuable dietary source of nutrients, antioxidants, bioactive constituents and pigments, thereby representing a promising functional food with nutraceutical benefits. The fruits are consumed fresh and used in a range of value-added products, thus, play a significant role in the economy and traditional food systems in the region. The major scientific advances to improve the production and quality of Sohiong fruits are germplasm improvement, nutrient and bioactive compound profiling, standardisation of propagation techniques, sustainable orchard management, development of value-added products, and conservation strategies. Conservation and popularisation strategies are essential for sustainable utilisation, biodiversity conservation, livelihood enhancement, and strengthening climate-resilient food systems in Northeast India.

Keywords: Medicinal properties; Nutrition; Propagation; *Prunus nepaulensis*; Value additions

SOHIONG (*Prunus nepaulensis* (Ser.) Steud.) is a member of the rosaceae family and is also known as the Khasi cherry. It is an important indigenous fruit species native to the Eastern Himalayan region and widely distributed in the hill ecosystems of Northeast India, particularly Meghalaya. The fruit has deep cultural, nutritional, medicinal, and economic significance among the Khasi and Jaintia tribal communities. The fruits are consumed fresh and also used for various value-additions. The fruits are a valuable dietary source of many bioactive constituents and pigments, which also impart the characteristic colour and flavour of the fruit. Various scientific advancement for promotion, popularisation and conservation of this fruit crop has been attempted. The promotion of indigenous fruit species such as Sohiong can significantly contribute to sustainable food systems while supporting local livelihoods.

Botanical description and habitat: It is an evergreen or semi-evergreen tree that grows naturally in subtropical and temperate forest ecosystems. Trees are medium to large, deciduous, and 15-20 m high with grey bark, upright branches, and oblong-lanceolate leaves. The tree produces small, round fruits that turn deep purple to black upon ripening. The fruits possess a characteristic sweet-acidic flavour and are highly appreciated by local communities.

The species require low chilling hours, about 300 hours for good flowering and fruiting. The fruit tree species is believed to have originated in the foothills of the eastern Himalayas of India, particularly in the hills of Khasi and Jaintia. It is growing wild in the subtropical and temperate Himalayan regions at altitudes between 800 and 3000 m a.s.l.

Sohiong Tree

The major advancement in Sohiong

Germplasm improvement: The Sohiong genotypes are classified into two groups based on fruit size: The big-sized and small-sized fruits. Considerable variability was observed between the bigger and smaller fruit types. The bigger fruits are superior in size, carbohydrates, vitamin C, and minerals, while smaller fruits possess better pulp recovery and

Table 1. Organic and carbohydrates in the fruits of *Prunus nepaulensis*

Parameters	Value
Titratable acidity	1.15-3.32 %, fw
pH	3.53
Citric acids	335.0 mg/100 g fw
Total soluble solids	16.73-21.43% fw
Reducing sugar	4.26-4.89% fw
Total sugar	6.40-8.75% fw
Carbohydrate	14.90% fw
Glucose	1.52% fw
Fructose	1.62% fw
Sucrose	3.03% fw
Pectin	1.80-2.54% fw
Lignin	1.2% dw
Cellulose	14.4% dw
Hemi-cellulose	19.8% dw
Fibre	1.71-5.50% dw
Acid detergent fibre	16.5% dw
Neutral detergent fibre	36.3% dw

Table 2. Fats and protein composition in fruits of *Prunus nepaulensis* Ser.

Parameters	Value
Fat	2.68% fw
Total oil	0.66% fw
Protein	1.49-1.76% fw
Proline	3.08 µ moles/gm fw

Table 3. Mineral composition in fruits of *Prunus nepaulensis* Ser.

Parameters	Values
Nitrogen	69.95 - 70.01 mg/100 g dw
Phosphorus	70-115 mg/100 g dw
Potassium	485.01-530.00 mg/100 g dw
Calcium	1220 mg/100 g dw
Magnesium	217.7 mg/100 g dw
Sulphur	787.50-1362.52 mg/100 g dw
Iron	2.32 -10.70 mg/100 g dw
Copper	1.01-1.56 mg/100 g dw
Sodium	0.10 mg/100 g dw
Zinc	1.5-2.42 mg/100 g dw
Manganese	5.62-7.70 mg/100 g dw
Selenium	0.5 µg/100 g dw

FW, fresh weight; DW, dry weight

Table 4. Pigmentations and antioxidants composition in fruits of *Prunus nepaulensis* Ser.

Parameters	Values
Pigmentations	
Total carotenoids	15.72 mg/100 g fw
β carotene	0.22 mg/100 g fw
Total anthocyanin	293.33-341.70 mg/100 g fw
Total Flavonoid	4.93 mg QE/100 g fw
Total flavonol	2.77 mg QE/100 g fw
Antioxidant activities	
Ascorbic acid	46.03-52.3 mg/100 g fw
Total Tannin	143.6 mg TAE/100 g dw
Reduced glutathione	3.68 µM/g fw
Total phenols)	86.93-1131.30 mg GAE / 100 g fw
DPPH	0.27-0.67 IC_{50} mg/mL
FRAP	10.19 mg AAE/g fw

other antioxidant properties. These traits are valuable for germplasm conservation, breeding, nutritional improvement, and value-added product development.

Nutritional, pigmentation and bioactive compound profiling: Sohiong fruits can be highlighted as a nutrient-dense functional fruit due to its rich sources of nutrients, antioxidants and bioactive compounds. The nutritional and bioactive compounds of Sohiong fruits vary by fruit type and maturity stage. The fruits are a good source of organic acids and carbohydrates, as indicated in Table 1. In addition, the structural polysaccharides found in fruits are pectin (1.80–4.6%), lignin (1.2%), cellulose (14.4%), and hemicellulose (19.8%). Elevated levels of cellulose, hemicellulose, and pectin improve texture, firmness, and dietary fibre. The fibre content ranges from 1.71–7.2%, with high acid- and neutral-detergent fibre, which benefits health by protecting against metabolic and colonic disorders.

The fruits of Sohiong are also sources of protein (1.49–1.76%), fat, proline, and total edible oil (Table 2).

Sohiong fruits are known as a source of excellent health supplements due to their high nutrient and mineral content (Table 3). The ash content in Sohiong fruits varies with genotype and fruit type while nitrogen, phosphorus, potassium, sulphur, and sodium are fairly high with a substantial amount of iron.

The vitamin and antioxidant content are also fairly high, as shown in Table 4. The other bioactive compounds, such as tannic acid, purpurin, reserpine, methyl gallate, catechin, rutin, quinic acid, quercetin, scopoletin, palmitoleic acid, and naringenin, are also present in the fruit of Sohiong. In addition, 16 polyphenolic compounds were identified in an optimised extract of Khasi cherry.

Standardisation of propagation techniques

Sohiong plants are traditionally propagated from seed, resulting in inferior fruit quality. The gestation period exceeds seven years, and the canopy is extensive. The ICAR Research Complex for the North East Hill (NEH)

Quality planting materials of Sohiong

Region has developed the 'Tongue' grafting technique for the rapid multiplication of Sohiong.

Raising of rootstocks: Fully ripened fruits were harvested and collected in September and October for seed extraction. The fruits should be soaked in water for 3-4 days to ferment, facilitating the removal of pulp adhering to the seeds. Subsequently, the seeds should be washed with water and shade-dried for 24 hours. Stratification was conducted in moist sand, with seed coat rupture observed after 3-4 weeks. These ruptured seeds should be sown in polythene bags containing equal parts of soil, sand, and farmyard manure (FYM) at a depth of approximately 5 cm. Seed germination generally commences between 20 to 30 days post-sowing, with an observed rate of 95%. Additionally, soaking seeds in 100-150 ppm GA_3 or 0.5% Thiourea overnight has been shown to enhance germination.

***Grafting*:** The mother tree should be precocious, high-yielding, and free from pests and diseases, with the fruit of superior quality. Scion material for grafting should be selected from five- to six-month-old shoots that are pencil thick, 25–30 cm long, and have 3–4 internodes. Grafting should be performed using one-year-old rootstocks with a pencil-thickness of 0.5 to 1.0 cm. The optimal period for grafting extends from the second week of September to the second week of October, coinciding with the dormancy of both the stock and scion. Two grafting techniques, namely Tongue grafting and Wedge grafting, have been successfully adopted in Sohiong. Notably, Tongue grafting demonstrated a superior success rate, ranging from 80% to 85%. Additionally, grafting conducted within a shade-net polyhouse has yielded higher success rates than in open-field conditions.

Sustainable orchard management

The practices standardised to improve fruit productivity, quality, climate resilience, and sustainability of cultivation systems are:

***Planting system*:** The land should be cleared, and pits measuring 0.75 x 0.75 x 0.75 m should be dug. While digging, the topsoil and subsoil should be kept separate. The pits should be exposed to sunlight for 15 days to destroy harmful microorganisms and insects. The pits should be filled with topsoil mixed with 15 kg of FYM. The plants should be planted at a spacing of 7 x 7 m. The best time for planting Sohiong is at the onset of the monsoon. If there is no rain after planting, light irrigation should be given.

***Nutrition management*:** Application of 10 kg FYM/plant each year, along with 150 g: 50 g: 150 g NPK/plant per year, yields optimally. Alternate-year application of 0.5 kg lime for up to 7 years, and thereafter 1.5–2 kg in alternate years, is helpful.

***Pest and disease management*:** Sohiong is a resilient plant, and very minimal pests and diseases were observed in this crop under field conditions. However, under polyhouse conditions in the nursery, leaf blight and powdery mildew have been observed.

***Leaf blight*:** The disease is caused by Cladosporium oxysporum. Initial symptoms manifest at the leaf margins and gradually progress towards the midrib. In the advanced stages, entire leaves exhibit necrosis, accompanied by prominent sporulation on the underside of the leaves. Such sporulation is seldom observed on the upper leaf surfaces. Necrotic lesions are typically encircled by a yellow halo. Significant defoliation of affected leaves is also noted, with symptoms being more pronounced on immature foliage. Application of Mancozeb (2.5 g/l) is recommended for effective disease control.

***Powdery mildew*:** The disease is caused by *Podosphaera* spp. Symptoms include whitish, irregular patches on the lower leaf surface, with corresponding yellow lesions on the upper surface. Symptoms occur on both young and mature leaves. Heavy infection leads to severe defoliation. Spraying with wettable sulphur (3 g/l) may effectively control the disease.

Season of availability and fruit colour

The tree of seedling origin begins bearing fruit within 7-10 years of planting, depending on the age of the seedling. Flowering occurs in October-November, and the fruit ripens in August–September.

The best time for harvesting is 270-285 days after fruit set, when the colour changes from light purple to dark purple. Dry matter content, acidity, antioxidants, ascorbic acid, TSS, ash, anthocyanins, reducing sugars and total sugars were found to be higher during 270–285 days. Harvesting immature or overripe fruit adversely affects quality. The fruit should be harvested when fully ripe, with the colour darkening to purple or blackish (Figure 2). The whole bunch should be harvested with a sharp knife. A fully mature tree yields about 70-125 kg of fruit

Ripe fruits of Sohiong

Different products developed from the fruits of Sohiong. A – Jam, B – Squash, C- Juice, D – Wine

per tree every year. These fruits have appealing pigments in both the peel and the juice, as evidenced by significant variation in the L*, a* and b* values of the peel and juice colour. The peel pigmentation was L* (15.8±1.30), a* (2.6±0.44), and b* (-0.7±0.71). The juice colour was L* (8.2±1.21), a* (14.1±2.15), and b* (4.3±1.90).

Development of value-added products

The fruits of Sohiong are highly perishable and have a very short shelf life, about 4-5 days. During the harvesting season, a glut in the market leads to distress sales. Therefore, the incorporation of fruits in value addition may reduce post-harvest losses and enrich the nutrition and economics of the growers. A protocol has been developed for the preparation of various processed products from fruits of sohiong, such as Sohiong ready-to-serve (RTS), Sohiong squash, Sohiong candy, Sohiong powder, Sohiong jam, Sohiong jelly, Sohiong wine, Banana-*Sohiong* mixed leather and Sohiong fruit powder (Figure 3). A dairy-free probiotic drink and a probiotic powder were developed for lactose-intolerant people by incorporating *Lactobacillus plantarum* into Sohiong fruit juice for fermentation. The pretreatment of Sohiong with ultrasound, centrifugation, and fruit-juice enzymes prior to microfiltration increased juice yield and quality. The Sohiong slices pretreated with citric acid (0.55%), followed by drying at a microwave power (400 W) and vacuum pressure (690 mmHg), yielded the highest quality dried fruits. The value-added products prepared from this fruit had a very attractive flavour with a stable purple colour. Advances in post-harvest processing and value addition improve shelf life, consumer acceptability, market value, and opportunities for rural entrepreneurship.

Market development and entrepreneurship

Efforts are underway to promote Sohiong fruits and its products through branding, Farmer producer organisations (FPOs), Agri-startups, women entrepreneurs, and agri-exhibitions. There are market development opportunities for Sohiong fruits, considering its anthocyanin-rich extracts can be used as natural edible pigments. The fruit is rich in nutrients, antioxidants, vitamins, and minerals and can be formulated into antioxidant-rich probiotic-fermented beverages and processed into value-added products. The gross return generated is about ₹8,400-13,000 per mature tree, which may create opportunities for entrepreneurship and livelihood improvement.

Conservation and popularisation

Conservation and popularisation are essential for sustainable utilization and biodiversity preservation.

Conservation strategies

In-situ conservation and habitat protection

- Protect the native habitats such as national parks
- Conserve forests, community reserves and sacred groves
- Promote community-led conservation and stewardship
- Implement eco-restoration and habitat enrichment

Ex-situ conservation

- Seed Banks
- Germplasm Repositories
- Botanical Gardens

Domestication and improvement

- Selection of superior genotypes
- Standardised ppropagation technique
- Orchard management
- Conservation of genetic diversity

Popularisation strategies

Awareness and extension

- Training programmes, workshops, field days
- Demonstrations and exposure visits
- Educational campaigns and IEC materials
- Engage researchers, farmers, students and entrepreneurs

Value addition and processed products

- Develop processed and value-added products
- Improves shelf life
- Enhances nutritional value and consumer acceptability
- Reduces post-harvest losses
- Encourages local enterprises and rural livelihoods

Market development

- Branding and promotion of Sohiong products
- Establish producer groups and cooperatives
- Link producers with markets and processors
- Participate in exhibitions, organic markets and online platforms
- Develop standardization and quality certification

Research and policy support

- Research on improvement, nutrition, propagation and market potential
- Policy support for conservation, cultivation, processing and marketing

Future prospects

Future advancement areas include:

- Genome characterisation and molecular breeding,
- Development of improved cultivars,
- Large-scale commercial cultivation,
- Export-oriented processing,
- Functional food and nutraceutical industries,
- Inclusion in government horticulture missions and biodiversity programmes.

SUMMARY

Sohiong fruit is a nutritionally rich and economically significant indigenous fruit species, with substantial potential to enhance nutrition, health, livelihood security, and sustainable food systems. Recent scientific advancements in sohiong, including germplasm characterisation, propagation techniques, orchard management, post-harvest handling, and value addition, have opened new avenues for commercial cultivation and entrepreneurial development. The promotion and expansion of the commercial cultivation of these crops, along with their utilisation, may provide additional sources of income, employment opportunities, and improvements to nutritional and food systems in the hill ecosystem.

For further correspondence, contact:
Dr Heiplanmi Rymbai, Senion Scientist, ICAR-Research Complex for NEH Region, Umiam 793 103, Meghalaya, India. Email: rymbaihort@gmail.com

Saniya T and Shifna P

Probiotic Fermentation of Fruits and Vegetables: A Novel Approach for Nutritional Enhancement and Horticultural Value Addition

India faces a critical 'triple burden' of malnutrition: undernutrition, hidden hunger, and rising overnutrition. Alarmingly, 35% of children under five are stunted, and fewer than 10% of rural Indians eat enough vegetables. The root issue is a lack of nutrient-dense food, worsened by high spoilage rates and thermal preservation methods that destroy vital vitamins. The breakthrough solution? Advanced probiotic bioprocessing. By moving away from heat treatments and embracing targeted microbial fermentation, scientists are turning highly perishable produce into shelf-stable, therapeutic functional foods. This modern twist on a traditional technique promises to bridge India's steep nutritional gap.

Keywords: Fruits and Vegetables; Functional food; Probiotic fermentation; SDG; Sustainable food systems

CURRENTLY, India is witnessing triple burden of malnutrition in the era of globalization, characterised through the concurrent occurrence of undernutrition, hidden hunger, and overnutrition. This condition arises from interconnected determinants like poverty, dietary transition towards ultra-processed foods, limited access to nutrient-dense foods, and a lack of knowledge about nourishing foods and a healthy diet. However, a unifying cause of the triple burden of malnutrition among these distal factors is the low nutrient density of foods and diets.

Findings from the Comprehensive National Nutrition Survey conducted in 2016-2018, provide explicit evidence of the triple burden of malnutrition in India, with 35% of children under 5 years being stunted, 17% wasted, and 33% underweight. Concurrently, a high prevalence of hidden hunger persists, as 46-53% of preschoolers being anaemic, along with considerable deficiencies of vitamin A (18%), vitamin D (14%), Zinc (19%), and other micronutrients (14-31%) reported in this age group. Further, recent evidence from the latest NIN survey indicates inadequate consumption of fruits and vegetables, with merely 8.8% of rural population consuming recommended vegetable intake and 15.9% meets fruit intake levels, while in urban population the corresponding values are 17% and 28.6% respectively, against the recommended consumption of more than 350g per day vegetables and 150g per day fruits.

The inadequate intake is not merely a matter of the availability of this produce, but also relates to the perishability, seasonal supply, and consumer acceptability in the fresh form. Although numerous processing methods and value-added fruit and vegetable products exist, most of them rely on thermal preservation techniques that may compromise the nutritional quality to some extent. Therefore, increasing attention is being directed towards bioprocessing technologies that improve the nutritional profile while achieving desirable shelf life. Fermentation represents one such traditional method offering improved nutritional characteristics and shelf stability. Further, advancements in knowledge about health-promoting microbes, 'probiotics' have expanded the horizons of conventional fermentation into a targeted value-addition approach producing functional fruit and vegetable-based products with defined therapeutic potential.

Fruits and vegetables as ideal carriers for functional food

Probiotics are beneficial viable microorganisms when ingested in adequate quantities, can colonize in the gut, and confer health benefits to the host. Generally, dairy products are served as substrates for probiotic delivery; however, increasing allergenicity towards them and veganism led to the necessity for research into non-dairy substrates for this purpose. Fruits and vegetables are ideal substrates for probiotic delivery, as they contain readily available macronutrients like sugars, vitamins, and minerals, which support the growth and proliferation of probiotic microorganisms. Further, the presence of phenolic compounds and dietary fiber not only enhances the growth of beneficial probiotics, but also aids in the synthesis of novel bioactive metabolites with specific therapeutic potential, thereby enhancing the functional value and utilization of this horticultural produce. Numerous probiotic products have been developed using fruits and vegetables as substrates, including probiotic fruit and vegetable-based beverages, semi-solid or pulp-based products, dried powders, confectioneries, as well as traditional pickled products.

Types of probiotic fruit and vegetable products

From fresh produce to functional foods: Probiotic processing as a horticultural value addition strategy

Fruit / vegetable-based probiotic beverages: Probiotic fruit or vegetable beverages are prepared either by the addition of probiotic strains into the final beverage or by a fermentation technique. The latter was found to enhance the nutritional quality and shelf stability, since fermented food matrix will harbour potent metabolites like short-chain fatty acids, organic acids, and bacteriocins, which facilitate the keeping quality of the produce. The key probiotic strains used in juice fermentation are from the genera *Lactobacillus*, *Bifidobacterium*, *Enterococcus*, *Lactococcus*, *Streptococcus,* and heat-resistant spore formers, including *Bacillus spp.*

A variety of fruits like apple, pineapple, grapes, pear, strawberry, jackfruit, chokeberry have been successfully used as substrates for probiotic fermentation. Fermentation of pineapple juice using *L. plantarum* exhibited high probiotic viability and enhanced antioxidant properties. Likewise, probiotic fermentation in apple juice resulted in reduction of patulin, a common contaminant found in apple juice, therefore enhancing the product safety. Further, certain probiotics like *Bacillus coagulans* enriched fruit beverages improve immunoglobulins and lymphocytes.

Fermentation of fruits and vegetables with probiotics has also been explored for the production of functional compounds like γ-aminobutyric acid (GABA), an inhibitory neurotransmitter that promotes relaxation and mental calmness. Grape-must fermented with *L plantarum* yielded significant levels of GABA along with a viable probiotic population in the final food matrix.

Fermentation of fruit juices using probiotics not only improves the nutritional quality but also alters the flavour profile of the final product by producing various volatile and non-volatile compounds. Probiotic passion fruit juice with *L. plantarum* resulted in the production of volatile compounds like 2,6-octadien-1-ol, 3,7-dimethyl-, (z), 1-dodecanol, and methyl salicylate, providing sensory perceptions pertaining to floral, fatty odour and taste of wintergreen, respectively.

Probiotic fruit and vegetable beverages qualify as the most feasible technology among probiotic horticultural products due to high consumer acceptance and good probiotic survival in liquid matrix, while cold storage, sedimentation and phase separation in the product may be of practical concern.

Semi-solid/pulp-based products: Microencapsulated probiotic strains enriched vegetable pastes have gained increased attention recently and have facilitated product diversification in premium fruit and vegetable product lines. Olive paste has been reported to be an effective carrier of microencapsulated *L. plantarum* strains without altering the sensory attributes of the product while maintaining the probiotic viability.

Probiotic fruit leathers have been developed and optimized via the incorporation of probiotic cultures into fruit puree dispersions. However, the conventional process of fruit leather production was challenging due to high-temperature processing, which can be mitigated by the use of spore formers like *Bacillus coagulans.*

Semi-solid and pulp-based probiotic products are promising carriers for the microencapsulation and targeted delivery of probiotic strains; however, process parameters like texture standardization and drying temperature must be optimized to prevent loss of probiotic viability.

Probiotic fruit and vegetable powders: Juice powders enriched with probiotics constitute another form of plant-based probiotic products. Several fruit and vegetable food matrices have been optimized as suitable substrates for the development of probiotic powders. Underutilized fruits have also been explored for this purpose; for instance, sohiong (*Prunus nepalensis*), an underutilized fruit from the Northeastern region of India, has been identified as an ideal substrate for the delivery of *L. plantarum.* Maoberry, a tropical fruit from Southeast Asia rich in anthocyanins, phenolics, and flavonoids, has been successfully enriched with *L. casei* for optimization of probiotic powder.

Spray-dried probiotic orange juice powder was developed as a novel functional non-dairy product, using *Lactobacillus plantarum* and *Pediococcus acidilactici,* demonstrating promising probiotic potential. Probiotic banana powders are proposed for complementary feeding, as fermentation facilitates the breakdown of complex nutrients and enhances nutrient bioavailability. Furthermore, controlled fermentation with probiotic strains enhances the mineral and antioxidant composition of such flours.

Probiotic powders represent the most shelf-stable format and are suitable for large-scale distribution; however, maintaining cell viability during drying remains a key technological challenge.

Confectioneries: Fruit or vegetable-based jellies often exhibit limited consumer acceptance due to increasing avoidance of high-sugar products and the use of animal-derived bovine gelling agents. Consequently, the demand for searching for vegan probiotic alternatives has

accelerated the search for new delivery matrices. Tomato and peach juice fermented with probiotic *L. rhamnosus* exhibited higher antioxidant capacity, as probiotic metabolism induced enzymatic activity led to increased release of phenolic compounds in jellies, providing additional functional benefits to the consumers.

Dried fruits snacks have been traditionally consumed since drying enhances the total energy, nutrient density, and fiber content in fruits. Additionally, they serve as a promising substrate for probiotic delivery via techniques such as vacuum impregnation. Impregnation of apple slices with probiotic *L paracasei* enhanced their total phenolic content, bioactive properties, and sensory characteristics. Thus, the incorporation probiotics into fruits and vegetables can lead to the development of high-value premium products.

Snack-type probiotic products enhance consumer acceptance and market value, but standardization and regulatory positioning needs careful consideration.

Key advancements in the nutritional profile of fruits and vegetable based probiotic products

Fibres and prebiotics in fruits and vegetables not only sustain probiotic growth but also act as precursors for the production of beneficial metabolites. Beyond promoting microbial growth, these fibres are further utilized by probiotics to produce functional metabolites such as short-chain fatty acids, including acetate, propionate, and butyrate. Inulin, fructo-oligosaccharides, and galacto-oligosaccharides are examples of prebiotics in these plant matrices, which will be utilized by probiotic enzymes for the production of SCFAs. SCFAs further enhance gut integrity, strengthen immune responses, and also stimulate protective immune cells. Fermentation also facilitates the breakdown of complex and bound compounds, anti-nutrients, resulting in the release of bound minerals and phytochemicals into the final food matrix. This process enhances the antioxidant potential and reduces oxidative stress of the fermented food when compared to their unfermented counterparts.

Fermentation further improves digestibility by partially hydrolysing complex carbohydrates and plant proteins, thereby lowering glycaemic response and making the products suitable for children and elderly individuals. Additionally, certain probiotic strains are capable of producing vitamins, particularly B-complex vitamins such as folate, leading to natural micronutrient enrichment of the final product. Thus, probiotic fermentation transforms horticultural produce from merely perishable commodities into nutritionally enhanced, bioactive, and health-promoting functional foods.

Contribution to sustainable food systems & SDGs

Probiotics have transformed traditional fermentation into a scientifically validated process, enhancing the nutritional and therapeutic value of the products. Converting fresh horticultural produce into fermented probiotic foods offers a sustainable preservation strategy by reducing post-harvest losses and extending shelf life without heavy reliance on energy-intensive preservation techniques or synthetic preservatives. Probiotic-based preservation enhances the shelf life by suppressing pathogens and reducing contamination. Integrating probiotics into food supply chains, therefore, has the potential to minimize post-harvest wastage and support global sustainability objectives.

Probiotic fruit and vegetable products can also improve dietary diversity and nutrition security. Fermentation encourages regular intake of protective foods, helps address micronutrient deficiencies, and enhances taste, stability, and convenience. Fermented powders and beverages are shelf-stable formats that can be integrated into school meals and community nutrition programmes, supporting preventive health care.

Fermentation-induced biochemical and nutritional changes in fruits and vegetables

Seasonal surpluses or visually imperfect produce can be transformed into high-value functional foods through fermentation, which otherwise go to waste, thereby benefiting rural livelihoods by opening new avenues of fruit and vegetable valorisation. This approach will strengthen local food systems by creating opportunities for farmer-producer organisations, women self-help groups and small entrepreneurs, further reducing transport-related losses.

Such interventions support several Sustainable Development Goals (SDGs), including Zero Hunger (SDG-2) by improving access to nutritious foods; Good Health and Well-being (SDG-3) through preventive nutrition; Responsible Consumption and Production (SDG-12) by minimizing

waste; and Climate Action (SDG-13) through low-energy processing. Thus, probiotic fermentation bridges the gaps in horticulture, nutrition, and sustainability in a practical and impactful way.

Indian opportunities and future scope

Despite sufficient production of fruits and vegetables, India still witnesses a substantial portion of this produce remaining underutilized or wasted, due to seasonal gluts, inadequate cold-chain infrastructure, and market price fluctuations. Optimization of probiotic foods from locally available horticultural crops presents a promising opportunity to enhance both utilization and nutritional impact. Region-specific crops such as mango, banana, jackfruit, amla, pineapple, carrot, and beetroot can be developed into fermented beverages, powders, and semi-solid products suited to local dietary preferences. Such products have potential applications in national nutrition programmes, including mid-day meal scheme, Integrated Child Development Services (ICDS), and community health initiatives, where shelf-stable and nutrient-rich foods are required.

India's growing functional food market and increasing consumer awareness about gut health further support the commercial potential of probiotic horticultural products. Future research should focus on selecting region-specific probiotic strains adapted to tropical conditions, improving ambient shelf stability, and developing synbiotic formulations combining native fruits, vegetables and probiotics. Standardisation, regulatory clarity, and clinical validation of health benefits will strengthen consumer trust and market adoption.

SUMMARY

Bioprocessing of fruits and vegetables via controlled and precision fermentation using probiotic microorganisms offers a promising avenue in fruit and vegetable value addition. On the other hand, perishable produce can be converted to high-value therapeutic foods for specific health uses, thereby enhancing product diversity and marketability. Beyond commercial prospects, such products can contribute to improving dietary quality, addressing micronutrient deficiencies, and supporting preventive healthcare through regular intake of bioactive foods. Fermentation also aids in reducing post-harvest losses and enables better utilization of seasonal surpluses, creating livelihood opportunities for farmer-producer organizations and small-scale enterprises.

Further, more research is required in this arena for identifying potent probiotic strains and analysing suitable fruit and vegetable matrices for fermentation. Fruit and vegetable-based beverages, fermented fruit and vegetable powders, and snacks are some of the existing scalable products in this area. With coordinated efforts among horticulturists, food technologists, and public health agencies, probiotic fermentation of fruits and vegetables can evolve from a niche concept into a scalable strategy that supports nutrition security, farmer income, and preventive healthcare in India.

For further correspondence, contact:
Vadassery Krishnasree, Assistant Professor, College of Agriculture, Padannakkad, Kerala Agricultural University, Thrissur, Kerala, India. Email: krishnasree.v@kau.in

Niraj Kumar Prajapati and
Sanjay Kumar*

Vegetables as Medicine: The Bioactive Potential of Vegetables

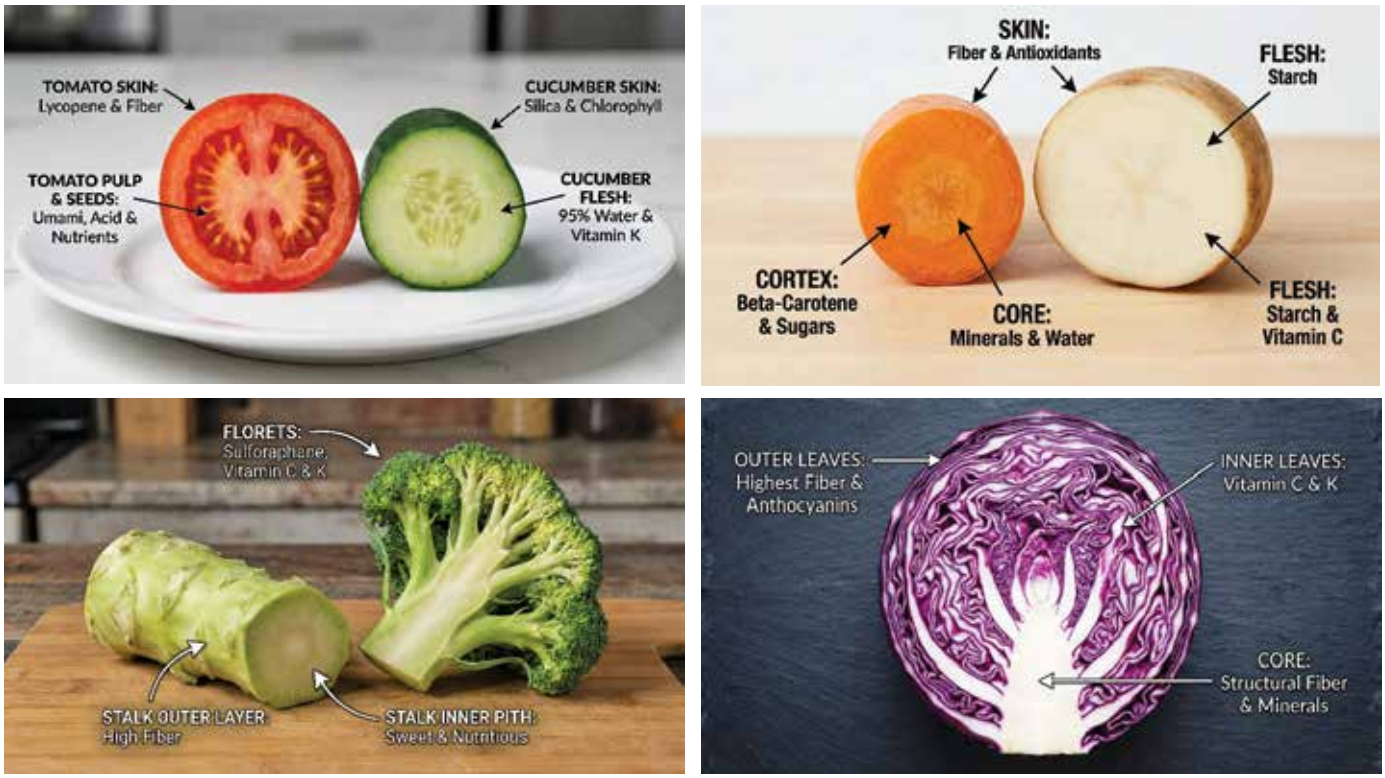
This study explores the remarkable medicinal properties of commonly consumed vegetables, emphasizing their role as natural pharmaceuticals. With India ranking second globally in vegetable production at 200.45 million tonnes, our traditional vegetables contain powerful bioactive compounds including polyphenols, flavonoids, carotenoids, and glucosinolates. Recent researches demonstrates that regular vegetable consumption reduces risks of cardiovascular diseases by 31%, stroke by 11%, and various cancers by 19%. The article highlights specific Indian vegetables like bitter gourd for diabetes management, drumstick for immunity, fenugreek for blood sugar regulation, and leafy greens for anemia prevention. Understanding vegetables as functional foods rather than mere dietary supplements can revolutionize nutritional approaches in Indian agriculture and public health, addressing both malnutrition and lifestyle diseases through farm-to-plate strategies.

Keywords: Bioactive compounds; Functional foods; Indian vegetables; Medicinal properties; Phytonutrients

INDIA'S rich agricultural heritage has blessed us with an incredible diversity of vegetables, each containing nature's pharmacy in concentrated form. While vegetables have traditionally been valued for basic nutrition, modern scientific research reveals they are powerhouses of bioactive compounds with proven medicinal properties. With over 25,000 identified phytonutrients in plant-based foods, vegetables offer therapeutic benefits ranging from diabetes management to cancer prevention. As India faces the dual burden of malnutrition and lifestyle diseases, understanding vegetables as functional foods becomes crucial for both farmers and consumers.

Understanding vegetables as nature's medicine: Phytonutrients, also known as phytochemicals, are bioactive compounds produced by plants beyond essential nutrients like vitamins and minerals, serving as natural defences against environmental stressors. Major categories include polyphenols (such as flavonoids like quercetin and catechins), carotenoids (like beta-carotene and lycopene), glucosinolates (found in cruciferous vegetables), and organosulfur compounds (prevalent in garlic and onions). These compounds enable vegetables to protect themselves from pathogens, UV radiation, and herbivores through antioxidant activity, enzyme inhibition, and signalling pathways that deter predation. Humans gain analogous benefits upon consumption, as these bioactives mimic protective roles by neutralizing free radicals, modulating inflammation via pathways like NF-κB, enhancing detoxification enzymes, and supporting gut microbiota that further metabolize them into active forms. Recent research from 2014-2025 underscores their efficacy. A 2022 review highlighted carotenoids and polyphenols reducing oxidative stress in family health contexts, with variable European intakes linked to WHO diet adherence. A 2024 study showed flavonoids regulating PI3K/Akt/mTOR and activating SIRT1 to combat aging hallmarks and chronic disease risk in plant-based diets. Findings from 2025 affirmed phytonutrients' roles in

Indian Medicinal Vegetables



Vibrant cross-sections reveal concentrated phytonutrients

preventing diabetes, obesity, hypertension, and cancers by modulating metabolic and inflammatory pathways. Overall, these compounds promote health span extension through senolytic effects and nutrient-sensing modulation like AMPK.

The science behind vegetable medicine: Vegetables deliver potent antioxidant properties through polyphenols, flavonoids, and carotenoids that neutralize free radicals, preventing cellular damage linked to chronic diseases. Studies show turmeric's curcumin scavenges reactive oxygen species (ROS) with up to 75% efficiency *invitro*, while green tea's epigallocatechin gallate (EGCG) inhibits lipid peroxidation by 60-80% in human trials. Broccoli and spinach exhibit high DPPH radical scavenging, with IC50 values below 50 µg/mL, outperforming synthetic antioxidants in leafy greens analysis. Anti-inflammatory mechanisms arise as these compounds suppress NF-κB pathways and cytokine release; for instance, grape polyphenols reduce TNF-α by 40% in rodent models. Anthocyanins from berries block COX-2 enzymes, mirroring aspirin effects but without side effects. Vegetables modulate immunity by enhancing T-regulatory cells and IL-10 production, boosting NK cell activity by 25-30% via beta-glucans in mushrooms and fibres. They transform gut microbiomes, fostering SCFA-producing bacteria like Bifidobacterium; daily intake increases Akkermansia by 20%, improving barrier function. Blood sugar regulation occurs via soluble fibres like pectin slowing glucose absorption, reducing postprandial spikes by 35%, alongside quercetin activating AMPK for insulin sensitivity.

Practical applications for farmers and consumers

Farmers: Farmers can capitalize on high-demand medicinal vegetables like moringa, ashwagandha greens, and fenugreek, which fetched premium prices in 2024, moringa leaves sold at ₹200-300/kg in Indian markets (APEDA, 2024). Growing consumer awareness of functional foods surged 25% globally per NielsenIQ (2024 report), boosting demand. Organic cultivation enhances bioactive compounds; studies show 30-50% higher antioxidants in organically grown drumstick. Value addition via processing into dried powders or extracts yields 3-5× profits–e.g., turmeric extracts at ₹1,500/kg (FSSAI data, 2024). Integrating with ayurvedic firms like Himalaya Wellness ensures steady contracts, as India's nutraceutical market hit ₹50,000 crore (IBEF, 2024).

Consumers: Consumers benefit from 5-7 daily servings (≈400g) of medicinal veggies, aligning with WHO's 400g fruit-veg guideline for reducing NCDs by 20% (WHO, 2023). Follow the 'Eat the Rainbow' principle: Red beets for betalains, green spinach for lutein, per Harvard T.H. Chan (2024). Preserve bioactives with steaming (retains 90% vs. boiling's 50% loss; USDA study, 2022). Prioritize seasonal picks like monsoon amaranth for peak nutrients (ICMR-NIN, 2024). Combine for synergy–tomato + broccoli boosts lycopene absorption 4×.

Economic and health impact of India's vegetable boom

India's vegetable sector thrives with 10.86 million hectares yielding 200.45 million tonnes annually, bolstering food security and farmer incomes while curbing imports. Vegetables serve as cost-effective preventive medicine, slashing chronic disease risks–studies show each extra daily portion cuts coronary heart disease odds by 4% via antioxidants in greens and cruciferous varieties, easing a healthcare burden exceeding $100 billion yearly from NCDs like diabetes and CVD. Dietary shifts to 3.5

Table. Vegetables as medicine

Vegetable	Local Name	Medicinal Properties
		Cucurbit Vegetables (Gourd Family)
Bitter Gourd	Karela	Blood sugar regulation through charantin and polypeptide-p, insulin sensitivity enhancement, antioxidant properties, anti-cancer compounds
Ridge Gourd	Turai	Anti-inflammatory properties, respiratory health support, lymphatic system cleansing, liver detoxification
Bottle Gourd	Lauki	Heart health, cholesterol management, blood pressure regulation, kidney health support, cooling properties
Ash Gourd	Petha	Digestive health, cooling effect, mental clarity enhancement, peptic ulcer treatment, weight management
Snake Gourd	Chichinda	Digestive health, blood purification, anti-diabetic properties, liver protection
Pointed Gourd	Parwal	Digestive tonic, blood purifier, anti-inflammatory, constipation relief
Ivy Gourd	Kundru/ Tindora	Anti-diabetic properties, obesity management, antioxidant rich, liver protection
Round Gourd	Tinda	Hydrating properties, digestive support, kidney health, skin health enhancement
		Leafy Green Vegetables
Spinach	Palak	Iron for anemia prevention, calcium for bones, vitamin K for blood clotting, nitrates for blood pressure regulation, lutein for eye health
Fenugreek Leaves	Methi	Blood sugar control through galactomannan, cholesterol reduction, folic acid for pregnancy, iron content, lactation enhancement
Amaranth	Chaulai	High calcium content (3 times milk), iron-rich for anemia, protein source, vitamin A for eye health, anti-inflammatory properties
Mustard Greens	Sarson	Vitamin K for bones, glucosinolates for cancer prevention, respiratory health, cholesterol reduction, anti-inflammatory
Moringa Leaves	Sahjan Patta	Vitamin C (7x oranges), calcium (4x milk), iron-rich, immunity booster, anti-inflammatory, blood sugar regulation
Colocasia Leaves	Arbi Patta	Digestive health, vitamin A and C rich, anti-inflammatory, folate for pregnancy, blood pressure control
Curry Leaves	Kadi Patta	Digestive health, diabetes management, cholesterol reduction, hair health, antioxidant rich
Coriander Leaves	Dhaniya	Digestive support, cholesterol reduction, blood sugar control, heavy metal detoxification, anti-anxiety properties
Mint	Pudina	Digestive health, respiratory relief, headache treatment, anti-microbial, cooling properties
Indian Pennywort	Brahmi	Cognitive enhancement, memory improvement, anxiety reduction, wound healing, anti-inflammatory
Radish Leaves	Mooli Patta	Vitamin C rich, kidney stone prevention, digestive support, calcium and iron content
Turnip Greens	-	Calcium-rich, vitamin C source, heart health, antioxidant properties, anti-cancer compounds
Water Amaranth	Ponnaganti	Blood tonic, laxative properties, high in iron and calcium, anti-oxidant
Purslane	Kulfa	Omega-3 fatty acids (highest in leafy vegetables), vitamins A, C, E, inflammation reduction, heart health
Bathua	Chenopodium	Iron and calcium rich, vitamin A source, digestive health, weight management
Indian Sorrel	Chuka/ Ambadi	Vitamin C rich, digestive support, cooling properties, antioxidant benefits
Red Sorrel	-	Blood tonic, antioxidant rich, digestive health, iron content
Watercress	Jalkumbhi	Antibacterial, anti-inflammatory, liver health, kidney protection, vitamin C and K rich
Nettle Leaves	Bichu Buti	Anti-inflammatory, iron-rich for anemia, joint pain relief, prostate health
Betel Leaves	Paan	Digestive stimulant, antimicrobial, respiratory health, mouth freshener
		Root and Bulb Vegetables
Radish	Mooli	Liver health, digestive enzyme production, detoxification, vitamin C rich, kidney stone prevention
Carrot	Gajar	Beta-carotene for vision, antioxidants for immunity, heart health, skin health, anti-cancer properties
Beetroot	Chukandar	Blood pressure regulation, hemoglobin increase, liver detoxification, athletic performance enhancement, folate rich
Turnip	Shalgam	Low-calorie, fiber-rich for digestion, vitamin C source, heart health, weight management
Taro Root	Arbi	Digestive health, blood sugar control, heart health, potassium and magnesium rich
Sweet Potato	Shakarkandi	Vitamin A for vision, immune support, anti-inflammatory, blood sugar regulation, fiber-rich
Onion	Pyaz	Blood sugar control, heart health, anti-inflammatory, antimicrobial, quercetin for immunity
Garlic	Lehsun	Blood pressure reduction, cholesterol management, immune booster, antimicrobial, anti-cancer properties

Vegetable	Local Name	Medicinal Properties
		Brassica Family (Cruciferous Vegetables)
Cabbage	Patta Gobi	Anti-inflammatory, vitamin C and K rich, digestive health, anti-cancer glucosinolates, ulcer healing
Cauliflower	Phool Gobi	Vitamin C rich, anti-cancer compounds, brain health support, detoxification, collagen production
Broccoli	-	Cancer prevention, vitamin C and K rich, bone health, immune support, detoxification
Kohlrabi	Ganth Gobi	Vitamin C source, digestive fiber, potassium for heart health, immune support
Nightshade Family		
Tomato	Tamatar	Lycopene for prostate and heart health, vitamin C and K, antioxidant rich, cancer prevention
Eggplant	Baingan	Nasunin for brain health, heart health support, fiber-rich, cholesterol reduction, anti-cancer properties
Bell Pepper	Shimla Mirch	Vitamin C rich (3x oranges), vitamin A for eyes, antioxidants, anti-inflammatory
		Legume Vegetables
Green Peas	Matar	Protein source, fiber for digestion, vitamin K for bones, blood sugar control, heart health
Broad Beans	Sem	Iron and folate rich, protein source, digestive health, blood pressure control
Cluster Beans	Guar	Blood sugar regulation, cholesterol reduction, digestive health, bone health
		Other High-Value Medicinal Vegetables
Okra	Bhindi	Diabetes management, digestive health, folate for pregnancy, vitamin C and K, cholesterol reduction
Bamboo Shoots	-	Low-calorie, high-fiber, cholesterol reduction, weight management, potassium-rich
Lotus Stem	Kamal Kakdi	Vitamin C rich, blood purification, digestive health, respiratory support, stress reduction
Jackfruit (Raw)	Kathal	Immunity booster, digestive health, blood sugar control, anti-cancer properties
Banana Flower	Kela Phool	Iron-rich for anemia, menstrual health, diabetes management, weight loss support
Papaya (Raw)	-	Digestive enzymes (papain), immunity support, anti-inflammatory, wound healing
		Wild and Underutilized Medicinal Vegetables
Takla Saag	-	Monsoon health support, anti-oxidant rich, minerals and vitamins, immunity booster
Khesari Leaves	-	Protein-rich, anti-inflammatory, traditional remedy for fevers
Brahmi Saag	-	Memory enhancement, cognitive support, wound healing, anxiety reduction
Shepu/Dill Leaves	-	Digestive health, bone health, menstrual pain relief, lactation support
Agathi Leaves	-	Anti-inflammatory, fever reduction, digestive support, respiratory health

weekly green leafy servings reduce ischemic heart disease risk by 67%, per Indian case-controls, freeing resources for development. Success stories abound: Rural programs in Tamil Nadu transformed malnourished communities via kitchen gardens, dropping anemia by 40% and boosting productivity; similar interventions in Ghana yielded GH¢178 million benefits from avoided deaths and gains. Export potential surges with okra, onions topping global ranks–2022-23 saw $185 million in processed veggie shipments, poised for medicinal herbals like turmeric extracts to tap $50 billion markets.

Recent research breakthroughs (2014-2025) in vegetables for health

From 2014 to 2025, studies spotlighted Indian vegetables like fenugreek (*Trigonella foenum*-graecum) and bitter gourd (*Momordica charantia*) for diabetes management, revealing fenugreek seeds reduced fasting blood glucose by 13-25% in type 2 diabetics via soluble fiber and 4-hydroxyisoleucine. Cruciferous vegetables such as broccoli and cabbage demonstrated anti-cancer prowess, with sulforaphane inhibiting colorectal tumour growth by 40-60% in cohort studies tracking over 60,000 participants, linking weekly intake to 17-50% risk reduction. Regular consumption of these veggies shielded cardiovascular health, as a 2021 meta-analysis showed 20% lower coronary risk from high Brassica intake due to glucosinolates lowering LDL oxidation. Leafy greens like spinach exerted neuroprotective effects, with lutein and zeaxanthin from 2018-2023 trials preserving cognitive function in 1,500 elderly subjects by curbing amyloid-beta aggregation in Alzheimer's models. Dietary fiber in these plants modulated gut microbiome, boosting beneficial Bifidobacteria by 30% per 2022 interventions, enhancing insulin sensitivity.

Overcoming challenges to boost vegetable intake in India

Indian diets show vegetable consumption averaging under 200g per capita daily, far below WHO's 400g recommendation, with over 70% of households falling short as per ICMR-NIN surveys. Traditional knowledge on medicinal plants like fenugreek and amaranth faces erosion, despite CSIR's TKDL preserving tribal herbal data since 2001. Modern cultivars exhibit nutrient drops– calcium by 16%, iron by 15%–versus nutrient-

rich heirlooms. Pesticide residues plague 65% of chilies and 39% of okra, posing safety risks. Affordability strains persist, as healthy diets claim 50-90% of daily wages, hindering access.

SUMMARY

Vegetables truly represent nature's pharmacy, offering affordable, accessible, and effective solutions to many health challenges facing India today. Scientific researches continue to validate what traditional knowledge has long recognized: Regular vegetable consumption prevents chronic diseases, strengthens immunity, and promotes longevity. For Indian farmers, cultivating high-medicinal-value vegetables presents lucrative opportunities, especially as consumer awareness grows. For consumers, making vegetables the centrepiece of daily diet can dramatically reduce disease risk and healthcare costs. The path forward requires integrating traditional knowledge with modern research, promoting organic cultivation methods that enhance medicinal properties, and educating communities about vegetables' therapeutic potential. By recognizing vegetables as functional foods rather than mere side dishes, we can transform agricultural practices, dietary habits, and public health outcomes.

For further correspondence, contact:
Dr. Sanjay Kumar, Senior Professor, Department of Horticulture, School of Agricultural Sciences and Technology, Babasaheb Bhimrao Ambedkar University, Lucknow 226 025, Uttar Pradesh, India. Email: sanjay123bhu@gmail.com

Divya Chamyal[1], Jagbir Rehal[1] and Harshad M Mandge[2]

Moringa *(Moringa oleifera)*: Whole-Plant Nutrition and Health Applications through Processing and Value Addition

Moringa *(Moringa oleifera)* is widely recognized for its nutritional richness, yet most discussions remain limited to its leaves. This article presents a whole-plant perspective, examining the nutritional contributions of leaves, pods, seeds and flowers, and how processing influences their health relevance. It emphasizes that nutritional value is not static but depends on cleaning, drying, extraction and value-addition pathways that determine bioavailability and safety. Special attention is given to seed-based water clarification as a preventive health application, linking nutrition with hygiene. Moderate-depth insights into leaf extracts, seed oil and product development illustrate how processing bridges raw plant material and functional health applications. By integrating whole-plant utilization with nutrition-preserving processing strategies, the article highlights moringa's broader role in dietary diversification and health-oriented value addition.

Keywords: Dietary diversification; Food processing; Functional nutrition; Nutrient retention; Value-added products

AGRICULTURE and horticulture are increasingly expected to contribute to nutrition and health alongside productivity. In this context, plant-based foods with both nutritional and functional value are receiving renewed attention. Moringa (*Moringa oleifera*), widely cultivated and consumed across India, is well known for its nutrient-rich leaves. However, most dietary discussions focus primarily on the foliage, overlooking the nutritional and health relevance of other edible plant parts.

From a nutrition perspective, moringa is best understood as a whole-plant resource. Leaves, pods, seeds and flowers provide distinct nutrients and bioactive components that collectively enhance dietary diversity. Importantly, the health value of moringa depends not only on its composition but also on how it is cleaned, processed and converted into usable products. Processing influences nutrient retention, bioavailability and safety, thereby shaping nutritional outcomes. In addition, applications such as seed-based water clarification extend its relevance to preventive health.

Moringa as a whole-plant nutritional resource: From a nutrition and health perspective, *Moringa oleifera* is more than a leafy vegetable. It functions as a whole-plant nutritional resource in which different edible parts contribute complementary nutrients and functional components. Recognizing this diversity is essential for moving beyond leaf-centric use toward a broader approach that supports dietary quality and health outcomes.

Different edible and functional parts of moringa (*Moringa oleifera*), including leaves, pods, seeds and flowers

The leaves are the most widely consumed component and provide a concentrated source of plant proteins, essential minerals, vitamins and bioactive compounds. When incorporated into diets in appropriate forms, leaf-based products can support micronutrient intake and help address dietary gaps, particularly in predominantly plant-based food systems.

In contrast, moringa pods differ nutritionally from the leaves and are valued primarily for their dietary fibre content and associated micronutrients. Regular consumption of pods contributes to digestive health and influences nutrient absorption, making them relevant to balanced dietary patterns.

The seeds represent a distinct nutritional fraction, characterized by higher lipid and protein content. Seed-derived products, particularly oil, provide functional dietary fats and extend moringa's relevance beyond direct food use to health- and hygiene-related applications. This highlights the importance of including non-leafy components in utilization strategies.

Moringa flowers, though less commonly consumed, are traditionally used in certain regions and contain antioxidant compounds that further diversify the plant's nutritional profile. While the stem and bark are not primary food sources, their traditional relevance reflects the long-standing recognition of moringa as a multifunctional plant. Overall, the nutritional diversity across moringa's edible parts explains its broader health relevance. Each component contributes distinct functions, reinforcing the value of a whole-plant approach rather than reliance on a single edible fraction.

Processing as a bridge between nutrition and health: In nutrition-oriented horticultural crops, processing is often treated as a routine step before consumption. From health perspective, processing critically determines nutrient retention, bioavailability and safety. In moringa, appropriate processing serves as a bridge between raw plant material and its health-promoting potential.

Cleaning and washing are the most fundamental steps in moringa processing. Leaves, pods and flowers are commonly exposed to soil, dust and surface contaminants during harvesting and handling. Thorough washing improves hygiene and reduces microbial load, directly influencing food safety. From a nutritional standpoint, effective cleaning ensures that subsequent processing is applied to safe raw material without compromising edible quality.

Blanching is particularly relevant for leaves and flowers. Short exposure to hot water reduces microbial contamination and inactivates enzymes that can accelerate nutrient loss during storage. When performed properly, blanching enhances product safety while retaining most heat-stable nutrients, functioning as a health-protective rather than a nutrient-destructive step.

Drying practices further influence the nutritional quality of moringa products. Shade drying is generally preferred over direct sun drying, as excessive heat and ultraviolet exposure can degrade sensitive nutrients and bioactive compounds. Gentle drying helps preserve functional components, improving the nutritional effectiveness of the final product.

Step-by-step process of household-level water clarification using moringa seeds. (1) Mature moringa seeds are crushed into fine powder. (2) The seed powder is added to turbid water and mixed thoroughly. (3) Coagulation and settling occur as suspended particles bind and begin to separate from the water. (4) After settling, clearer water is obtained for safer household use

Grinding and storage determine the stability of processed products. Although fine grinding improves ease of use, it can accelerate nutrient degradation if storage conditions are inadequate. Protection from moisture, heat and light is therefore essential to maintain nutritional integrity. Together, these processing choices shape how moringa contributes to nutrition and health, reinforcing that processing is a nutrition-preserving strategy rather than mere preparation.

Seed-based water purification: A health-protective application of moringa: Access to safe drinking water is a critical determinant of health and nutrition. Beyond its dietary uses, moringa offers a unique health-protective application through the use of its seeds in household-level water clarification. This application links processing of plant material with preventive health outcomes, making it relevant within a nutrition and health framework.

Moringa seeds contain natural compounds that act as coagulating agents. When crushed seed powder is added in small quantities to turbid water and gently stirred, suspended particles bind together and settle at the bottom. This simple process improves water clarity and reduces particulate contamination. While the method does not replace comprehensive water treatment systems, it provides a practical option for improving water quality at the household level, particularly in resource-limited settings.

From a health perspective, the relevance of this application lies in its contribution to safer water for consumption. Consumption of contaminated water is closely associated with gastrointestinal infections and reduced nutrient absorption, which can undermine

nutritional status even when diets are adequate. By improving basic water quality, moringa seed-based clarification indirectly supports nutritional health and overall well-being.

The use of moringa seeds for water clarification also reflects the broader concept of whole-plant utilization. Seeds that are not used for oil extraction or food purposes can be processed into powder for this application, enhancing resource efficiency while addressing a key public health concern. Importantly, this practice relies on simple processing steps that can be adopted at the household level without specialized equipment.

By framing seed-based water purification as a health-protective measure, moringa extends its relevance beyond food and nutrition to preventive health, reinforcing its multifunctional role in supporting human well-being.

Moringa Tree

Extraction approaches and health-relevant components: Extraction serves as a bridge between raw plant material and health-oriented utilization by converting nutrients and bioactive compounds into more accessible forms. In moringa, extraction should be viewed not as a laboratory procedure, but as a nutrition-enabling process that improves usability and bioavailability through mild, food-compatible techniques.

Leaf extracts are widely used beyond whole leaves and powders. Simple aqueous extraction–such as soaking or gentle heating in water–releases water-soluble nutrients and functional components into forms suitable for consumption, including herbal infusions. Mild alcoholic extraction, when applied carefully, can enhance the release of certain bioactive compounds without compromising safety. These approaches are nutritionally relevant because they increase the availability of beneficial components while avoiding excessive processing.

Seed oil extraction provides another important health-linked application. Cold pressing of moringa seeds, performed without high temperatures or chemical solvents, yields oil containing stable lipids and functional constituents. From a nutritional standpoint, cold-pressed oil preserves its natural composition and supports dietary as well as topical use. The avoidance of harsh conditions helps maintain quality and health-relevant properties.

The choice of extraction method directly influences nutrient stability. Aggressive processing may degrade sensitive compounds, whereas gentle techniques help retain functional integrity. This relationship underscores the link between extraction practices and health outcomes.

The concept of bioavailability further clarifies the importance of extraction. Nutrients must be accessible and absorbable to exert physiological benefits. By facilitating the release of nutrients from plant structures, appropriate extraction enhances their effective utilization. Thus, in moringa, extraction enhances nutritional functionality rather than representing mere chemical manipulation.

Value-added products from different parts of moringa: Value addition provides a practical pathway for translating the nutritional and health potential of *Moringa oleifera* into usable and accessible forms. Compared with raw plant

Table 1. Value-added products from different parts of moringa and their health relevance

Plant part	Processing method	Product	Health relevance
Leaves	Drying, powdering	Leaf powder	Micronutrient support
Leaves	Extraction	Herbal tea/extract	Antioxidant intake
Pods	Cooking, drying	Pod-based foods	Dietary fibre
Seeds	Cold pressing	Seed oil	Functional fats
Seeds	Powdering	Water purifier	Safe drinking water
Flowers	Drying	Herbal infusions	Traditional wellness

Table 2. Market-available products from different parts of moringa

Plant part	Product category (market form)	Typical form / presentation	Typical uses	Notes (scale / buyer group)
Leaves	Leaf powder / flour	Fine dried powder, sachets, bulk jars	Fortification of porridge, smoothies, bakery items	Widely sold; suitable for household & small-scale processors
Leaves	Capsules / tablets	Gelcaps, compressed tablets	Dietary supplement (micronutrients, antioxidants)	Commercial nutraceutical market; requires quality control
Leaves	Herbal tea / infusion	Tea bags, loose leaf blends	Antioxidant beverage	Popular in health-food segment
Leaves	Leaf extract (powdered)	Standardised extracts	Functional food ingredient	Used by food formulators
Pods	Dried pods / canned	Dried whole/segments, canned drumsticks	Culinary uses (soups, curries)	Local markets & processed food firms
Seeds	Cold-pressed oil	Bottled oil (culinary/ cosmetic grade)	Cooking, topical use, cosmetic ingredient	Niche market; small-batch producers common
Seeds	Seed powder / cake	Dried powdered seeds, seed cake	Water clarification (household), animal feed ingredient	Used locally; seed cake used as soil amendment
Seeds	Extracts (e.g., oil fractions)	Refined oil fractions	Ingredient for cosmetics & functional foods	Requires processing capacity
Flowers	Dried flowers / tea	Dried flowers, infusion packs	Herbal infusion, traditional uses	Small-scale/heritage markets
Whole-plant / multiple parts	Mixed blends & premixes	Fortified mix (flours, snack mixes)	Nutrition supplements, ready foods	SHG & startup product opportunities
By-products	Cosmetic formulations	Soaps, creams, shampoos	Skin/hair care	Growing small-enterprise market
By-products	Animal feed supplements	Pellets, meal	Livestock nutrition	Local mixed-farm use & commercial feeds

materials, value-added products offer improved shelf life, convenience and clearer health relevance. A whole-plant approach to value addition recognizes that different parts of moringa are suited to distinct processing routes, each contributing specific nutritional and functional benefits.

Leaf-based products remain the most widely developed. Drying and powdering yield stable products that can be incorporated into various foods to support micronutrient intake, while leaf infusions and herbal teas provide alternative formats that emphasize bioactive consumption and ease of use. Moringa pods are mainly processed through cooking or drying and are consumed as part of regular diets, where their fibre content supports digestive health.

Seeds expand value addition beyond conventional food uses. Cold-pressed seed oil supplies functional lipids suitable for dietary and topical applications, whereas powdered seeds serve a health-protective role in household water clarification. Flowers, though less commercialized, are traditionally dried for herbal infusions, contributing to dietary diversity and wellness-oriented use.

Overall, aligning plant parts with appropriate processing and product pathways enhances nutritional usability while reducing waste. This integrated approach highlights how moringa can support health-oriented consumption through diverse and accessible value-added products.

Nutritional and health relevance of whole-plant utilization: Whole-plant utilization of moringa has important implications for nutrition and public health,

Table 3. Nutritional and public health relevance of whole-plant utilization of moringa

Whole-plant aspect	Nutritional relevance	Health implication	Public health significance
Use of multiple edible parts	Improves dietary diversity	Reduces risk of micronutrient gaps	Supports balanced diets at population level
Leaf-based foods	Source of vitamins, minerals and bioactives	Supports overall nutritional adequacy	Useful for nutrition-sensitive interventions
Pod consumption	Provides dietary fibre	Supports digestive health	Encourages regular vegetable intake
Seed-derived products	Supplies functional fats; improves water quality	Indirect protection from water-borne illnesses	Links nutrition with hygiene and safe water
Processed, shelf-stable products	Enhances accessibility and usability	Improves regular consumption	Suitable for vulnerable and remote populations
Whole-plant approach	Reduces reliance on single food sources	Supports preventive nutrition	Aligns with food-based public health strategies

Moringa leaves

particularly in the context of dietary diversity and preventive nutrition. Diets based on a limited range of foods often fail to meet micronutrient requirements, even when energy intake is adequate. Using multiple edible parts of moringa–such as leaves, pods, seeds and flowers–introduces a wider spectrum of nutrients and functional components, thereby supporting more balanced dietary patterns.

From a preventive nutrition perspective, whole-plant use helps address nutritional gaps before deficiency-related health problems emerge. Leaf-based products support micronutrient intake, pods contribute dietary fibre, and seed-derived products supply functional lipids while also offering indirect health protection through improved water quality. Together, these contributions strengthen nutritional adequacy and reduce diet-related vulnerabilities.

The relevance of this approach is particularly pronounced for nutritionally vulnerable populations, including children, women and older adults, as well as communities with limited access to diverse foods. Moringa-based foods and products provide accessible options for improving dietary quality without requiring substantial dietary changes. Processing and value addition further enhance usability and acceptability, increasing the likelihood of regular consumption.

At the population level, whole-plant utilization aligns with public health strategies that emphasize food-based solutions to nutrition challenges. By integrating multiple plant parts into diets and health-oriented applications, moringa supports a preventive framework that links nutrition, food safety and hygiene, underscoring its broader public health significance.

SUMMARY

A whole-plant approach to moringa extends its relevance beyond leaf consumption and positions it as a multifunctional resource for nutrition and health. Leaves, pods, seeds and flowers provide distinct nutrients, and their benefits depend on appropriate processing and extraction practices that influence nutrient retention, bioavailability and safety. Beyond dietary use, seed-based water clarification highlights its broader health-protective value. Value addition improves accessibility and regular consumption, particularly among vulnerable populations. By linking nutritional science with practical processing pathways, whole-plant utilization of moringa supports dietary diversification, preventive nutrition and public health objectives within horticulture-based systems.

For further correspondence, contact:
[1]Dr. Jagbir Rehal, Food Technologist (Fruit and Vegetable), Department of Food Science and Technology, Punjab Agricultural University, Ludhiana 141 004, Punjab, India; [2]Banda University of Agriculture & Technology, Banda 210 001, Uttar Pradesh, India. Email: jagbir@pau.edu

Arvind Kumar Jaiswal[1], Dharmendra Kumar[2], Som Dutt[2] and Brajesh Singh[2]*

Potato: A Key Crop for Global Food and Nutritional Security

Potato (*Solanum tuberosum* L.) is one of the most important food crops in the world and a major source of food and nutritional security. It is widely grown, low in cost, easy to prepare, and valued for its ability to provide quick energy and useful nutrients. Although it is mainly known as a starch-rich food, potato tubers also contain proteins, dietary fibre, vitamins, minerals, phenolics, anthocyanins, carotenoids, and other bioactive compounds that support human health. Potatoes are also a good source of resistant starch and high-quality protein, and they contribute important amounts of vitamin C, vitamin B6, potassium, and iron to the diet. Coloured and biofortified potatoes are especially rich in health-promoting compounds and may help reduce the risk of chronic diseases such as diabetes, obesity, and cardiovascular disorders. In addition, potato proteins and phenolic compounds show antioxidant, anti-inflammatory, and cholesterol-lowering properties. Value-added potato products, including cookies, halwa premix, semolina, porridge, gulab-jamun, jalebi, muffins, and other convenient foods, increase the use of potato in healthy and consumer-friendly forms. Overall, potato is not only a staple crop but also a versatile and nutritious food with strong potential to improve public health and support future food security.

Keywords: Bioactive elements; Indoor farming; Microgreens; Novel culinary element

POTATO (*Solanum tuberosum* L.) is one of the most important food crops in the world, ranking after rice and wheat. It originated in the Andes Mountains and has been cultivated for more than 8,000 years. From its early use in the pre-Columbian period, when it was processed into products like chuno, the potato has spread to over 160 countries. Today, it serves as a staple food for more than one billion people worldwide. Recognizing its global importance, the year 2008 was declared the "International Year of the Potato." Potatoes play a key role in meeting the energy and nutritional needs of populations in both developing and developed countries. They are widely consumed because of their low cost, easy availability, and versatility in cooking. Their mild taste allows them to be used in a variety of dishes and combined with many other foods. Due to these advantages, potatoes contribute significantly to global food security and have the potential to help reduce malnutrition.

Although potatoes are often viewed as foods high in carbohydrates and calories, their nutritional value is frequently underestimated. Many people wrongly associate potato consumption with obesity and diabetes, while ignoring their health benefits. In reality, potatoes are a rich source of essential nutrients such as vitamin C, vitamin B3, vitamin B6, dietary fibre, potassium, phosphorus, and good-quality protein. They also contain several bioactive compounds that promote health. Coloured potatoes, such as yellow- and purple-fleshed varieties, are especially rich in beneficial compounds. Yellow-fleshed potatoes contain carotenoids, while purple potatoes are rich in anthocyanins. These compounds are known for their antioxidant properties and their role in reducing the risk of chronic diseases, including cancer, diabetes, and age-related disorders. In addition, potato protein peptides have shown potential in managing conditions such as hypertension, obesity, hyperlipidaemia, and certain microbial infections.

Potatoes also contain small amounts of antinutritional compounds such as glycoalkaloids, proteinase inhibitors, and lectins. However, when present within safe limits, these compounds may also provide health benefits. Scientific studies, including laboratory experiments, animal studies, and human clinical trials, have demonstrated the positive effects of potato consumption on health. These studies highlight the anticancer, anti-inflammatory, anti-diabetic, and cholesterol-lowering properties of potato components. Several studies have primarily focused on the characterization of nutrients and bioactive compounds, including carotenoids, phenolics, anthocyanins, vitamins, proteins, and minerals, in both

raw and processed potatoes. Recent investigations have further addressed the bio-accessibility of these compounds. Although coloured potato varieties have received considerable attention, conventional cream- and yellow-fleshed potatoes also possess substantial levels of health-promoting constituents. This article emphasizes the phytonutrient profile and possibilities of value- addition in potatoes and elucidates their role in human health promotion.

Potato is wholesome and nutrient-dense food

The nutritional importance of any crop depends on its metabolic composition, and potato holds a unique position in this regard. It is considered a nutrient-rich food due to the presence of several health-promoting components. Starch is the major constituent of potato and serves as a significant source of dietary carbohydrates. In addition to starch, potato tubers contain proteins, vitamins, minerals, bioactive compounds, phytochemicals, phenolics, anthocyanins, and carotenoids, all of which contribute positively to human health. Due to its high consumption, potato is also one of the major contributors of total phenolic intake among fruits and vegetables. Furthermore, potatoes are highly efficient in energy production, yielding more calories per unit area (216 MJ ha^{-1} day^{-1}) compared to crops such as maize (159 MJ ha^{-1} day^{-1}) and rice (121 MJ ha^{-1} day^{-1}).

Nutritional profile of the potatoes from different database is provided in table 1. In general, potatoes consist of about 80% water and 20% dry matter, which includes carbohydrates (about 15 g), proteins (about 2 g), and small amounts of other components that vary among cultivars. Potato starch, which accounts for 65–85% of the dry matter, is mainly composed of amylose and amylopectin. Cooked potatoes are generally classified as high glycaemic index foods due to rapid starch digestion. However, raw potatoes contain resistant starch, which is not easily digested and offers several health benefits. Resistant starch has been associated with improved glucose tolerance and insulin sensitivity, reduced cholesterol and triglyceride levels, enhanced satiety, and protection against colon cancer. Although potatoes contain relatively low protein, their protein quality is high, with a biological value of approximately 90–100, comparable to that of whole egg protein. Potato proteins have a well-balanced amino acid profile and are particularly rich in essential amino acids, including lysine, which is often limited in plant-based foods.

From a dietary perspective, 100 g of potato can provide about 4% of daily energy requirements, 6% of carbohydrates, 9% of dietary fibre, 4% of protein, 33% of vitamin C, 15% of vitamin B6, and 12% of potassium. Because potatoes are consumed regularly and in significant quantities, they make a meaningful contribution to daily nutrient intake. Their versatility and wide acceptability further enhance their importance, as they can be consumed in fresh or processed forms in a variety of food preparations.

Table 1. Nutritional profile of potato

Constituents	Constituents/ 100 g tuber fresh weight	Recommended Dietary Allowances (RDA)	% RDA fulfilled by 100 g potato
Carbohydrates (g)	14.89	130	11.5
Protein (g)	1.54	54	2.9
Dietary fibre (g)	1.71	40	4.3
Energy (kcal)	69.7	2710	2.6
Calcium (mg)	9.52	1000	1.0
Iron (mg)	0.57	19	3.0
Zinc (mg)	0.28	17	1.6
Sodium (mg)	4.11	2000	0.2
Potassium (mg)	541	3500	15.5
Phosphorus (mg)	43.42	1000	4.3
Vitamin C (mg)	23.15	80	28.9
Thiamin (mg)	0.06	1.8	3.3
Riboflavin (mg)	0.01	2.5	0.4
Niacin (mg)	1.04	18	5.8
Pantothenic acid (mg)	0.38	5	7.6
Vitamin B6 (mg)	0.1	2.4	4.2
Biotin (µg)	1.35	30	4.5
Folate, total (µg)	17	300	5.7

Source: ICMR-NIN Expert Group (2020); Recommended dietary allowances and estimated average requirements for Indians: A short report; National Institute of Nutrition; and USDA Reference Legacy database 170032

Potato: A rich source of health promoting compounds

While often viewed primarily as a staple carbohydrate source, the potato is a complex matrix of bioactive compounds with significant therapeutic potential. Recent nutritional research has shifted focus from the potato's basic macronutrient profile to its diverse array of secondary metabolites. These include glycoalkaloids, polyphenols, anthocyanins, carotenoids, vitamins, and specialized proteins. Collectively, these compounds contribute to various health benefits, including anti-cancer, anti-diabetic, anti-inflammatory, and anti-hyperlipidemic effects, while also supporting gastrointestinal health.

Glycoalkaloids: Natural defense with therapeutic potential: Glycoalkaloids are nitrogen-containing steroid glycosides found naturally in potatoes. The two primary types, alpha-solanine and alpha-chaconine, account for roughly 95% of the total glycoalkaloid content. While these compounds can be toxic at high levels (above 20 mg/100g of fresh weight), they offer remarkable health benefits when consumed within safe limits.

Anticancer and anti-inflammatory properties: Research indicates that alpha-solanine can trigger programmed cell death (apoptosis) in human liver and colon cancer cells. Specifically, at a concentration of 30 µM, it has been shown to reduce the formation of cancer colonies without damaging healthy cells. In animal studies, low doses (5 mg/kg body weight) have led to a visible reduction in the size and incidence of breast and prostate tumors.

Alpha-chaconine is noted for its ability to inhibit the spread (metastasis) of cancer. It achieves this by suppressing specific signalling pathways (PI3K/Akt/NF-κB) and reducing proteins responsible for cancer cell invasion. Beyond oncology, these glycoalkaloids act as anti-inflammatory agents by reducing the production of pro-inflammatory cytokines in the body's immune cells.

Antioxidant compounds: Phenolics and pigments: Potatoes are a rich source of antioxidants, including phenolic acids, carotenoids, and Vitamin C. The most prominent polyphenol in potatoes is chlorogenic acid, which is highly effective at preventing the proliferation of colon and prostate cancer cells. The variety of the potato significantly influences its antioxidant capacity. Purple and red varieties are particularly dense in anthocyanins. Extracts from these colored potatoes have demonstrated the ability to suppress the growth of stomach cancer cells, eliminate cancer stem cells in the colon and improve metabolic markers in diabetic subjects by lowering blood glucose and increasing glucose tolerance. Furthermore, human studies show that consuming approximately 150g of purple potatoes daily for six weeks can significantly lower C-reactive protein levels, which is a key marker of systemic inflammation.

Dietary fiber and resistant starch: The dietary fiber and resistant starch found in potatoes play a vital role in weight management and digestive health. The amount of resistant starch is largely determined by the amylose content of the potato variety.

Gut health and prebiotic effects: ***Bacterial modulation***: In both human and animal studies, potato-derived resistant starch has been shown to increase populations of *Bifidobacteria* and *Lactobacilli*. Simultaneously, it reduces harmful bacteria like *Clostridium*, which are often associated with gut dysbiosis and disease.

- *Short-Chain Fatty Acids (SCFAs):* As bacteria ferment potato fiber, they produce butyrate. Butyric acid is the preferred energy source for the cells lining the colon. It strengthens the gut barrier, reducing 'leaky gut' symptoms, and has been shown to accumulate inside cancer cells, leading to their destruction by suppressing histone deacetylase.

Proteins and bioactive peptides: Potato proteins are more than just a source of amino acids; they contain bioactive peptides that target metabolic and cardiovascular health.

- *Metabolic and Cholesterol Management:* Potato protein hydrolysates (proteins broken down by enzymes) have shown the ability to protect against complications of diabetes by supporting muscle synthesis even under high-glucose conditions. Additionally, they exhibit antihyperlipidemic effects by reducing total serum cholesterol and increasing the excretion of bile acids. Studies on rats fed with cooked, unpeeled potatoes showed significant decreases in liver and plasma cholesterol.
- *Satiety and Weight Control:* Potatoes contain specific 'trypsin inhibitors' that stimulate the release of cholecystokinin (CCK), a hormone responsible for signalling fullness to the brain. This explains why individuals often report feeling more satisfied and fuller after a meal containing potatoes compared to meals containing rice or pasta.

Enzyme inhibitors and blood sugar regulation: Potatoes contain natural inhibitors of enzymes like α-amylase and α-glucosidase. These enzymes are responsible for breaking down starches into sugars. By slowing this process, potato extracts help prevent sharp spikes in blood sugar after meals. Red and purple varieties are especially effective, with inhibitory properties that can reduce blood glucose levels by 18% to 30%.

Other specialized compounds: Beyond the well-known vitamins and minerals, potatoes contain 'niche' compounds with specific medical applications.

- ***Biguanides*:** These compounds, found in higher concentrations in the potato peel, are natural analogues to modern diabetes medications. They help lower glucose production in the liver.
- ***Kukoamines*:** Originally discovered in expensive wolfberries (Goji berries), kukoamines have also been identified in potatoes. These molecules are known for their ability to naturally lower blood pressure, making the potato a potential dietary ally for hypertensive patients.
- ***Insulin-like antigens*:** Found especially in sprouted potatoes, these antigens provide a fascinating area for future research into how plant-based molecules can mimic human hormones to regulate metabolism.

The 'healthfulness' of a potato is not a fixed value; it is highly dependent on how the tuber is handled from farm to fork. Consumers looking for maximum antioxidant density should prioritize purple, red, or deep-yellow varieties. These contain significantly higher levels of anthocyanins

and carotenoids than standard white or russet potatoes. Furthermore, how a potato is prepared matters. Boiling can result in the loss of water-soluble vitamins, whereas baking or steaming preserves more of the bioactive profile. Interestingly, processing methods like spray-drying potato juice can actually concentrate its cytotoxic (cancer-killing) properties against intestinal cancer cells. Then the storage also affects the chemical composition of a potato. Proper storage can actually lead to an increase in certain phenolic compounds, though excessive light should be avoided to prevent glycoalkaloids from reaching toxic levels.

Safety considerations and balanced consumption: It is important to address the 'anti-nutrients' in potatoes. Glycoalkaloids, lectins, and proteinase inhibitors are often labelled as 'bad' because they are the plant's defence system. However, as the evidence shows, in controlled amounts, these are the very compounds that provide anticancer and satiety benefits. The key is moderation and proper preparation–removing green skin and sprouts ensures that glycoalkaloids remain in the therapeutic range rather than the toxic range.

Efforts towards further enriching potatoes nutritionally

The development of bio-fortified crop varieties is a critical strategy for addressing nutritional deficiencies in the human diet. The ICAR-Central Potato Research Institute (CPRI) in Shimla has successfully developed several potato cultivars that are enriched with essential minerals, antioxidants, and vitamins. These varieties, including *Kufri Manik*, *Kufri Neelkanth*, and *Kufri Jamunia*, offer significantly higher nutritional value compared to standard white-coloured potato varieties.

Kufri Manik: Mineral and anthocyanin enrichment: *Kufri Manik* is a specialized variety recognized for its high mineral content and deep pigmentation (Fig. 1a). This variety was formally notified in the Gazette on April 1, 2021.

- *Nutritional Profile*: This variety contains 33 ppm of Zinc and 30 ppm of Iron. In contrast, standard white potatoes typically contain only 0.5–4.6 ppm of Zinc and 3–23 ppm of Iron.
- *Antioxidants*: It is also rich in anthocyanin, providing 68 mg/100g, while standard varieties often contain only 0–5 mg/100g.
- *Yield and Maturity*: The variety produces an average yield of 23–25 t/ha and reaches maturity within 75–90 days.
- *Adaptation*: It is specifically suited for the Eastern plains, including regions such as Bihar, Orissa, West Bengal, Assam, and Eastern Uttar Pradesh.

Kufri Neelkanth: High antioxidants and carotenoids: *Kufri Neelkanth* is designed for the North Indian plains and is notable for its high concentration of beneficial plant pigments (Fig. 1b). This variety was notified in the Gazette on February 5, 2019.

- Nutritional Profile: This variety is rich in antioxidants, specifically containing 11 mg/100g of anthocyanin and 292 µg/100g (fresh weight) of carotenoids. Whereas normal white potatoes have significantly lower levels, typically ranging from 0–5 mg/100g for anthocyanin and 27–74 µg/100g for carotenoids.
- Yield and Maturity: It offers a high average yield of 36–38 t/ha with a maturity period of 90–100 days.
- Adaptation: The variety is well-adapted to Punjab, Haryana, Uttar Pradesh, Uttarakhand (plains), Bihar, Madhya Pradesh, and Chhattisgarh.

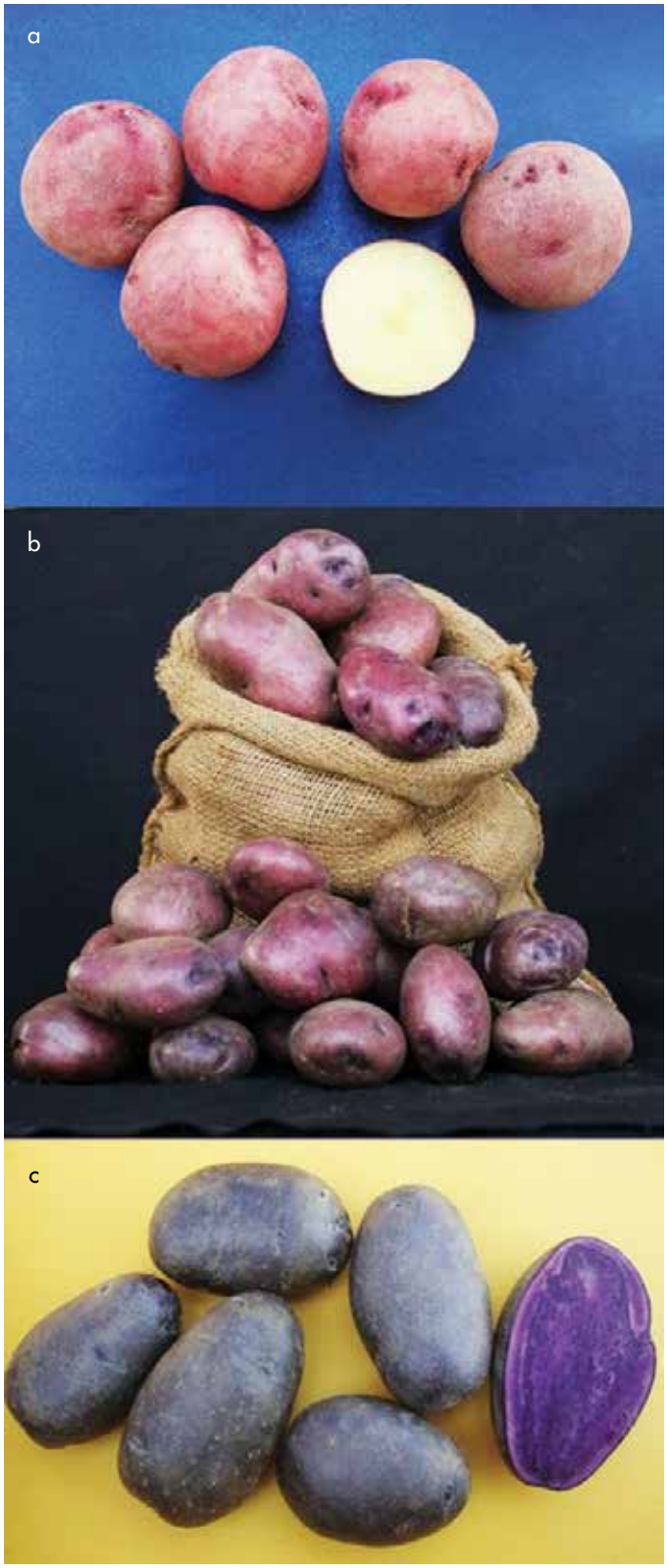


Fig. 1: Fresh tubers of: (a) *Kufri Manik*, (b) *Kufri Neelkanth*, (c) *Kufri Jamunia* biofortified varieties of potato developed by ICAR-CPRI, Shimla

c) Kufri Jamunia: Vitamin C and anthocyanin rich specialty table purpose variety

Kufri Jamunia serves the specialty table potato segment and provides a broad range of vitamins and antioxidants (Fig. 1c). Its Gazette notification was issued on November 13, 2024

- Nutritional Profile: It contains 32.36 mg/100g of anthocyanin, 51.52 mg/100g of Vitamin C, and 163.04 µg/100g of carotenoids. Compared to the standard 11–30 mg/100g of Vitamin C found in white potatoes, *Kufri Jamunia* provides a superior source of this essential vitamin.
- Yield and Maturity: It yields approximately 32–35 t/ha and matures in 90–100 days.
- Adaptation: This variety has broad adaptation across the Northern, Central, and Eastern plains, covering states like Gujarat, Rajasthan, and West Bengal.

The bio-fortified varieties developed by ICAR-CPRI represent a significant advancement in agricultural

Table 2: Potato based value added products

Category	Products	Suitable type potatoes	Speciality
	Potato cheeselings	All types, normal sugar	Gluten-free, high fiber
	Potato Murukku	All types, normal sugar	Gluten-free, high fiber
	Potato boondi	All types, normal sugar	Gluten-free, high fiber
	Potato jalebi	All types, normal sugar	Ready-to-reconstitute, gluten-free, high fiber, fasting friendly
Baked	Potato-Fruit-butter cookies	All types, normal sugar	Gluten-free, high fiber, fasting friendly, low sodium
	Potato-Kodo millet cookies	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato-Finger millet cookies	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato-Sorghum cookies	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato-Pearl millet cookies	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato-Chickpea cookies	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato-Barnyard cookies	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato-coconut cookies	All types, normal sugar	Gluten-free, high fiber, low sodium, fasting friendly
	Potato-tapioca cookies	All types, normal sugar	Gluten-free, high fiber, low sodium, fasting friendly
	Potato-water chest nut cookies	All types, normal sugar	Gluten-free, high fiber, low sodium, fasting friendly
	Potato-finger millet dry cake	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato-corn dry cake	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato muffins	All types, normal sugar	Gluten-free, high fiber, low sodium
	Potato pastry	All types, normal sugar	Gluten-free, high fiber, low sodium
Dehydrated	Potato porridge	All types, normal sugar	Gluten-free, high fiber, fasting friendly
	Potato semolina	All types, normal sugar	Gluten-free, high fiber, fasting friendly
	Potato cubes	High dry matter, low sugar	Ready-to-reconstitute
	Potato shreds	High dry matter, low sugar	Ready-to-reconstitute
	Potato chips	High dry matter, low sugar	Gluten-free, high fiber, fasting friendly
	Potato sticks	High dry matter, low sugar	Gluten-free, high fiber, fasting friendly
	Potato flour	All types, normal sugar	Gluten-free, high fiber, fasting friendly
Premix	Gulab jamun premix	All types, normal sugar	Gluten-free, high fiber, fasting friendly
	Jalebi premix	All types, normal sugar	Gluten-free, high fiber, fasting friendly
	Halwa premix	All types with high sugar	Gluten-free, instant, high fiber, fasting friendly
	Idli premix	All types, normal sugar	Gluten-free, high fiber, fasting friendly
Sweets	Potato preserve	Low dry matter, high sugar, undersize, oversize	Fasting friendly
	Potato burfi	All types, high sugar	Lactose free, high fiber, fasting friendly
	Frozen gulab jamun	All types, high sugar	Gluten-free, high fiber, fasting friendly
	Potato ice-cream	All types, high sugar, coloured	Gluten-free, high fiber, fasting friendly, anthocyanin rich

Normal sugar -<300 mg/100g Fresh Weight (FW), Low sugar <150 mg/100g FW, High sugar->300 mg/100g FW ; High dry matter≥ 20%, Low dry matter ≤17 %

Fig. 2: Innovative value-added products developed by ICAR-CPRI

nutrition. By providing higher levels of Zinc, Iron, Vitamin C, and antioxidants, these potatoes serve as more than a basic starch source; they are a functional food capable of improving public health across various regions of India.

Innovative value-added potato-based products

With advancements in technology and increasing market demand, the sector of potato processing is experiencing substantial growth. As per prevailing culinary preferences and dietary habits of the Indian populace, the ICAR-Central Potato Research Institute has innovatively developed a variety of novel value-added potato products tailored to meet the needs of a broader segment of the Indian population. A variety of innovative potato-based products including potato cookies, millet potato cookies, halwa premix, semolina, porridge, gulab jamun, jalebi, muffins, and numerous others (Table-2, Fig. 2) has been created with consideration of the dietary inclinations of the Indian populace. All of which are enriched with dietary fibre, protein, vitamin C, and potassium. The low sodium concentration and gluten-free nature of these products render them appropriate for individuals with celiac disease, wheat allergies, and hypertension. A particularly significant characteristic of these products is their versatility, as they can be produced from potatoes of diverse shapes, sizes, colors, and dry matter content, even post-storage. This adaptability not only enhances the culinary experience but also ensures minimal waste, allowing for a wider range of dishes that cater to both traditional and contemporary tastes.

SUMMARY

From a humble tuber grown to fill stomachs, potato is steadily transforming into a 'smart food' that can nourish, protect and empower people across all age groups. It not only delivers quick energy, but also offers good quality protein, fibre, vitamins, minerals and a rich mix of protective plant compounds that support heart health, blood sugar control, healthy cholesterol levels and a strong gut. Coloured and bio-fortified varieties such as *Kufri Manik, Kufri Neelkanth* and *Kufri Jamunia* add a new chapter to this story by providing extra iron, zinc, vitamin C and antioxidants, turning an everyday vegetable into a powerful tool against hidden hunger and lifestyle diseases. At the same time, long-standing doubts about antinutritional factors are being addressed through better varieties, proper storage and simple kitchen practices, so that consumers can confidently enjoy potatoes in safe and wholesome forms. Parallel to this nutritional progress, potato-based value-added products–ranging from gluten-free cookies and premixes to dehydrated snacks and traditional sweets are opening new avenues for farmers, women entrepreneurs, food processors and health-conscious consumers alike. Looking ahead, the real opportunity lies in bringing these scientific gains from lab and field to the common plate: promoting bio-fortified and coloured potatoes, refining processing methods that retain sensitive nutrients, and spreading clear, practical messages on how to select, cook and store potatoes for maximum benefit. If integrated thoughtfully into nutrition programmes, school meals and public health campaigns, potatoes can help tackle undernutrition and non-communicable diseases in an affordable and culturally acceptable way. With continued research on genetics and processing, active participation of farmers and industry, and growing public awareness of 'food as medicine,' the potato is well placed to move beyond its image as mere starch and claim its role as one of nature's most effective, farmer-friendly health foods.

For futher correspondence, contact:
[1]ICAR-Central Potato Research Institute, Regional station, Jalandhar 144 003, Punjab, India; [2]Dr. Brajesh Singh, Director, ICAR-Central Potato Research Institute, Shimla 171 001, Himachal Pradesh, India. Email: brajesh.singh@icar.org.in; birju16@gmail.com

Meenu Kumari[1]*, H P Sumangala[2]
G J Janavi[3], Shyama Kumari[1]
and Lalita Rana[4]

Scientific cultivation of Jasmine: A potential avenue for women-led Entrepreneurship

Floriculture is slowly transitioning from a low-return farming practice to a very profitable agricultural company as demand for flowers grows in the area and the ability to export them grows. Jasmine cultivation is now a profitable industry, and this article talks about the scientific cultivation, year round production, value added product, profits earning and the business as a whole. Jasmine flowers all year long, and the weather in India is always changing, which is perfect for it. The flower will still be in high demand even when the economy is down because it is important for religious events, festivals, and weddings. Beyond fresh flowers, it is chiefly used in cosmetics, essential oils, pharmaceuticals, and perfumes. Small-scale farmers and business owners in India, especially women's groups, can become financially independent by adopting jasmine cultivation as entrepreneur. The adoption of scientific technologies including right choice of Jasminum species, timing of planting to harvesting, postharvest and its processing led to become a modern-day gold mine.

Keywords: Ghanjeevamrit, Jeevamrit, Lettuce, Natural Farming

JASMINE, 'Queen of Flowers', native to India, most significant and profitable crops are deeply associated in the Indian culture and customs. It is used in every occasion ranging from religious ceremonies to hair adornments and garlands. India is the global leader in jasmine production, cultivating almost 27.08 thousand hectares to yield roughly 273.91 thousand metric tonnes annually. The main cultivation hubs are in states like Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat and West Bengal. Tamil Nadu is the epicentre of this industry and home to small-scale jasmine oil extraction industries, with key cultivation areas including Madurai (known as the 'Jasmine City of India'), Dindigul, Tirunelveli, Kanyakumari and Coimbatore. The flower's appeal comes from its strong, captivating fragrance and diverse uses. The flowers are in high demand for a variety of purposes like making garlands and floral decorations, religious and ceremonial uses, extraction of essential oil for perfumes and cosmetics and export especially to the Middle East and European Union countries. This consistent demand of jasmine flowers offers profitable crop for Indian farmers especially the women farmers

Jasmine flowers

Different types of jasmine flowers

and SHGs/FPOs

Popular jasmine species: Different species are cultivated for specific purposes. The delicate loose flowers are grown for garlands and adornments and the robust ones are for essential oil extraction. Some of the which are listed hereunder.

Loose Flower (Garlands & Adornment)

Jasminum sambac (Mogra/Arabian jasmine): It has double-petalled, intensely fragrant white flowers with important varieties of like '*Gundumalli/Iruvatchi*' which is highly fragrant and the most common commercial variety and '*Khoya*' with double-flowered type but with a long shelf-life. It also has varieties like '*Ramu*' which is single-petalled, bears flowers in clusters aand is also considered good for oil.

Jasminum auriculatum (*Juhi*): Known for its smaller, highly fragrant flowers that stay fresh for a long time, it is a favourite choice for making long-lasting garlands.

Oil extraction

Jasminum grandiflorum (Spanish jasmine/ Pitchi/ Chameli): It is the most important species for the perfume industry for its large, white, single-petalled flowers which yield a rich, complex and highly prized absolute (a type of essential oil). It is primarily cultivated in the states of Tamil Nadu and Karnataka for this purpose. It has high-yielding varieties like '*CO1 Pitchi*' and '*CO2 Pitchi*' developed by TNAU, Coimbatore, bred specifically for oil content.

Jasminum auriculatum (*Juhi*): This versatile species is also used for oil extraction, producing a warm, sweet fragrance.

Jasminum humile (Yellow jasmine) and ***Jasminum mesnyi*** (Primrose jasmine) possess characteristics of diurnal nocturnal blooming of yellow jasmine. Primarily grown in garden for its cheerful, bright yellow flowers and hardy nature having aroma of noticeably different-lighter, fresher and less intense than the heady aroma of 'Sambac' or 'grandiflorum'. It is sometimes used in aromatherapy and niche perfumery for its unique sunny and uplifting note.

Ideal cultivation conditions: Jasmine requires warm summer, mild winters and plenty of sunshine. It is mostly grown in the tropical and subtropical climates. It requires an ideal range of temperature of 20–30°C along with moderate rainfall (800-1000 mm) and grows well up to 1200m altitude. This crop requires sandy loam or red loamy soil with good drainage and a high amount of organic matter.

Cultivation practices: Jasmine is often propagated by layering or semi-hardwood cuttings. Cuttings treated with rooting hormone and planted in sand will root more readily. During the monsoon season or February–March, mother plants are cut and layered. A mixture of soil, farmyard manure (FYM)/vermicompost, and coarse sand is used to fill pre-made pits. The monsoon season is usually the ideal time of year to plant.

Planting: After the land has been ploughed, pits of roughly 30 cm x 30 cm x 30 cm sizes are prepared and filled with top soil and 15-20 kg FYM/ vermicompost. The species determines the planting distance, which is often done during the monsoon season. Planting is done at 1.25 x 1.25 m to accommodate 6,400 plants/ha.

Table 1. Planting distance of different jasmine species

Species	Planting distance	No. of plants/ha
Jasminum sambac	1.2 m x 1.2 m	6,944
Jasminum auriculatum	1.8 m x 1.8 m	3,086
Jasminum grandiflorum	2.0 m x 1.5 m	3,333

Nutrient and water management: Jasmine plants are heavy feeders and require a balanced dose of NPK fertilizers. Drip irrigation is a highly efficient method for consistent watering.

Table 2. Fertilizer schedules for jasmine species

Nutrients	*J.sambac & J. auriculatum*	*Jasminum grandiflorum*
Organic Manure (FYM)	10–15 kg/plant/year during the pre-monsoon period (May–June)	15–20 kg/plant/year during the pre-monsoon period (May–June)
Recommended NPK Dose (g/plant/year)	120:80:120	150:100:150
Nitrogen (N)	Applied in 3 equal splits At pruning/planting • 45 days after pruning • At onset of flowering	
Phosphorus (P)	Entire dose applied as basal at pruning/planting	Entire dose applied as basal at pruning/ planting
Potassium (K)	Applied in 2 equal splits: • Basal (at pruning) • At onset of flowering	
Micronutrient application	Generally not required under normal conditions	Foliar spray at bud initiation 0.5% Zinc sulphate 0.3% Boric acid
Special Notes	Fertilizers should be applied in a circular trench (20-30 cm away from plant base)	Foliar application improves flower yield and quality

Pruning: Pruning is a critical practice that stimulates new growth and flower bud formation. It is done after the main flowering season.

Flowering and harvesting: Jasmine plants usually start flowering within 6–12 months of planting, depending on the variety. Flowers are harvested in the early morning at unopened mature bud stage when they are fresh and fragrant. Fully opened flowers are harvested for oil extraction for maximum oil recovery. Daily picking during the blooming season ensures maximum yield. Following planting, the crop will produce an economically viable yield for up to 10-12 years, provided it is maintained with good agricultural practices.

Yield **:** Flower and oil yield varies according to the different species and cultural practices followed.

Disease and pest management strategies: For an effective and successful Disease and Pest management, the following steps to be taken strictly.

Prevention: The most effective method to manage diseases is to prevent its establishment. Concentrate on fostering a healthy growing environment through cultural practices by i). Selecting robust planting material, ii). Soil should be well-drained soil to reduce the risk of soil borne disease iii). Practicing appropriate spacing and pruning to facilitate optimal air circulation, iv). Implementing field

Table 3. Region-specific puring details of different jasmine species

Region	Species	Time of Pruning	Type of Pruning	Pruning details
South-Tamil Nadu, Karnataka	*Jasminum sambac, Jasminum grandiflorum, Jasminum auriculatum, Jasminum nitidum*	Late October–November Last week of December	Hard pruning	Sambac are pruned higher 1m from ground level Plants are cut back to 30–45 cm from ground level after the main kharif flowering flush
	Jasminum multiflorum	September	Hard pruning	Plants are cut back to 60 cm from ground level after the main kharif flowering flush
West-Maharashtra, Gujarat	*Jasminum sambac, Jasminum auriculatum*	November–December	Light pruning	About 1/3 of shoot length is removed, especially in *Jasminum sambac*
Bihar, West Bengal, Uttar Pradesh	*Jasminum sambac, Jasminum grandiflorum*	February–March	Hard pruning	Removal of weak, diseased, and crossing branches along with cutting back to 45~30 cm

Table 4. Yield of jasmine

Species	Flower yield (t/ha)	Concrete Yield (% from flowers)	Concrete Yield (kg/ha)
Jasminum sambac	8-10	0.20-0.30%	16-30
Jasminum grandiflorum	10-12	0.25-0.35%	25-35
Jasminum auriculatum	8-10	0.20-0.30%	16-30

Table 5. Flowering time of different species of jasmine

Jasmine species	South India (Tamil Nadu, Karnataka, Andhra Pradesh)	North India (UP, Delhi, Bihar)	West India (Maharashtra, Goa, Gujarat)	East India (WB, Odisha, Assam)
Jasminum sambac,	Year-round flowering, peak Mar-Oct	April-October, peak May-August	March-October	April-September
Jasminum grandiflorum	May-Nov,(Peak June-Sept),extend to December	June-October	May-October	May-September
Jasminum auriculatum	May-September	June- September	May-September	May-August
Jasminum officinale	May-September	May-September	May-September	May-September
Jasminum multiflorum	October-March	February-April	November-February	December-March
Jasminum nitidum	Year Round, peak April-September	April-October	May -October	--------

Table 6. Pests of jasmine and their control

Pest	Symptoms	Control Methods
Budworm (*Hendecasis duplifascialis*)	The caterpillar eats the interior contents of the flower bud and creates holes in it. Flowers with the infestation become violet and fall off. When the infestation is severe, silken thread is used to web adjacent flower buds together.	Collect and destroy the infested buds. Use light trap to attract and kill the adult moths Foliar application of NSKE 5%. Carbofuran treatment at the base @ rate of 40 g/plant Appropriate bush pruning and sanitary upkeep.
Gallery worm (*Elasmopalpus jasminophagus)*	Caterpillars create silken tunnels on the outside of buds, often accompanied by excreta	Destroy damaged buds and tunnels. Use light traps to kill moths. Spray NSKE 5%
Leaf web worm (*Nausinoe geometralis*)	Caterpillars web leaves and branches together with silk. They scrape off green tissue (parenchyma), skeletonizing the leaves.	Collect/ destroy webbed leaves; use light traps. Spray NSKE 5% or Imidacloprid 2 ml/L
Jasmine eriophyid mite	Mite feeding leads to a hairy, felt-like growth, called erineum, on the leaves, stems, and buds. This growth is a visible symptom of their presence and feeding activity. Plant growth is stunted, and flower production drops.	Remove and destroy affected plant parts. Grow resistant varieties like 'Parimullai'. Spray Dicofol 18.5EC 3 ml/L, Wettable Sulphur, or Abamectin 0.5 ml/L
Flower thrips (*Thrips orientalis*)	Feed on flower petals, leaving silvery scratch marks. Infested flowers may fall off prematurely, and pollen is often destroyed.	Use insecticidal soap or neem oil to manage the infestation
Whitefly (*Dialeurodes kirkaldyi*)	Nymphs and adults both suck the sap from the underside of the leaves and cause yellowing leaves, wilting, and sticky honey dew.	Yellow sticky traps; insecticidal soap; neem oil; encourage natural predators like parasitic wasps. Foliar spray methyl demeton 25 EC 2 ml/L
Blossom midge (*Contariniam aculipennis*)	Maggots enter the buds, causing swelling of base of the buds. Ultimately it causes drying of the buds.	Foliar spray of Thiamethoxam 2.5% WG (0.75 g/L)

Table 7. Diseases of jasmine and their control

Disease	Symptoms	Control methods
Cercospora leaf spot (*Cercospora jasminecola*)	Circular or irregular brown to black spots on leaves, often with a yellowish halo. Severe infection causes yellowing and premature leaf drop.	Remove infected leaves. Improve air circulation. Spray Mancozeb (2 g/L) or carbendazim (1g/L).
Alternaria leaf blight (*Alternaria jasmini*, *A. alternata*)	Dark brown, concentric rings on leaves, resembling a target. Spots often start on older leaves and can cause blighting.	Avoid overhead watering. Destroy plant debris. Spray Mancozeb (2 g/L) or Chlorothalonil (2 g/L).
Root rot – (*Sclerotium rolfsii*)	Symptoms begin with the yellowing of older leaves, which then progresses to younger leaves, ultimately killing the plant. The roots show black discoloration, and the infected tissues are covered with white, thread-like fungal growth (mycelia) and mustard-seed-sized resting bodies (sclerotia).	Heavy application of FYM with *Trichoderma viride*
Phyllody – *Phytoplasma sp.*	The most dramatic symptom: floral parts (petals, stamens) turn into small, green, leaf-like structures**.** Plants become stunted and bushy.	Remove and destroy infected plants immediately. Control leafhopper vectors. Spray insecticides like Dimethoate to control leafhoppers

sanitation measures (removal of infected plant debris), and v). Avoid overhead irrigation to reduce moisture leaf wetness.

Use eco-friendly options: Focus should be given on biological or botanical methods before considering chemical pesticides. This approach is more environmentally responsible and supports long-term sustainability.

Jasmine entrepreneurial venture: Jasmine cultivation offers a profitable and exceptional opportunity for women farmers to adopt it as commercial avenue because of :

a). Strong demand and stable market: Jasmine flowers are in high demand both at domestic and abroad, and this demand will persist for a long time**.** This guarantees that farmers always have a place to sell their goods and earn money. *b). Versatility*: Jasmine is hardy crop that flourishes in a range of climates, especially in the tropical and subtropical regions of India. It can be cultivated in various soil types, provided they are well-drained and abundant in organic matter. *c). Perennial crop*: being a perennial crop and economic yield upto 12-13 years once planted, offers one time investment. This cut down input cost only require maintenance cost. *d). Employment generation*: The process of cultivating jasmine is not only rewarding but also labour-intensive, especially during the bustling harvest season. This opens up an opportunity, particularly empowering women in rural communities. *e). Value-added products*: There are several value-added product in addition to selling loose by making garland, veni, floral jwellery, and other processed like essential oil, absolute, cosmetic items, and dried product like potpourri, that fetch good price.

Average economics of jasmine cultivation

Average economics of jasmine cultivation (*Jasmine sambac*) per hectare from the second year onwards.

For *J. grandiflorum* grown for oil extraction, the economics are even more attractive. With a flower yield of 10 t/ha and a concrete recovery of 0.27%, approximately 27 kg of concrete is obtained per hectare per year. At

Table 8. Average economics of jasmine

Particulars	Value	Particulars	Value
Average flower yield	7,000 kg/ha	Harvesting and transportation	₹30,000
Average market price (wholesale)	₹150/kg	Total Cost of Production	₹1,15,550
Gross Income	₹10,50,000	Net Profit	₹9,34,450/ha
Total recurring cost of cultivation	₹85,550	Benefit: Cost Ratio	9.08:1

the current rate of ₹60,000–80,000/kg for concrete, the total revenue generated from oil extraction can soar to ₹16–22 lakh/ha, transforming it into a lucrative venture for women farmers who are linked to processing facilities or have agreements with fragrance enterprises.

Major challenges in oil extraction

The foremost challenges limiting large-scale commercial extraction is the staggering expense.

a) ***Requirement of large quantity of flowers***: To extract 1 kg of absolute, nearly 1.5-2.0 tonnes of flowers are essential.

b) ***Labor-intensive harvesting***: The flowers are harvested at mature bud stage that would be open in next 10-12 hrs in early morning hours. This needs a lot of workforce.

c) ***Perishable raw material***: The flowers start withering and losing their delicate fragrance soon after they are plucked. They have to be processed within hours, so the extraction plant has to be located near the fields.

Indian Jasmine Absolute is one of the most luxurious essential oils in the world. The risk involved in its production make it very expensive, and it can cost between 150,000 and 250,000/kilogram, and sometimes even more depending on the season and the quality of the product.

Commercial extraction process

The procedure is intricate and necessitates substantial capital investment in apparatus.

i). Harvesting and Collection: The flowers are harvested by female laborers between the hours of 4 AM and 8 AM, placed into baskets designed to facilitate air circulation in order to avert overheating and subsequent spoilage. They are promptly transported to the processing facility.

ii). Pre-processing: The flowers are systematically arranged and scrutinized for the presence of stems, leaves, and other contaminants. They are 'not washed' purposely as water exposure can degrade and remove aromatic constituents.

iii). Solvent extraction: Jasmine cannot be distilled by steam because the jasmine fragrance is very delicate. It gives a poor output and ruins the scent profile. So, the solvent extraction is an efficient method by using hexane as a solvent. The flowers are put into large extraction vessels. The solvent is then made to pass through the flowers, dissolving aromatic compounds, waxes and pigments. The result is a waxy semi-solid mixture called 'jasmine concrete'.

iv). Production of absolute: The concrete is not usable as such in perfumery, being too waxy. It is then subjected to a second process:

a). Alcohol washing: The concrete is mixed with pure ethyl alcohol (ethanol) and cooled. The aromatic compounds dissolve in the alcohol. The waxes and non-aromatic materials solidify.

b). Filtration and vacuum distillation: The alcohol solution is filtered to remove waxes. The alcohol is then evaporated off gently under vacuum (low pressure) at low temperatures, so as not to destroy the fragrance, leaving the pure jasmine absolute.

Market and economics

Domestic consumption: A very small fraction of the absolute is consumed in the domestic market for premium attars (traditional perfumes), agarbattis (incense sticks), and niche personal care products. The cost is too high for mass market products. Its premier locations are in France, Switzerland, the United States and the United Kingdom, where it is considered an important ingredient of luxury perfumes.

Challenge/Competition: India faces stiff competition from Egypt and Morocco for '*Jasminum grandiflorum*', and from China for *'Jasminum sambac*. However, the Indian absolute is demanded due to its peculiar intricate aromatic characteristics.

SUMMARY

Commercial jasmine cultivation in India is a high-value, low-volume industry that thrives on the exceptional quality of its produce. It is not a mass-market agricultural activity but a precision-oriented, capital-intensive process catering almost exclusively to the local consumption and global luxury perfume industry. While India is a giant in jasmine flower production, converting that into oil remains a challenging and niche enterprise due to immense cost pressures, making the resulting jasmine absolute a true "liquid gold". Some of Government institutes involved in research for breeding and improvement in jasmine cultivation and extraction process, *viz.* CSIR-CIMAP, Lucknow, The Fragrance & Flavour Development Centre (FFDC), Kannauj (Uttar Pradesh),TNAU, Coimbatore and National Horticulture Board (NHB), Gurugram and State Agriculture Departments. Regional demands is the key for area expansion in both fresh flower and oil extraction trade in a cluster mode supported by government schemes. This sector can be the game changer for several women SHGs and FPOs having huge entrepreneurial avenues. Farmers, researchers, garden lovers can purchase rooted cutting of jasmine species from different genuine sources, like Tamil Nadu Agriculture University, Coimbatore, IIHR, Bengalore, BCKV, West Bengal and from private nursery.

For further correspondence, contact:
[1]Dr. Meenu Kumari, Asstt. Professor cum Jr Scientist, Bihar Agricultural University, Sabour, Bhagalpur 813 210, Bihar, India; Email: meenubhu08111@gmail.com. [2]ICAR-Indian Institute of Horticultural Research, Hesaraghatta Lake Post, Bengaluru 560 089, Karnataka, India; [3]Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam East 525 604, Theni, Tamil Nadu, India; [4]Dr. Rajendra Prasad Central Agricultural University, PUSA, Samastipur 848 125, Bihar, India.

Payal Chauhan and Poonam Kumari*

Edible Flowers: A Nutritional Powerhouse for Health and Sustainability

Edible flowers, the non-toxic floral parts of the plants, are increasingly recognized as functional food due to their rich nutritional and bioactive properties. Historically, they have been utilised for decoration, cooking, and medicinal purposes. Evidence from ancient Roman, Greek, Chinese, and Ayurvedic traditions shows their importance for health and culinary practices. Edible flowers are rich in vitamin C and essential minerals like calcium, iron, and magnesium. Edible flowers also contain dietary fiber and bioactive compounds such as polyphenols, flavonoids, carotenoids and anthocyanins. These components are closely linked to several health benefits, such as antioxidant, anti-inflammatory, anticancer, liver-protective and cardiovascular diseases. Edible flowers such as Calendula officinalis, Hibiscus, Rosa sinensis, and Tropaeolum majus show immunomodulatory, digestive, and brain-protective properties. Cultivating edible flowers supports a sustainable food system, promotes biodiversity, reduces pesticide use and encourages urban agriculture. However, it is important to identify species carefully and manage contaminants to ensure safety. Overall, edible flowers have great potential to improve nutrition, health and environmental sustainability.

Keywords: Antioxidants; Bioactive compounds; Edible flowers; Floral nutrition; Polyphenols

EDIBLE flowers have been a significant part of human diets. Historical sources provide evidence of their gastronomic and nutritional qualities. These edible flowers contain nutrients and health-promoting components that are safe for human consumption. Edible flowers, which were previously employed for aroma and decorative purposes, are now believed to be an essential component in the food chain. This recognition is

Photographs of common cultivated edible flower A) Calendula, B) Chrysanthemum, C) Dianthus, D) Marigold, E) Pansy, F) Rose, G) Hibiscus and H) Nasturtium

supported by historical and archaeological evidence that indicates their use as early as 3000 BC. Many culinary traditions have incorporated edible flowers, with European countries being among the first to acknowledge their potential. These flowers are often included in confections, preserves, and herbal infusions. Historical records from ancient Roman, Greek, Chinese, ayurvedic practices show their potential for both therapeutic and nutritional benefits. Hibiscus (*Hibiscus sabdariffa*) was often consumed as a drink to treat fever and high blood pressure. These traditional applications demonstrate an early understanding of the advantageous properties of flowers. Edible flowers are attractive and packed with essential vitamins and minerals that may improve overall health. These flowers are especially high in vitamin C, which is important for immune function, collagen production and skin health. Rose petals and hibiscus flowers have significantly higher vitamin C content, similar to citrus fruits. Additionally, edible flowers contain antioxidants that help reduce oxidative stress and lower the risk of chronic diseases. Calendula and chamomile are rich in antioxidants that have anti-inflammatory properties. Many edible flowers also contain essential minerals like calcium, iron and magnesium. For example, edible violets are high in calcium, while rose petals provide a good amount of iron. In addition, certain edible flowers are high in fibre, which promotes gut health and aids in digestion. Flowers such as nasturtium and marigold are particularly high in fiber. Additionally, polyphenols found in edible flowers have anti-inflammatory and anti-cancer properties. These compounds are more concentrated in flowers like blueberries and elderflowers.

Common edible flowers: A wide range of edible flowers is currently available in commercial markets, and their consumer demand has increased considerably in recent years. Globally, edible flowers are reported to originate from approximately 97 plant families, 100 genera, and 180 species; however, the diversity and availability of edible flower species vary significantly across geographical regions. Studies on edible flowers are crucial because the global flora includes a vast diversity of plant species, yet only a limited number are safe and suitable for human consumption.

Nutritional benefits of edible flower: Edible flowers are increasingly recognised not only for their aesthetic and culinary value but also for their significant nutritional and functional properties. From a nutritional perspective, pollen, nectar and floral tissues such as petals are the three primary constituents of edible flowers that contribute significantly to human nutrition. Pollen is a thick, concentrated, but quantitatively low fraction of the flower. Despite its restricted distribution, it contains high-quality proteins, essential amino acids, carbohydrates and both saturated and unsaturated lipids. It also contains bioactive compounds with antioxidant properties, such as flavonoids and carotenoids. Nectar is the main energy source in edible flowers and contains amino acids (mostly proline), proteins, inorganic ions, lipids, organic acids, phenolic

Table 1. Common edible flowers

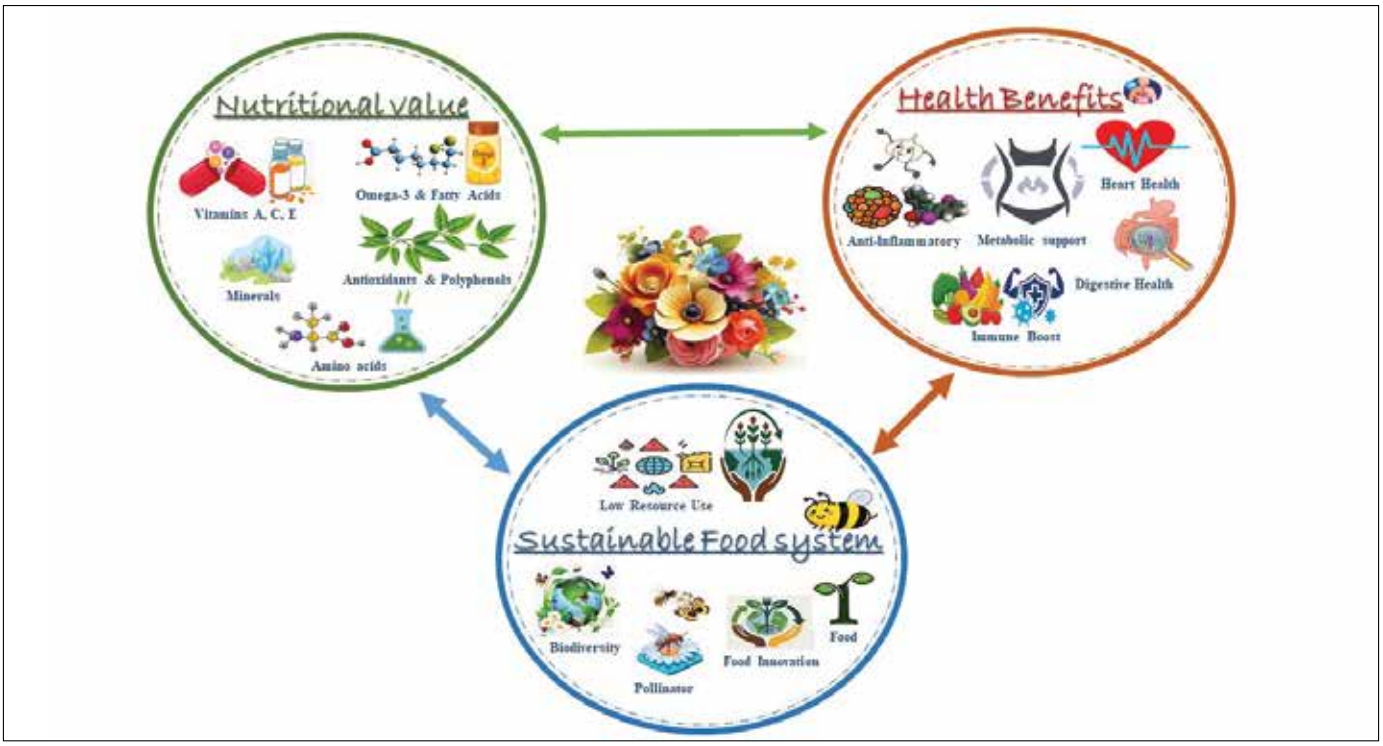
S.no	Common name	Scientific name	Description
1	Anise Hyssop	*Agastache foeniculum*	A perennial herb that self-seeds and has a flavour and scent similar to anise.
2	Hollyhock	*Althea rosea*	Flowers have a subtle vegetal flavour and are mostly used as eye-catching decorations.
3	Tuberous Begonia	*Begonia tuberhybrida*	Slightly lemon-flavoured edible flowers have ophthalmic, anti-inflammatory, antispasmodic, and calming properties and are frequently used as a garnish.
4	Daisy	*Bellis perennis*	People with hay fever, asthma, or severe allergies should avoid mildly bitter foods, as they may trigger allergic reactions.
5	Calendula	*Calendula officinalis*	The slightly bitter petals help with digestion, boost immunity, lower fever, control menstruation, and have anti-inflammatory properties that are beneficial for gastrointestinal issues.
6	Chrysanthemum	*Chrysanthemum spp.*	Only the petals of Chrysanthemum coronarium are edible; the florets have a strong flavour. Traditionally used to treat infections, colitis, pneumonia, fever, constipation, and hypertension.
7	Carnation	*Dianthus spp.*	Bitter petal bases should be eliminated before using; sweet, clove-like flavour. For cooking, perennial species are favoured.
8	Hibiscus	*Hibiscus rosa-sinensis*	Rich in antioxidants and good for liver health and cholesterol control, these blossoms have a subtle citrus flavour and are used as ornamental edible garnishes.
9	Lavender	*Lavandula spp.*	Strongly fragrant, sweet, and fragrant, used in moderation. Helps reduce stress and encourages sleep, but using too much essential oil could be harmful.
10	Rose	*Rosa spp.*	Rich in vitamin C and offering anticancer, diuretic, laxative, and eye-health benefits, fragrant petals are used in salads and as garnishes after the bitter white base is removed.
11	Lilac	*Syringa vulgaris*	Petals, which are added to salads and have a lemony, floral taste, are believed to lower fevers and aid in removing internal parasites.
12	Marigold	*Tagetes spp.*	Flowers with a slight bitterness should be consumed infrequently and in moderation, as they are potentially dangerous in large quantities.
13	Dandelion	*Taraxacum spp.*	Young blooms taste sweet and are high in iron, calcium, phosphorus, and vitamins A and C.
14	Nasturtium	*Tropaeolum majus*	Antibiotic, disinfecting, wound-healing, expectorant, anticancer, and antiscorbutic qualities make these peppery-flavored blossoms and leaves useful in salads.

Table 2. Nutritional composition of edible flowers

Edible flowers	Moisture (%)	Ash (%)	Fat (%)	Total Carbohydrates (%)	Fibre (%)	Protein (%)
Tegetus minuta	12.28	8.79	23.82	11.31	34.03	9.75
Costus afer	18.63	11.47	1.83	55.83	21.16	2.73
Tithonia diversifolia	11.8	16.7	4.0	26.0	19.0	20.3
Hibiscus rosasinesis	12.37	2.64	4.7	61.11	17.27	1.90
Matricaria chamomilla	80.45	4.9	3.99	80.98	-	11.62
Spilanthes oleracea	81.74	1.44	0.41	13.56	10.11	2.84
Moringa olerifera	13.66	1.89	3.36	49.01	29.00	3.07
Musa paradisiaa	12.95	3.34	5.60	50.59	25.54	1.97
Plumeria alba	77.33	4.39	1.36	-	8.86	-
Rhododendron arboreum	79.40	2.30	1.52	12.20	2.90	1.68
Rose hybrida	-	2.47	3.80	73.31	6.19	14.23
Fuchsia hybrida	11.47	6.00	1.76	71.55	-	1.76
Tropaelum majus	89.32	0.63	0.33	7.14	4.51	1.99
Acmella oleracea	11.36	8.85	21.71	39.33	24.10	18.75
Capparis decidua	73.11	5.96	7.43	15.03	12.32	14.88
Glycyrrhiza glabra	2.24	5.10	2.61	68.43	15.77	5.85
Bauhinia variegata	2.10	5.97	10.58	58.12	12.97	10.26
Malvaviscus arboreus	21.22	7.23	10.82	48.12	17.86	12.60
Tagetes erecta	83.39	0.80	0.32	14.15	9.20	1.32
Alcea rosea	8.67	7.62	2.67	68.95	-	2.67
Cassia auriculata	8.11	6.83	3.03	64.45	7.82	9.76
Jasminum grandiflorum	92.76	2.94	2.56	-	3.60	-
Tropaedum majus	86.66	6.75	3.53	74.46	-	11.79

compounds, alkaloids and terpenoids. It is primarily composed of soluble sugars, including fructose, glucose and sucrose. These components are present in high amounts and together give nectar its distinctive, gentle and sweet flavour. Petals, together with other floral structures, constitute the vast majority of the edible components and are a significant source of micronutrients. Edible flowers are also rich sources of essential vitamins, particularly vitamin C, which plays a significant role in immune defence, collagen synthesis and skin health. Flowers such as rose petals and hibiscus are reported to have higher vitamin C content than citrus fruits. Additionally, edible flowers contain abundant antioxidants that reduce oxidative stress and may lower the risk of chronic diseases; species such as calendula and chamomile exhibit notable anti-inflammatory properties. Despite being low in calories, edible flowers are usually high in dietary fibre, which supports digestive health, as seen in flowers such as nasturtium and marigold. Studies on flowers, including *Agave salmiana*, *Cucurbita pepo*, *Yucca filifa*, *Aloe vera*, dahlia, rose and calendula have shown that their nutritional profiles are similar to those of leafy vegetables. In terms of nutrition, edible flowers generally have a high moisture content (over 80%), low fat and protein, and varying amounts of carbohydrates, sugars, minerals and fibre depending on the species and flowering stage. Such flowers often contain organic acids such as quinic and malic acid. Moreover, flowers such as *Yucca elephantipes* are known for their significant amounts of dietary fibre and unsaturated fatty acids. Fully opened flowers are valuable sources of minerals and bioactive compounds, including polyphenols, carotenoids, anthocyanins and vitamin C. This highlights their potential to improve dietary quality and support human health.

Health benefits of edible flowers: Integrating edible flowers into the diet can provide various health benefits. The high levels of vitamin C in edible flowers strengthen the immune system, helping the body fight infections and illness. These flowers are also rich in antioxidants and polyphenols, which have anti-inflammatory effects. This may help reduce inflammation and lower the risk of chronic diseases, including heart disease and diabetes. The high fiber content in edible flowers supports healthy digestion, relieves constipation and promotes the growth of healthy gut bacteria. In addition, the antioxidants and vitamin C in these flowers help protect the skin from damage caused by free radicals. Edible flowers contain polyphenolic compounds known for their anti-inflammatory and anticancer effects. These effects are particularly pronounced at higher concentrations, as in elderflower and blueberry flowers. They support collagen production, which is important for keeping skin firm and elastic. However, flowers rich in polyphenols may also support heart health by lowering cholesterol and



Edible flowers for nutrition, health and sustainability

enhancing vascular function.

Sustainability and the food system: Edible flowers are important in sustainable food systems because they offer health benefits for people. They require minimal resources for cultivation, have short growing periods, and can thrive in limited spaces. These characteristics make them particularly suitable for urban agriculture and vertical gardens. Growing flowers alongside other crops can increase overall production and reduce the need for pesticides and fertilizers. Additionally, this practice encourages biodiversity by providing habitats for pollinators like bees and butterflies, which helps sustain ecosystem health and enhances pollination of various crops. Additionally, edible flowers can be utilized to develop innovative culinary products, helping to reduce food waste and improving the nutritional value of meals. Flower-infused oils, teas, and jams can improve both flavor and nutritional content in a variety of dishes. Edible flowers have cultural importance. They can be used to develop unique and valuable food items, thereby strengthening local economies by supporting small-scale farmers and producers who focus on flower-based products.

Safety considerations of edible flowers: Consumers are increasingly interested in foods that offer improved nutritional and functional benefits. However, it is important to carefully consider the safety of edible flowers. Many studies have explored the nutritional and beneficial properties of these flowers. It is important to recognise that some flowers can be hazardous if misidentified or collected from inedible species that contain harmful compounds. Moreover, edible flowers might be contaminated with biological agents, such as harmful microbes or with chemical residues from fertilisers and pesticides. These contaminants can occur during cultivation, harvesting, processing or as a result of soil conditions. As consumers increasingly demand foods with specific nutritional and functional benefits, maintaining the safety of edible flowers remains crucial. While numerous studies investigate the nutritional and bioactive qualities of these flowers, it is important to remember that misidentifying or consuming non-edible species that contain toxic compounds can pose health risks. Additionally, flowers may carry biological contaminants such as harmful microorganisms or chemical residues from fertilisers and pesticides. These contaminants may be present due to cultivation, harvesting, processing methods or soil conditions. Edible and non-edible flowers mainly differ in their chemical composition, particularly their alkaloid content. Non-edible flowers may contain alkaloids that are stimulant, psychotropic, or toxic, emphasising the need for precise botanical identification and evaluation of their chemical and microbiological properties before consumption. A study by Egebjerg found that many flowers contain potentially toxic or unknown compounds. However, commonly edible species such as calendula (*Calendula officinalis L.*), nasturtium (*Tropaeolum majus L.*), and Viola (*Viola tricolor*) may pose a significant risk to sensitive individuals due to their high levels of methyl salicylate. Proper identification and monitoring of edible flowers are important to ensure their safety as food ingredients while also considering their nutritional and functional benefits.

Innovative food solutions: Edible flowers offer a distinctive way to boost nutrition and support sustainable practices in today's food system. Their application goes beyond mere decoration, delivering health benefits and culinary options that can enhance everyday meals while promoting environmentally friendly food choices. Rosehips and calendula are particularly valued for their high content of essential fatty acids and antioxidants.

These compounds support heart health and protect immune cells. These essential oils can also be incorporated into cooking or salad dressings, enhancing flavour while providing beneficial nutrients. Edible flowers are often used in tea production. Chamomile and hibiscus teas are popular for their calming effects and are suitable for hot or cold consumption. Their floral infusions offer antioxidants and vitamins, promoting health and relaxation. Beyond beverages, these flowers can be used to make jams and preserves. Rose petal and violet jams add a unique floral sweetness and nutrients to foods such as yoghurt, cheese and toast. Similarly, flavoured waters infused with flowers such as cucumber or strawberry provide a refreshing and hydrating alternative to sugary beverages. These drinks often contain essential vitamins and minerals that promote overall health. Edible flowers are a charming addition to cuisine and promote sustainability by enhancing nutrition and environmental health. They can be used in infused oils, teas, jams and flavoured waters. Consequently, this demonstrates their potential to transform everyday meals into healthy, environmentally responsible choices.

SUMMARY

Edible flowers are increasingly favoured in international cuisine for enhancing the sensory qualities of food, such as flavour, aroma, colour, appearance and nutrition. They are widely recognised as natural sources of nutrients and health-beneficial compounds. However, proper chemical and biological identification is essential to reduce potential health risks. Edible flowers have great potential for nutrition and health because they may help protect against diseases related to oxidative stress. However, further research is necessary to confirm these benefits in humans. The nutritional and functional properties of edible flowers can vary based on factors such as species, growing conditions, geographical origin and the methods used to extract their bioactive compounds. This highlights the great potential of edible flowers as nutrient-dense functional foods that can improve dietary quality, increase nutritional diversity, and play an essential role in maintaining and promoting physiological well-being and overall human health.

For further correspondence, contact:
Dr. Poonam Kumari, Senior Scientist, Division of Agrotechnology, CSIR-Institute of Himalayan Bioresource Technology, Palampur, Himachal Pradesh 176 061, India. Email: poonamjaswalfls@gmail.com

Tejaswini Kapil*,
Pragya Bhadauria, Md. Monobrullah
and Anjani Kumar

From wetlands to wellness: Makhana a functional superfood for nutritional and Health security of India

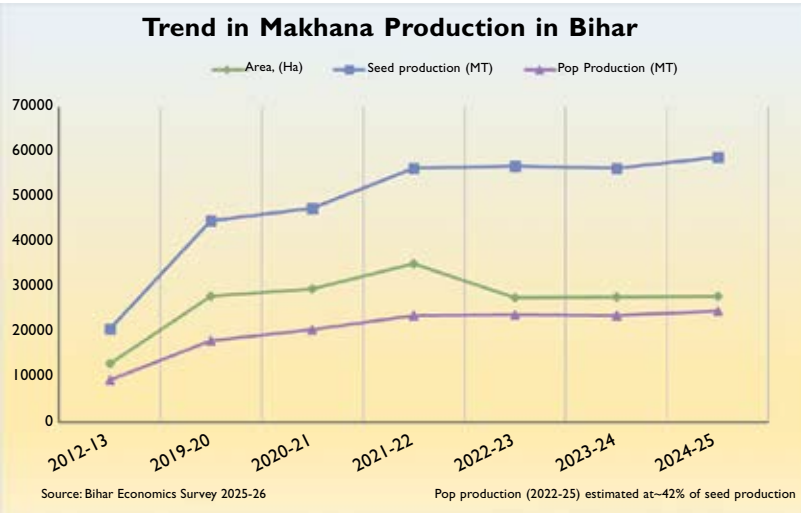
Makhana (fox nut), a traditional wetland crop of Bihar, is emerging as a nutrient-rich functional food supporting India's nutrition and health security. In recent years, increasing health awareness and market demand have transformed makhana from a local crop into a high-value agri-enterprise. Its rich protein, mineral and antioxidant content helps address hidden hunger and lifestyle diseases. A key innovation is the shift from traditional pond systems to scientifically managed pond–cum-field cultivation, which has improved productivity, processing efficiency and farmer income. Expansion of value-added products and stronger market linkages have further boosted its economic potential. Integrating makhana into public nutrition programmes such as Mid-Day Meal and ICDS offers a practical strategy to improve dietary quality. Future growth depends on enhancing productivity, decentralised processing and market integration to ensure sustainable nutrition and livelihood security.

Keywords: Functional food; Lifestyle disorders; Makhana; Nutritional security; Wetland agriculture

INDIA faces a dual nutritional challenge: Persistent hidden hunger marked by deficiencies of protein, iron and zinc, alongside a rising burden of non-communicable diseases (NCDs). While calorie availability has improved, diet quality remains inadequate. In this context, locally available functional foods that are nutrient-dense, affordable and culturally acceptable are essential.

Makhana (fox nut) represents one such indigenous solution. Traditionally cultivated in shallow wetlands, it has evolved from a fasting food to a modern health snack valued for diabetes management, cardiovascular health and weight control. With Bihar contributing nearly 80–90%of national production, makhana holds strategic importance for both nutrition and livelihood security.

Agro-ecological adaptation and production dynamics: India accounts for 70–80% of the global in Makhana production, out of which the Bihar is the leading producer, contributing over 80-90% of country's makhana production. The nine districts of Bihar namely Madhubani, Darbhanga, Sitamarhi, Saharsa, Katihar, Purnia, Supaul, Kishanganj, and Araria are the major producers of makhana. These districts lie in the north Bihar floodplain region, resulting in low-lying wetlands, ponds, oxbow lakes and seasonal waterlogging conditions that are highly suitable for makhana cultivation. The total area under makhana cultivation in India is estimated to be 15,000 hectares. The average productivity of makhana in these districts is close to 1,800 kg/hectare. About 5 lakh families are directly involved in its cultivation, harvesting, popping, and marketing. Makhana is uniquely adapted to waterlogged and wetland ecosystems where most field crops fail. The crop thrives under shallow standing water, warm humid conditions and organic-rich soils, making it particularly suitable for flood-prone regions of eastern India. Importantly, it utilises underexploited wetlands without competing for prime agricultural land or irrigation resources, thus contributing to climate-resilient farming systems.



Demonstration of scientific makhana cultivation at KVK

Makhana cultivation in wet land

Makhana field demonstration unit showcasing sustainable aquatic cultivation practices

Farmers harvesting makhana during KVK-led field demonstration in a wetland system

Traditionally confined to ponds and oxbow lakes, cultivation has gradually expanded to managed private ponds and modified low-lying fields. The shift toward pond–cum-field systems has enabled better water control, improved agronomic practices and enhanced productivity.

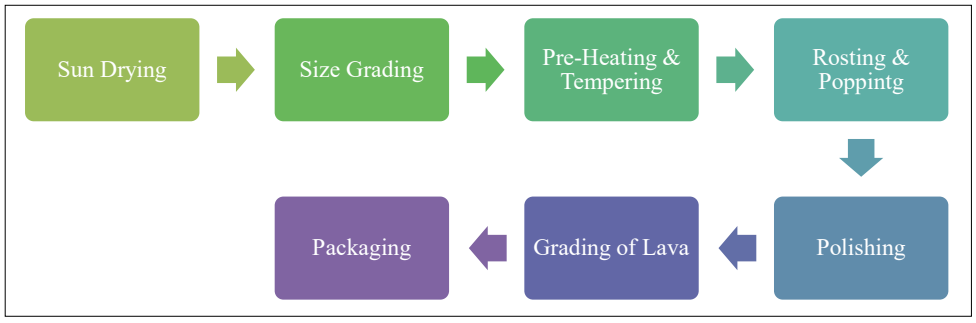
Over the last decade, Bihar has witnessed a substantial increase in makhana cultivation and output. The cultivated area expanded from approximately 13,000 ha in 2012–13 to nearly 28,000 ha in 2024–25. Seed production rose from about 20,800 MT to 58,800 MT during the same period, while popped makhana production increased from 9,360 MT to around 24,700 MT. The most significant growth occurred between 2019–20 and 2021–22, coinciding with improved pond management, varietal refinement and better processing skills. Though area stabilised after 2022, production efficiency improved, reinforcing Bihar's status as the national hub of makhana cultivation and value addition.

Processing and value chain addition of makhana

Processing and value chain development play a pivotal role in enhancing the economic, nutritional and market value of makhana, particularly in Bihar, which dominates national production. Traditionally, makhana processing has been labour-intensive and skill-driven, but recent interventions have demonstrated significant scope for efficiency gains and income enhancement through improved practices.

Processing stages: The makhana value chain begins with harvesting of raw seeds from ponds and low-lying fields, followed by sun drying to reduce moisture content. Dried seeds are then graded and tempered before popping, a critical operation that determines expansion, texture and quality. Popping is traditionally carried out using heated sand in iron pans, requiring considerable skill. The popped makhana is subsequently roasted, polished and graded into different size categories, which directly influence market price. Proper drying and hygienic handling at this stage are essential to improve shelf life and food safety.

Value chain addition: Value addition in makhana has expanded beyond raw popped kernels to include roasted and flavoured snacks, makhana flour, laddoos, breakfast mixes and bakery ingredients. Such diversification significantly enhances consumer appeal and market reach. Field-level experiences in Bihar show that graded and packaged makhana fetches 30–50% higher prices compared to ungraded bulk sales.



Institutional and livelihood linkages: Women-led Self-Help Groups (SHGs) play a central role in post-harvest processing, grading and packaging of makhana. Establishment of decentralised processing units has reduced

Table 1. Nutritional profile of makhana and its health benefits

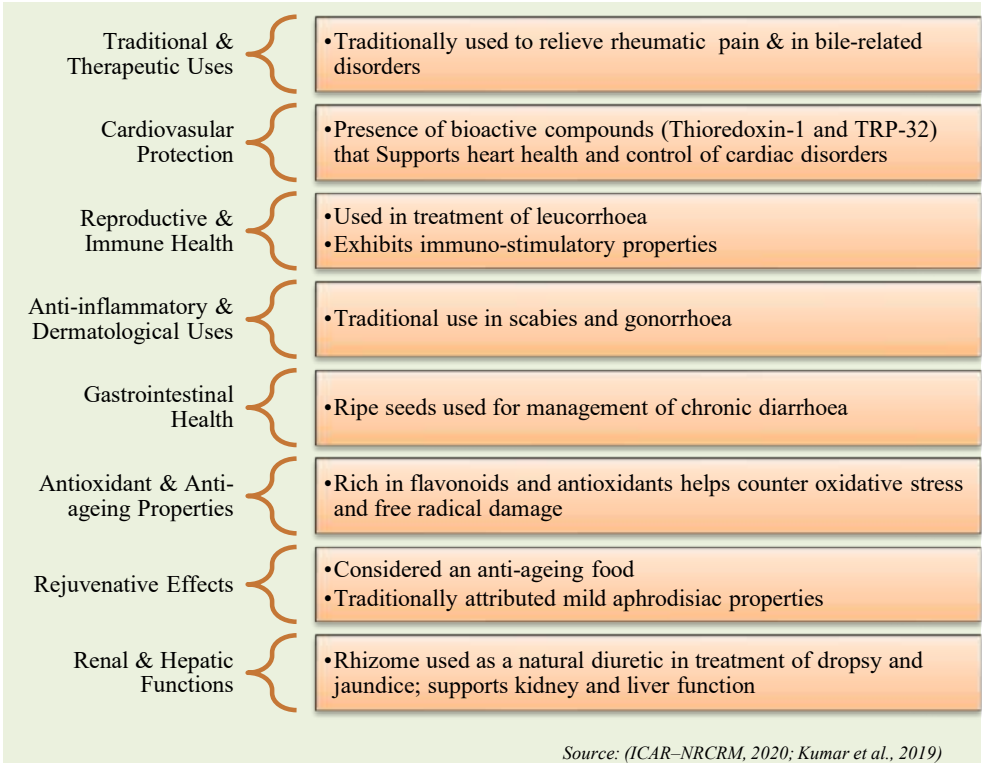
Aspect	Key Observations	Nutritional/ Health Implications
Dietary category	Considered a dry fruit (panchmeva), comparable with almond, walnut, cashew nut and coconut	Enhances dietary diversity and acceptability
Protein and fat profile	Moderate protein (8.6–8.7%) with very low fat (0.2–0.5%) and low sodium	Suitable for diabetes, hypertension and cardiovascular disorders
Digestibility	Gluten-free and easily digestible	Ideal for children, elderly persons and convalescents
Carbohydrate quality	High complex carbohydrates with amylose content of 18–18.5%	Slow digestibility and low glycaemic response
Mineral richness	Rich in P, K, Ca, Mg, Fe and Zn	Supports bone health, haemoglobin synthesis, immunity and electrolyte balance
Micronutrient security	Addresses deficiencies of iron, zinc and magnesium	Helps combat hidden hunger
Protein quality	High essential amino acid index (EAAI: 89–93%); favourable arginine + lysine/proline ratio (4.74–7.6)	Protein quality comparable to fish and superior to rice and wheat
Functional role	Low fat, mineral-rich, high-quality protein food	Supports metabolic health, cardiovascular well-being and nutritional security

drudgery, improved quality consistency and enhanced women's income. Strengthening backward linkages (improved varieties and scientific pond management) and forward linkages (branding, certification and institutional procurement) is crucial for transforming makhana into a high-value, nutrition-sensitive agri-enterprise. The Krishi Vigyan Kendra of Bihar are playing a key role in scientific cultivation of makhana. A classic example of horizontal technology dissemination is the expansion of scientific makhana cultivation by KVK across ten villages–Sandalpur, Gaira, Mirzapur, Sukhi, Dak, Musahri, Bhansia, Denga, Padampur and Bistoria of Araria district. Initially, Sandalpur was developed as a model cluster, where 30 farm women were trained in improved production and processing practices, and the high-yielding variety *Sabour Makhana*-1 was introduced. Subsequently, a Farmers Interest Group (FIG) comprising 30 growers was established, along with a commercial popping unit employing 20 workers. The FIG has evolved into a viable enterprise with an annual turnover of approximately ₹3.45 crore, and replication in neighbouring villages has led to the emergence of another FIG engaged in makhana pop exports, demonstrating the scalability of technology-driven livelihood interventions.

A similar institutional initiative is done by KVK Dharbanga in technical guidance to Shri Mithila Makhana Kisan Utpadak Sangathan Swavlambi Sahkari Samiti Limited. The FPO comprises over 560 member farmers and manages approximately 1,000 ha of pond-based makhana cultivation, with an average productivity of about 20 quintals per hectare. It has developed six value-added products–Makhana Atta, Pudina Snacks, Makhana Kheer Mix, Plain Makhana, Shishu Aahar and Makhana Vita enhancing market diversification and branding. The FPO has achieved an annual turnover of around ₹1 crore, demonstrating the viability of collective production, processing and marketing models in strengthening farmer incomes and nutrition-sensitive enterprises.

Nutritional profile and functional attributes of makhana

Makhana is recognised as a nutrient-dense food comparable to dry fruits. Both improved and local varieties contain: Protein: 8.6–8.7%, Fat: 0.2–0.5%, Carbohydrates: ~79–80%, Energy: 354–358 kcal/100 g and Amylose: 18–18.5%. Its low fat and low sodium



Medicinal and therapeutic value of makhana

Makhana based food products

Braded marketing of makhana by KVK beneficiary

Makhana seeds

content make it suitable for heart-friendly diets. The moderate amylose content contributes to slow digestion and a lower glycaemic response. Makhana is also a source of phosphorus, potassium, calcium, magnesium, iron and zinc, helping address micronutrient deficiencies. Its high essential amino acid index (89–93%) indicates superior protein quality comparable to animal sources like fish and superior to staple cereals.

Role of makhana in addressing lifestyle disorders

Makhana plays an important role in dietary strategies aimed at preventing and managing lifestyle-related non-communicable diseases, owing to its favourable nutritional and functional attributes.

Diabetes and metabolic health: The predominance of complex carbohydrates and moderate amylose content in makhana results in a low glycaemic response, helping to prevent sudden spikes in blood glucose levels. Regular inclusion of makhana in the diet supports improved post-prandial glucose regulation, making it a suitable snack option for individuals with diabetes and metabolic disorders.

Cardiovascular health: Makhana is naturally low in fat and sodium, while providing essential minerals such as magnesium and potassium. This combination contributes to better blood pressure regulation, improved electrolyte balance and a reduced risk of cardiovascular complications, supporting heart-friendly dietary recommendations.

Weight management: The presence of dietary fibre and moderate-quality protein enhances satiety and prolongs the feeling of fullness. As a result, makhana helps curb overeating and reduces dependence on calorie-dense, unhealthy snacks, making it a useful component of weight management and obesity control programmes.

Integration of makhana into nutrition programmes

Field demonstrations in Bihar show that replacing fried snacks with 10–15 g of roasted makhana improves satiety and reduces sugar intake among school children. Makhana can be incorporated into:

a. Mid-Day Meal (MDM) as roasted snacks or cereal mixes

b. ICDS supplementary nutrition for children and pregnant women

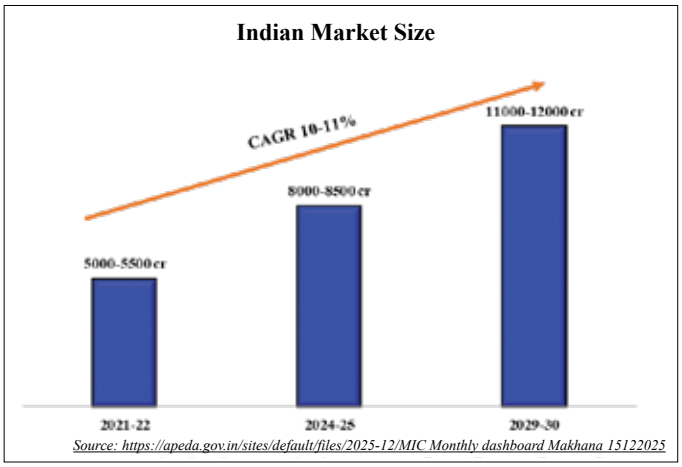
c. Community nutrition campaigns promoting healthy snacking

Low moisture content (10–11%) and a shelf life of 6–8 months support decentralised distribution. Its inclusion can improve dietary diversity and support prevention of lifestyle disorders.

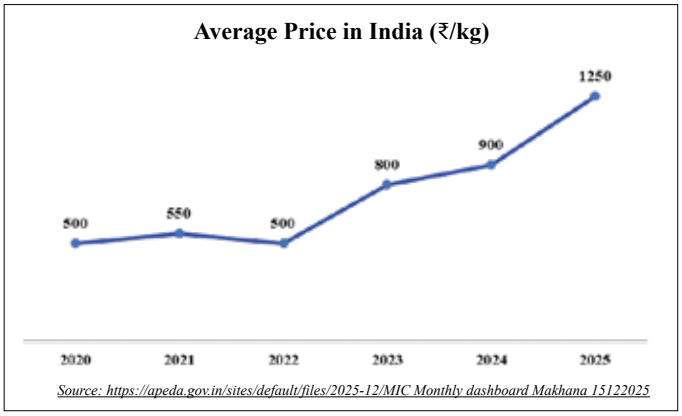
Health-driven market expansion

Domestic makhana prices in India have experienced a strong and sustained upward trend in recent years, largely driven by rising consumer awareness of health, nutrition and clean-label foods. Average prices have increased from approximately ₹500 per kg during 2020–2022 to nearly ₹1250 per kg in 2025, reflecting a clear shift toward health-focused snacking, premium branding and value-added makhana products. This escalation has been reinforced by supply-side limitations, as production growth has not fully matched the pace of expanding demand. As a result, the domestic market has become increasingly attractive for processors, often offering higher and more stable margins than exports. Seasonal dynamics also influence price movements; marginal increases are typically observed during early winter in northern Bihar–sometimes intensified by La-Niña–induced colder conditions–followed by stabilisation during summer. While lower

grades (4 and 5 Suta) have remained relatively steady, premium grades (6 and 7 Suta) have recorded a ₹20–30 per kg rise, reflecting stronger demand for superior-quality kernels among health-conscious consumers.



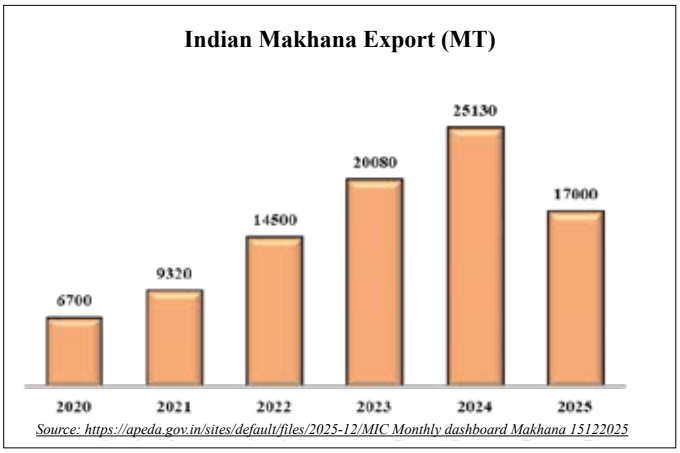
Source: https://apeda.gov.in/sites/default/files/2025-12/MIC Monthly dashboard Makhana 15122025



Source: https://apeda.gov.in/sites/default/files/2025-12/MIC Monthly dashboard Makhana 15122025

Simultaneously, India's makhana exports have expanded significantly in response to growing global demand for low-fat, gluten-free and plant-based snack options. Export volumes increased nearly four fold–from 6,700 MT in 2020 to 25,130 MT in 2024, registering a robust CAGR of around 39%. Growth has been supported by improved production practices, enhanced processing efficiency and wider adoption of organic and quality certifications. Premium kernels, particularly those exceeding 18 mm in size, dominate export markets due to their superior expansion and visual appeal. However, exports in 2025 are projected to remain slightly below the 2024 peak, with around 17,000 MT shipped during January–October, largely due to tariff pressures in the United States, which accounts for nearly 40 per cent of India's exports. Sustaining growth will depend on continued premiumisation, development of value-added health products and strategic branding in key markets such as the US, EU and Middle East.

Building on these domestic and export trends, India's makhana market has sustained a healthy annual growth of



Source: https://apeda.gov.in/sites/default/files/2025-12/MIC Monthly dashboard Makhana 15122025

17–18% between 2021–22 and 2024–25, largely propelled by heightened health consciousness, premiumisation and the rapid expansion of organised, branded players. Strong domestic consumption has insulated the sector from fluctuations in export demand, reinforcing market stability. The overall market size is projected to reach ₹11,000–12,000 crore by 2029–30. However, much of this expansion remains price-driven rather than volume-driven, as production has increased by only 4–5% during FY 2022–2025. The concentration of cultivation in Bihar's Mithilanchal and Kosi regions limits large-scale supply expansion, keeping prices firm. This scenario highlights the urgent need for productivity enhancement, improved water management, varietal improvement and farmer support to ensure sustainable, demand-responsive growth in the sector.

SUMMARY

Makhana is more than a niche wetland crop: It is a scalable source of nutrients, functional benefits and livelihood value that can be integrated into India's nutrition and health strategies. Evidence from Bihar, the nation's production engine for makhana demonstrates that modest, targeted interventions across pond management, processing hygiene, value addition and institutional procurement can deliver measurable gains for both dietary quality and rural incomes. To convert regional promise into national impact, coordinated research, targeted policy support and investment in decentralised processing are essential. By doing so India can legitimately move from wetlands to wellness, harnessing an indigenous superfood to strengthen nutritional and health security for millions.

For further correspondence, contact:
Dr. Tejaswini Kapil, Subject Matter Specialist (Agricultural engineering), ICAR-Agricultural Technology Application Research Institute, Zone IV, Patna 800 014, Bihar, India. Email: tejaswinirpcau22@gmail.com

M R Manikantan[1], P P Shameena Begum[2], S V Ramesh[1] and K B Hebbar[1]*

Diversified Nutritive Coconut Value-Added Products: Technologies and Innovations

Coconut-based agribusiness has emerged as a promising sector with significant domestic and international market potential, driven by the growing demand for value-added coconut products and modern processing technologies. However, the coconut industry has faced several challenges in recent years, including fluctuating market prices, competition from cheaper vegetable oils such as palm oil, and shortages of skilled labour. In this context, product diversification and value addition have become essential for stabilizing the coconut oil-driven market and revitalizing the industry in a cost-effective and globally competitive manner. These challenges, in turn, have encouraged farmers and entrepreneurs to explore innovative coconut-based agribusiness opportunities in India.

Keywords: Coconut; Kalparasa®; Nutrition;Value added products

IN this context, India has developed a range of processing equipment and technologies for the production of diversified coconut-based value-added products. The institutes have designed and standardized several machines and processing units, including copra dryers utilizing different energy sources, coconut splitting devices, coconut deshelling & dehusking machines, snowball tender coconut machines, coconut grating machines, tender coconut punch and cutter units, manual and power operated coconut slicing machines, coconut testa removers, coconut pulverizers, blanching units, coconut chips dryers (electrical and rotary), coconut flaking machines, infrared dryers, coconut milk expellers, virgin coconut oil cookers, and fermentation tanks for virgin coconut oil production. These technologies facilitate the integration of various unit operations in coconut processing and help in completing the coconut value chain efficiently.

The value-added product technologies developed can broadly be categorized into fresh kernel-based products, mature coconut water-based products, tender coconut-based products and inflorescence sap-based products, and thereby opening new avenues for entrepreneurship, income generation, and sustainable growth of the coconut sector.

Fresh coconut kernel based products

Coconut milk-based products: The global coconut milk market is experiencing robust growth, with market values estimated between USD 1.6 and 2.7 billion during the year 2023, and projections suggesting expansion to over USD 7 billion by 2032 at a compound annual growth rate (CAGR) of 12–17%. India, one of the leading coconut producers, is witnessing rapid expansion in its coconut milk sector, with a projected CAGR of 19.2% between 2023 and 2033. There are a number of coconut milk based products.

Virgin coconut oil

Virgin coconut oil (VCO): Virgin coconut oil is a premium value-added coconut product obtained through natural and mechanical extraction of coconut milk. Unlike conventional coconut oil, VCO retains natural bioactive compounds such as vitamin E, antioxidants, polyphenols, and lauric acid, which contribute to its nutritional and therapeutic value. Due to its antimicrobial and health-promoting properties, virgin coconut oil finds extensive applications in functional foods, cosmetics, nutraceuticals, and pharmaceutical formulations. The global demand for Virgin Coconut Oil (VCO) is witnessing rapid growth in recent years, driven by increasing consumer preference for organic cosmetics, functional beverages, and health-oriented diets. The global VCO market is currently valued between USD 2.6 and 3.15 billion and is projected to expand at a compound annual growth rate (CAGR) of 8.5–12.6% in the coming years. The Asia-Pacific region continues to dominate both production and consumption, accounting for nearly 40% of the market share.

Table 1 Nutritional information of Hot processed VCO (per 100g)

Calories (kcal	**900**
Cholesterol (mg)	0
Total phenolic content (mg Gallic Acid equivalent))	2.9
Total flavonoids (mg Quercetin Equivalent)	6.6
Moisture (%)	0.1
Free fatty acids (%)	0.1

CPCRI has developed efficient technologies for the production of Virgin Coconut Oil (VCO) through both hot processing and accelerated fermentation methods using skimmed coconut milk, creating significant opportunities for small-scale coconut-based enterprises. The institute has also standardized quality parameters for different VCO variants and developed chemometric techniques for detecting adulteration in virgin coconut oil and coconut oil, thereby ensuring product authenticity, quality assurance, and enhanced market competitiveness in domestic and international markets. The nutritional content of VCO is given in Table 1.

Further, the residues of virgin coconut oil production stream including the defatted coconut flour (DCF), popularly known as coconut milk residue (CMR) and VCO cake were diversified to different values added product. VCO processing from 500 nuts give rise to about 200 kg husk, 67 kg shell, 50 L nut water, 3.3kg testa, 25kg milk residue and 5kg VCO cake. The per cent recovery of coconut milk residue and VCO cake ranged from 38.5 to 55.6% and 6.3 to 8.8% respectively

Coconut milk residue (CMR) based value-added products: Coconut milk residue at 2.9% moisture level contains 46.5% crude fibre, 5.3% protein, and 49.2% crude fat. It has 4 times more fibre than oat bran, 2 times than wheat bran, which in fact, is calorie free. Some of the value-added products developed from the milk residue are described below,

Low fat desiccated coconut flour: Milk residue can be dried to 3-5% moisture content and sold as low fat desiccated coconut flour, which can be used for the preparation of bakery and of low calorie foods. It can be used as fillers, bulking agents and substitute for wheat flour, rice flour and potato flour at certain levels and incorporated into baked and extruded food products. Five % coconut milk residue flour can replace proportionate amounts of wheat flour and non-fat dry milk powder used in school nutrition programmes without affecting the baking qualities and food value.

Desiccated coconut powder

CMR based extruded snacks: A coconut milk residue-based extruded snack formulation containing 20% coconut milk residue, which was commercialized as *Kalpa Krunch* is a nutritious and crunchy ready-to-eat snack prepared using coconut milk residue blended with rice, corn, or millet flour and flavored with various spices and herbs for enhanced sensory appeal.

Kalpa krunch

CMR based NutriPuttu*: NutriPuttu* is a healthier and fibre-rich version of the traditional Kerala breakfast staple, developed using a combination of rice flour and CMR, a nutritious by-product rich in dietary fibre. Compared to regular *puttu* powder, *NutriPuttu* contains higher levels of protein, fibre, and healthy fats while retaining the authentic taste and texture of traditional *puttu.* The product provides about 395.25 kcal of energy and 7.09 g fat per 100 g and has a shelf life of 90 days. It also represents an eco-friendly innovation that promotes the valorisation of coconut processing by-products.

CMR based wafer cone: 'Kalpa Wafer Cones' are crispy and nutrient-rich wafer cones developed using sweet potato flour enriched with coconut milk residue, coconut milk and coconut sugar. The incorporation of coconut-based ingredients enhances the dietary fibre content while contributing essential nutrients and health-promoting fatty acids. The developed wafer cones contained 3.45% moisture, 6.94% protein, 24.67% fat, 3.49% fibre, and 1.15% ash, indicating their superior nutritional quality. With a balanced proximate composition, the product offers a sustainable and healthier alternative to conventional wafer cones through the effective utilization of coconut processing by-products.

CMR based pasta: Coconut milk residue-based pasta is a nutritious cold-extruded product prepared from coconut milk residue and wheat semolina. Incorporation of 10% coconut milk residue was found optimum for cooking quality, texture, and sensory attributes, while also enhancing the fibre, protein, and mineral content of the product. By supplementing 10% CMR in pasta, maximum Daily Recommended Allowance (DRA) of 6.5g fibre can be met.

Coconut milk residue-based pasta

CMR infused dark chocolate: Coconut milk residue (CMR) also finds promising applications in the chocolate industry. Since cocoa butter is an expensive and limited raw material, CMR can be utilized as a functional ingredient in bean-to-bite dark chocolate formulations. Partial replacement of cocoa butter with CMR enhanced the fibre and mineral content, particularly iron and manganese, without affecting the taste or consumer acceptability of the chocolate. Moreover, chocolate

Kalpa velvet chocolate

containing up to 10% CMR retained its valuable phenolic compounds, highlighting the potential of coconut processing by-products in developing healthier and more sustainable chocolate products.

Flavored coconut milk from CMR: A ready to drink low fat coconut milk was developed using the coconut milk extracted from CMR which had 69.60% moisture, 14.85% fat, 11.65% carbohydrates, 2.80% protein, and 1.10% minerals. The beverage formulation was further standardized by optimizing fat and solids-not-fat content along with sweetness, emulsifier, colour, and flavour levels to achieve desirable quality, stability, and consumer acceptability. The product was commercialized as 'Kalpa Bliz'.

VCO cake based muffins: Muffins enriched with virgin coconut oil (VCO) cake have been developed as soft, healthy, and nutritious baked products suitable for consumers of all age groups. Incorporation of 40 g VCO cake per 100 g flour blend significantly enhanced the nutritional quality of the muffins, resulting in 8.49% protein, 18.46% fat, 1.14% crude fibre, and 1.15% minerals. The technology effectively utilizes VCO processing by-products while producing value-added functional bakery products.

Coconut milk kulfi: The process technology for coconut milk-based kulfi has also been commercialized by the institute under the brand name 'Kalpa Kulfi'. It is a non-dairy, coconut milk-based frozen dessert formulated using coconut milk, coconut sugar, and cardamom, offering a rich creamy texture and distinctive coconut flavour. Completely vegan and free from dairy ingredients, Kalpa Kulfi serves as a healthy plant-based alternative to conventional kulfi and is enriched with essential vitamins, minerals, and healthy fatty acids, thereby promoting value addition of coconut-based ingredients

Coconut vegan kulfi

Frozen coconut delicacy

Frozen coconut delicacy: Frozen coconut delicacy is a premium vegan dessert prepared from coconut milk, coconut sugar, tender coconut pulp, and tender coconut water, serving as a healthy non-dairy alternative to ice cream. The product is diabetic-friendly and enriched with vitamins, minerals, and healthy fatty acids, making it a nutritious value-added coconut product with high consumer appeal. In addition, another composite frozen dessert variant was developed using coconut milk as the fat source and skimmed milk powder as the protein source, offering a more economical alternative to the completely vegan formulation. The nutritional content of the products is presented in Table 2.

Coconut milk peda and paneer: An innovative coconut milk-based peda was standardized using the second and third extractions of coconut milk along with coconut sugar. Incorporation of 30% coconut sugar was optimum for achieving desirable taste and texture, with coconut sugar-based peda showing better acceptability than refined sugar variants. The product had a recovery of 50–53% and possessed a rich nutritional profile containing 23.5% moisture, 42.5% carbohydrates, 23.75% fat, 5.6% protein, and 3.01% minerals, making it a healthier and value-added alternative to conventional milk peda.

Coconut milk-based paneer is an innovative value-added product prepared from the second and third extractions of coconut milk. To achieve desirable texture and consistency, the formulation is fortified with protein sources such as soy protein, egg albumin, or skim milk powder, resulting in a nutritious and functional alternative to conventional paneer.

Foam mat dried coconut milk powder: Foam mat dried coconut milk powder was developed at the institute as a low-investment alternative to conventional spray-dried coconut milk powder with better shelf life and ease of transportation. The technology involves drying coconut milk incorporated with foaming agents, foam stabilizers,

Table 2 Nutritional information of the coconut delicacies

Parameter	Coconut milk delicacy	Vegan coconut delicacy
Moisture (%)	62.66± 4.72	56.65 ± 5.35
Total solids (%)	37.33± 2.46	43.34± 2.87
Total minerals (%)	0.52 ± 0.0023	0.64 ± 0.0042
Weight per volume (g/L)	588.23 ± 14.36	612.24 ± 12.43
Crude protein (%)	4.7 ± 0.25	5.0 ± 0.42
Crude fat (%)	11.00± 0.20	11.05± 0.56

Other coconut delicacy

Coconut milk powder

and encapsulating materials to obtain a free-flowing powder. The powder contained 97.82% total solids, 52.07% fat, 27.29% carbohydrates, 8.24% protein, and 7.47% minerals, with a Hausner ratio of 1.16 indicating good flowability. The process was successfully upscaled with a powder recovery of 33.0 ± 0.7% (w/v).

Coconut milk halwa: Coconut milk-based halwa was developed as a value-added traditional sweet using coconut milk, sugar, and wheat flour. The optimized formulation consisted of 70% coconut milk (pooled extraction), 25% refined sugar, and 5% refined wheat flour, achieving an overall acceptability score of 8.5. The optimized halwa contained 11% moisture, 57.1% carbohydrates, 30.6% fat, 0.7% protein, and 0.6% ash. These products demonstrate the potential of coconut ingredients in the development of nutritious and commercially viable bakery and confectionery products.

Shelf stable coconut gratings: A preservation protocol was developed for producing shelf-stable coconut gratings using different hurdle techniques. The treated coconut gratings were packaged in laminated pouches and vacuum sealed, resulting in an extended shelf life of up to 7 days under ambient conditions and 21 days under refrigerated storage. Among the treatments evaluated, a combination of 3% salt, 0.05% citric acid, 0.05% sodium citrate, and 0.05% sodium benzoate showed particularly promising results. The

treated samples exhibited minimal changes in *p*H, titratable acidity, and free fatty acid content, while maintaining sensory acceptability. Economic analysis further revealed a benefit–cost ratio of 1.31, indicating the commercial viability and profitability of the preservation technology.

Coconut chips: Coconut chips are healthy ready-to-eat snacks prepared from partially mature coconut kernels through slicing, osmotic dehydration, and hot-air drying. They serve as a nutritious alternative to conventional junk foods, as they are rich in dietary fibre, healthy fats, carbohydrates, and natural antioxidants. It contains approximately 622 kcal energy, 48.10 g fat, 46.13 g carbohydrates, 6.13 g crude fibre, 1.24 g protein, and 1.36 g total minerals per 100 g, making them an energy-dense and fibre-rich healthy snack option. Unlike many commercial snack products, coconut chips do not require deep-oil frying during processing, making them a healthier option for consumers. The chips can be prepared in sweetened, salted, spicy, or flavoured varieties, thereby enhancing consumer appeal and marketability. Their crisp texture, pleasant taste, and extended shelf life when packed in laminated pouches make them a promising value-added coconut product with significant market potential.

A standardized process technology has also been developed for the production of jaggery-based coconut chips using jaggery syrup or coconut sap (Kalparasa®) as the osmotic medium. The incorporation of jaggery or coconut sap enhances the nutritional quality of the product by increasing its mineral, antioxidant, and micronutrient content while imparting a natural flavour and sweetness. Coconut chips are considered a good source of dietary fibre, essential minerals, and energy, making them suitable as a healthy snack for health-conscious consumers.

Coconut cake: Coconut-based cake is an innovative confectionery product developed by replacing conventional ingredients with coconut-derived products such as coconut milk, coconut sugar, desiccated coconut powder, coconut milk powder, coconut vinegar, and virgin coconut oil. The optimized formulation consisted of coconut milk as the major ingredient, followed by wheat flour, coconut sugar, desiccated coconut powder, virgin coconut oil, coconut milk powder, and coconut vinegar, along with baking agents, and vanilla essence. The standardized baking conditions included preheating and baking at 180°C for 10 and 40 minutes, respectively. The developed cake contained 25% fat, 2% protein, and 20% moisture, offering improved nutritional quality and sensory appeal.

Mature coconut water-based products

Mature coconut water-based vinegar: Mature coconut water-based vinegar is a value-added product produced through alcoholic and acetic fermentation of sugar-enriched mature coconut water. It serves as a natural and healthier alternative to synthetic vinegar available in the market and is widely used in pickles, salads, and fish preservation. Studies have shown that coconut water vinegar possesses desirable physicochemical and nutritional properties, including mild acidity, high mineral content, and good storage stability. Compared with conventional vinegars, it is particularly rich in potassium and sodium, making it a nutritionally valuable product. The product offers significant potential as a natural alternative to conventional fruit and synthetic vinegars.

Coconut water based vinegar

Coconut water jelly: Coconut water jelly is a value-added product prepared from mature coconut water blended with coconut sugar or refined sugar along with suitable gelling agent. The product possesses a pleasant taste, attractive texture, and good nutritional quality. Coconut water jelly contains appreciable amounts of total sugars, protein, potassium, vitamin C, and phenolic compounds, making it a nutritious and refreshing food product. Its unique flavour, nutritional benefits, and consumer appeal provide significant scope for commercialization in the value-added coconut product sector.

Mature coconut water based squash: Mature coconut water-based squash is a refreshing value-added beverage prepared from mature coconut water blended with refined sugar, lemon, ginger, citric acid, and permitted preservatives. The product combines the natural nutritional qualities of coconut water with enhanced flavour and consumer appeal. It can be conveniently served after dilution with water in a 1:3 ratio, making it suitable as a refreshing health drink. The squash possesses good shelf stability and offers significant potential for commercialization as a functional coconut-based beverage product.

Tender coconut-based products

Carbonated tender coconut water: The ICAR-CPCRI developed a standardized technology for the production of carbonated tender coconut water as a refreshing value-added beverage. The technology involves the processing and carbonation of tender coconut water under hygienic conditions to retain its natural flavour, nutrients, and refreshing qualities while improving shelf life and

Young tender coconut

consumer acceptability. It serves as a healthy alternative to synthetic soft drinks, as it is rich in electrolytes, minerals, and bioactive compounds. The product has significant market potential owing to the increasing consumer demand for natural and functional beverages.

Snow Ball Tender Coconut: It is an innovative value-added coconut product prepared by completely removing the husk, shell, and testa from tender coconuts to obtain a smooth, ball-shaped nut with an attractive snowy white appearance. The product is marketed as a premium and refreshing natural beverage option and is often considered an aristocratic welcome drink due to its appealing presentation and freshness. Proper hygienic processing and suitable packaging techniques enable the product to be preserved for up to 15 days under refrigerated conditions without significant quality deterioration. Snow Ball Tender Coconut has considerable commercial potential in hotels, resorts, supermarkets, and export markets owing to the increasing consumer preference for convenient and natural health drinks.

Preservation protocol for minimally processed tender coconut: A preservation protocol has been standardized for minimally processed tender coconuts to maintain the colour, freshness, and overall quality of trimmed tender nuts during storage. The developed technology employs a combination of organic acids and resorcinol treatment to effectively reduce browning and quality deterioration. Using this protocol, the shelf life of minimally processed tender coconuts can be extended up to four weeks under refrigerated conditions while retaining their sensory and nutritional attributes. The technology offers significant potential for improving the marketability and export prospects of tender coconut products.

Tender coconut dessert: Tender coconut dessert (pudding) is a refreshing value-added product developed from tender coconut water and kernel with desirable taste, texture, and nutritional quality. The process protocol has been standardized. Studies were conducted to extend the shelf life of the product by developing suitable preservation protocols aimed at reducing enzyme activity and microbial load. Superior efficacy of biopreservatives over conventional chemical preservatives in maintaining the quality and safety of the tender coconut dessert, highlighting its potential as a healthy and commercially viable functional food product.

Kalparasa® and its value added products

Kalparasa® tapping technology: Kalparasa® tapping technology is an innovative coconut inflorescence sap collection method developed using a specialized "coco sap chiller" to obtain fresh, hygienic, and non-alcoholic coconut sap. The technology prevents natural fermentation immediately after tapping, thereby preserving the freshness and nutritional quality of the sap.

SUSTAINABLE DEVELOPMENT GOALS RELATED TO FRUITS AND VEGETABLES

SDGs 2 3

Health benefits of fruit and vegetables

Harness the goodness

Fruit and vegetables have multiple health benefits. They strengthen the immune system, combat malnutrition and help prevent non-communicable diseases.

SDGs 2 3

Diversified diet and a healthy lifestyle

Live by it, a diverse diet

Adequate amounts of fruit and vegetables should be consumed daily as part of a diversified and healthy diet.

SDGs 2 8 12 13 14 15

Food loss and waste

Respect food from farm to table

Fruit and vegetables are worth more than their price. Maintaining their quality and assuring their safety across the supply chain, from production to consumption, reduces losses and waste and increases their availability for consumption.

Innovate, cultivate, reduce food loss and waste

Innovation, improved technologies and infrastructure are critical to increase the efficiency and productivity within fruit and vegetable supply chains to reduce loss and waste.

SDGs 1 2 12 15

Sustainable value chains

Foster sustainability

Sustainable and inclusive value chains can help increase production, and help to enhance the availability, safety, affordability and equitable access to fruit and vegetables to foster economic, social, and environmental sustainability.

SDGs 1 2 3 4 5 8 11 12 15

Highlighting the role of family farmers

Growing prosperity

Cultivating fruit and vegetables contributes to a better quality of life for family farmers and their communities. It generates income, creates livelihoods, improves food security and nutrition, and enhances resilience through sustainably managed local resources and increased agrobiodiversity.

Source: *Fruit and vegetables – your dietary essentials, FAO background paper, FAO, Rome*

Kalparasa® is light orange to honey in colour and is rich in natural sugars, amino acids, minerals, antioxidants, and vitamins, making it a highly nutritious health drink. The technology offers significant potential for the production of value-added coconut beverages and related functional food products. The biochemical and nutritional profile of Kalparasa® is as follows;

Table 3. Biochemical and nutritional profile of Kalparasa® (per 100 mL)

Biochemical parameters	Average
*p*H	7.18
Total sugar (g)	15.18
Reducing sugar (g)	0.554
Amino acids (g)	0.245
Protein (g)	0.165
Phenolics (mg)	5.10
Antioxidant activity (mM TE)	0.321
Sodium (mg)	90.6
Potassium (mg)	168.4
Phosphorus (mg)	3.9
Manganese (mg)	0.012
Copper (mg)	0.031
Zinc (mg)	0.020
Iron (mg)	0.053

Coconut sugar: Coconut sugar is a natural sweetener produced by concentrating Kalparasa®, the fresh coconut inflorescence sap. It is considered a healthier alternative to refined sugar due to its low glycemic index and rich nutritional profile. During the concentration process to sugar, intermediary products such as Neera syrup and Neera honey are also obtained, which possess good nutritional value and commercial potential as natural sweeteners. Coconut sugar contains appreciable amounts of amino acids, dietary fibre, antioxidants, and essential minerals, particularly potassium and sodium, which contribute to its high electrolyte content. It is also a good source of vitamin E and B-complex vitamins. Owing to its nutritional and functional properties, coconut sugar has gained considerable importance as a value-added coconut product with strong domestic and international market potential. The nutritional composition of coconut sugar is given below.

Kalpa bean to bite dark chocolate: Homemade bean-to-bite chocolate using coconut sugar is an innovative value-added product developed through a complete standardized processing protocol for chocolate preparation using coconut sugar as a natural sweetener. The technology includes carefully standardized unit operations such as fermentation, drying, roasting, cracking, winnowing, grinding, tempering, moulding, and cold storage to ensure product quality and flavour development. The unique blending of cocoa beans with coconut sugar enhances the nutritional and sensory properties of the chocolate while providing a healthier alternative to refined sugar-based products. This technology offers promising opportunities for small-scale entrepreneurship and artisanal chocolate production.

Kalparasa based nutribar: Kalparasa®-based Nutribar is a nutritious value-added product prepared using concentrated Kalparasa® along with energy-rich ingredients such as peanut, green gram, and cocoa powder. The formulation involves concentrating Kalparasa® to about 75–80°Brix and blending it with selected ingredients before moulding into nutribars. The product is rich in protein, dietary fibre, and essential minerals, making it a healthy energy snack suitable for all age groups. Owing to its nutritional benefits and natural ingredients, the Kalparasa®-based Nutribar has significant potential as a functional food product in the health snack market.

Spray dried Kalparasa® powder: Spray-dried Kalparasa powder is a value-added product developed by converting fresh Kalparasa® into a free-flowing powder through spray drying technology. The process enhances shelf life, facilitates easy transportation and storage, and improves product convenience without significantly affecting its nutritional quality. The powder can be reconstituted at a 2:1 ratio with water to simulate the taste and characteristics of fresh Kalparasa®. Rich in natural sugars, minerals, and bioactive compounds, the product offers excellent potential as a convenient functional beverage ingredient and health drink supplement.

Coconut sugar-based chukka kappi mix (dry ginger coffee): Coconut sugar-based chukku kappi mix is an innovative value-added product developed using coconut sugar as a healthier alternative to conventional sugarcane jaggery. The product combines coconut sugar with traditional spices such as dry ginger, black pepper, cumin, basil, clove, cinnamon, and cardamom to create a convenient two-in-one herbal coffee mix. The optimized formulation consisted of 0.5 g coffee powder and 12.5 g spice-infused coconut sugar per 120 mL of water. Studies revealed that spice incorporation significantly enhanced

Table 4. Nutritional information of coconut sugar

Total calories	380kcals
Total sugars (g)	92
Protein (g)	2.9
Dietary Fibre (g)	2.5
Phenolics (mg)	25
Minerals	
Potassium (g)	1.0
Phosphorous (mg)	80
Magnesium (mg)	30
Sodium (mg)	50
Zinc (mg)	2.1
Manganese (mg)	0.1
Iron (mg)	2.2
Total calories	380kcals

the micronutrient content, total phenolic content, and antioxidant activity of the product while also improving sensory qualities such as aroma, taste, and overall acceptability. The developed product demonstrates excellent potential as a functional health beverage and provides a promising value-addition opportunity for coconut sap entrepreneurs.

Kalparasa® infused coconut flakes: Process methodology for coconut flakes using neera syrup as osmotic medium was optimized. Infusion of flakes enhances the nutritional value of the developed flakes. Based on the bioactive profile, coconut flakes dried using infra-red at 65°C showed good qualities, including improved rehydration ratio, hygroscopicity, bulk density, and tapped density. Further analysis revealed significant enhancements in protein, carbohydrate, and fat content, as well as increased total phenolic content, antioxidant activity (DPPH),and ferric reducing antioxidant power (FRAP).

Kalpa Qbitz (nata-de- coco): Kalpa Qbitz are fiber-rich, cubic nata de coco pieces soaked in the natural sweetness of coconut neera. The Institute produces these cubes using elite bacterial strains to valorize fermented kalparasa and mature coconut water that typically goes to waste.

Nata de coco jelly

Sap based vinegar: Sap vinegar is a nutritionally rich value-added product produced through controlled alcoholic and acetic fermentation of partially fermented coconut sap. Studies have shown that sap vinegar possesses higher acidity, total phenolic content, and antioxidant activity compared to coconut water vinegar and conventional apple cider vinegar. It is also rich in essential minerals such as iron, manganese, and zinc, contributing to its functional and nutritional properties. The high phenolic and antioxidant content makes sap vinegar a promising health-oriented product with good storage stability and consumer appeal. Owing to its superior functional qualities and natural origin, neera vinegar has significant potential as a cost-effective and nutritious alternative to conventional fruit vinegars.

SUMMARY

The coconut industry has evolved significantly from traditional raw nut utilization to diversified value-added processing. Products such as virgin coconut oil, coconut milk powder, desiccated coconut, tender coconut beverages, coconut flour, and sap-based sweeteners have opened new opportunities for farmers, entrepreneurs, and food industries.

Sustainable growth of the coconut sector depends not only on technological innovations but also on effective marketing, consumer awareness, export promotion, and entrepreneurship development. With increasing global demand for natural, plant-based, and functional foods, coconut-based products hold tremendous potential for future expansion in domestic and international markets.

For further correspondence, contact:
[1]Dr. K B Hebbar, Director, ICAR- Central Plantation Crops Research Institute, Kudlu, Kasargod 671 124, Kerala, India; [2]ICAR-Indian Institute of Spices Research, Kozhikode 673 012, Kerala, India. Email: directorcpcri@gmail.com

GUIDELINES TO AUTHORS

Visit us at https://epubs.icar.org.in/index.php/IndHort

Online submissions of article :

- Already have a Username/Password for *Indian Horticulture*? **GO TO LOGIN**
- Need a Username/Password? **GO TO REGISTRATION**
- Registration and login are required to submit items on-line and to check the status of current submissions.

Author Guidelines

Title of the article: Catchy, short and attractive; Compel the readers to read the article; Time-oriented; Serve the purpose of audience – means it should be audience-oriented, and News-oriented.

Intro/Introductory Paragraph: It has gist of the article; Preferably give answers of all 4 Ws and 1 H; Ws stands for: what, where, why and when, H stands for: how; and Intro paragraph should convey the complete message so that reader is satisfied.

Introduction: The very first paragraph of the article is known as Introduction; It is an introduction for the article; It shows the need of writing article. For example, we write an article on a new hybrid. We have to write its importance that it is better in such and such regards, and It should be of one paragraph or two paragraphs, if the subject is broader.

Text of article: Remaining text should be in a descending order of importance; Emphasize on your own findings; Follow proper heading scheme; Use key words in headings; Follow central heading, side heading, subheading, inset heading etc.

General guidelines: Follow guidelines strictly. In popular articles, number of authors should not be more than 3. Stick to number of words required (2,500 words); Do not exceed page limit; Write captions separately; Give 1-2 tables or graphs (avoid repetition); Name(s) of author(s), Complete postal address(es) of affiliations (place where work was conducted). Complete correspondence address including e-mail address of authors should be provided (these are given as footnote on first page).

***Units in metric system*:** Full forms of all abbreviations used in table; source of data should be given in detail. Units of measurement, symbols and standard abbreviations should conform to those recommended by the International Union of Biochemistry (IUB) and the International Union of Pure and Applied Chemistry (IUPAC). Metric measurements are preferred, and dosages should be expressed entirely in metric units (SI units). In exceptional circumstances, others may be used, provided they are consistent.

***Figures*:** Author is required to submit high-resolution (2 MB) images, preferably with the initial submission but no later than revision stage. Electronic (2 MB) images (figures and schemes) must be at a minimum resolution of 600 d.p.i. for line-drawings (black and white) and 300 d.p.i. for colour or gray-scale. Colour figures must be supplied in CMYK not RGB colors. Please ensure that the prepared electronic image files print at a legible size (with lettering of at least 2 mm). A number of file formats are acceptable, including: PowerPoint (.ppt), Tagged Image File Format (.tif), Encapsulated PostScript (.eps), Joint Photographic Experts Group (.jpg), Graphics Interchange Format (.gif), Adobe Illustrator (.ai) (please save your files in Illustrator's EPS format), Portable Network Graphics (.png), Microsoft Word (.doc), Rich Text Format (.rtf), and Excel (.xls) but not Portable Document Format (PDF). Type in 1.5- space everywhere.

Rewrite Your article

Language: Use simple words; Use short sentences in a logical order; Use active voice; Avoid passive voice; Relate all sentences with each other; Maintain coherence; Paragraphs should be short and readable; Short paragraphs give pause to readers; Give human touch to your article to make it interesting, and Give practical information.

Writing for success stories: Who has got success in; Introducing new technology/methodology etc.; Diversification of any farming system in a particular area for more return; How he/she is inspiration to other farmer; What is cost:benefit ratio of the farm produce?; What are the prospects of that farm commodity?; Show the difference in adoption of that particular technique, variety, seed, tool etc.

Summary: Summary of article should be provided at the end of article under the heading "Summary". Papers should be composed in MS Word, and double spaced throughout (including references and tables). Article (including illustrations) should be uploaded on Indian Horticulture site (as given on top), after a careful check up of typographical errors.

Submission preparation checklist

- ☑ As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.
- ☑ The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).; and submission file should be in Microsoft Word file format.
- ☑ The text is 1.5-spaced; uses a 12-point font; employs italics, rather than underlining (except with URL addresses); and all illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end. Data is correct, authentic and updated.
- ☑ If submitting to a peer-reviewed section of the *Indian Horticulture*, the instructions in Ensuring a Blind Review have been followed.
- ☑ Article is based on recent experiments or practical experience of the author.
- ☑ Article should not be based on compiled matter or on some survey, report or record of extension education.
- ☑ Article should not be of theoretical nature or only of local relevance. Article text gives complete relevant details of practical utility to the farmer in clear and simple English.

Subscription Form for ICAR Magazines/Journals

I am/We are interested to become a subscriber to the following ICAR Magazine(s) / Journal(s) for the period .... to ..... My old subscription no. (if any) is ..... for the year .....

Name of the Magazines	Annual Subscription in (₹)		(US$)*	
• **Indian Farming** (*English Monthly*)	500	☐	100	☐
• **Indian Horticulture** (*English Bi-Monthly*)	250	☐	60	☐
• **Kheti** (*Hindi Monthly*)	500	☐		
• **Phal Phool** (Hindi Bi-Monthly)	250	☐		

Research Journals	For Individuals		For Institutions	
• **The Indian Journal of Agricultural Sciences** (English monthly)	₹ 3,000	☐	₹ 5,000	☐
	US$ 300	☐	US$ 800	☐
• **The Indian Journal of Animal Sciences** (English monthly)	₹ 3,000	☐	₹ 5,000	☐
	US$ 300	☐	US$ 800	☐

Please accept my subscription amount of Rupees (₹)/US Dollar ($) ..... for the Magazine(s)/Journal(s) tick (√) marked above.

Name ..... Address .....

..... Pin .....

Phone/Mobile No. ..... Email .....

NEFT/RTGS/Demand Draft No. ..... Dated .....

Amount Rs. ..... Bank name & branch code .....

TERMS AND CONDITIONS

While placing order, the name and address with email, may be given in block letter. The Post Office, District, State and PIN code may also be indicated.

A. Payment should be made through Bank Draft or Net Banking. The remittance may be drawn in favour of the **"Business Manager, ICAR, New Delhi".**

B. Payment through online (RTGS/NEFT).

RTGS/NEFT Payment Details:

Journals/Magazines	
Name and Address of the Organization	Project Director, DKMA
Bank Name	Canara Bank
Bank Address	Pusa, New Delhi 110012
IFSC Code	CNRB0019029
MICR No.	110015391
Current Account No.	24133050000040

PFMS Unique Code: DLND00001925 (for Govt. Department & ICAR Institutes)

*Foreign price mentioned are inclusive of postal and forwarding charges by Air Mail.

Note: Please furnish the details of the payment with your name & address, NEFT/RTGS number, date, amount in ₹/US$, Bank name and address alongwith details of your order of Books and Magazines/Journals subscription to the E-mail: **businessuniticar@gmail.com**

Contact:
Incharge, Business Unit, Directorate of Knowledge Management in Agriculture
Indian Council of Agricultural Research
Krishi Anusandhan Bhawan-I, Pusa Campus, New Delhi 110012
Telephone: 011-25843657 (D) 011-25841993 (Ext. 657 & 220)
Website: **www.icar.org.in**

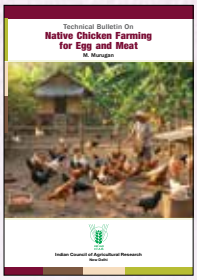
ICAR New Arrivals

Textbook on Food Toxicology

Page i-x+166
Rs ₹600
Postage ₹100
US $90

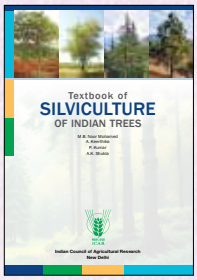
Textbook on Environmental Pollution

Page i-vi+298
Rs ₹950
Postage ₹100
US $140



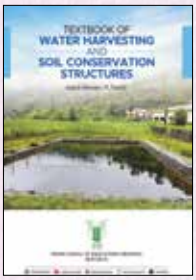
Technical Bulletin on Native Chicken Farming for Egg and Meat

Page i-vi+110
Rs ₹500
Postage ₹100
US $80



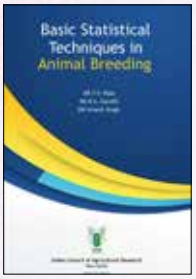
Textbook of Silviculture of Indian Trees

Page i-viii+164
Rs ₹800
Postage ₹100
US $100



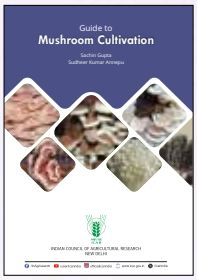
Textbook of Water Harvesting and Soil Conservation Structures

Page viii+376
Rs ₹1000
Postage ₹100
US $150



Basic Statistical Techniques in Animal Breeding

Page viii+211
Rs ₹700
Postage ₹100
US $90

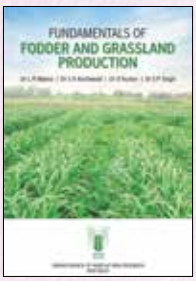


Mushroom Cultivation

Page x+134
Rs ₹600
Postage ₹100
US $85

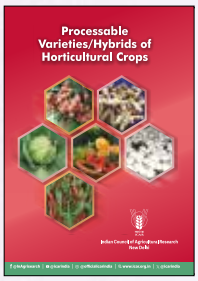
Textbook of Fish Processing Technology (REVISED EDITION)

Page xii+640
Rs ₹1200
Postage ₹100
US $185



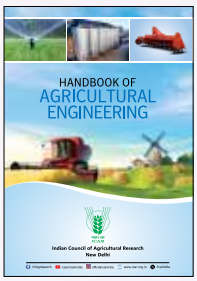
Fundamentals of Fodder and Grassland Production

Page vi+354
Rs ₹600
Postage ₹100
US $90



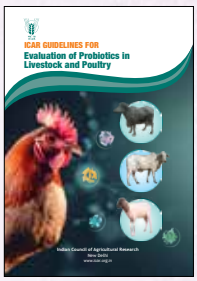
Processable Varieties/ Hybrids of Horticultural Crops

Page viii+168
Rs ₹100
Postage ₹50
US $15



Handbook of Agricultural Engineering (Revised Edition)

Page xii+1188
Rs ₹2000
Postage ₹200
US $300



ICAR Guidelines for Evaluation of Probiotics in Livestock and Poultry

Page x+22
Rs ₹50
Postage ₹50
US $8

मीठाजल कृषि प्रौद्योगिकी से आर्थिक उत्थान

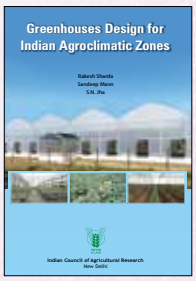
Page xii+320
Rs ₹800
Postage ₹100

सब्जियों में कीटों एवं रोगों का आधुनिक प्रबंधन

Page xii+448
Rs ₹860
Postage ₹50

दलहनी फसलों की सुरक्षा

Page xii+448
Rs ₹1000
Postage ₹100



Greenhouses Design for Indian Agroclimatic Zones

Page x+149
Rs ₹800
Postage ₹100
US $100

1. Payment should be made through Bank Draft in favour of "Business Manager, ICAR, New Delhi".
2. A 10% discount will be admissible on direct purchase of Books (only) from sales counter (DKMA) at Ground Floor, KAB-I, Pusa Campus, New Delhi-110012.
3. Textbooks and other publications can be purchased online also (QR code at bottom).
4. Payment through RTGS/NEFT mode is accepted.

Name and address of organization	**DKMA Revolving Fund Scheme**
Bank Name	**Canara Bank**
Bank Address	**Pusa Campus, New Delhi 110012**
IFSC Code	**CNRB0019029**
MICR No.	**110015391**
Current Account No.	**24131010000043**
PFMS Unique Code:	**DLND00001925 (Only for Govt. Department & ICAR Institutes)**

For Publications and Advertisement please contact

Incharge, Business Unit
Directorate of Knowledge Management in Agriculture
Indian Council of Agricultural Research
Krishi Anusandhan Bhawan-I, Pusa Campus, New Delhi 110012
Tel: 011-25843657; businessunitICAR@gmail.com
Website: **www.icar.org.in**

SCAN QR Code

ISSN : 0019-4875

Regd No. 4273/56
Price ₹ 50 per copy

New Edition

HANDBOOK OF HORTICULTURE

VOLUME 1 & 2

HANDBOOK OF HORTICULTURE

Volume 1 & 2

The Indian Council of Agricultural Research has brought out the Second enlarged and revised edition of the Handbook of Horticulture. Horticultural crops are gaining more and more importance as they have been instrumental in improving the economic condition of the farmer and contributing significantly to the national GDP. This new revised edition has been divided into 2 volumes – Volume 1 contains General Horticulture and Production Technologies (Fruit, Vegetable and Tuber crops) and Volume 2 has Production Technologies (Flower, Plantation, Spices crops and Medicinal and aromatic plants), Plant Protection and Post-harvest Management. The earlier chapters have been thoroughly revised and new chapters have been added. It is hoped that the readers will find this Second edition more useful and informative.

Technical Specifications

Pages : i-xxxiv + 1-682 (Vol. 1)
i-xxiii + 683-1218 (Vol. 2)
Price : ₹ 2000/- (Vol.1 & 2) Postage ₹ 200
ISBN : 978-81-7164-187-1

Copies available from:

Business Manager
Directorate of Knowledge Management in Agriculture (DKMA)
Indian Council of Agricultural Research
Krishi Anusandhan Bhavan, Pusa, New Delhi 110012
Tele: 011-25843657; email: businessuniticar@gmail.com

SCAN QR Code

Published by Dr Anuradha Agrawal, Project Director, ICAR-Directorate of Knowledge Management in Agriculture, Krishi Anusandhan Bhawan-1, Pusa Campus, New Delhi 110 012, on behalf of Indian Council of Agricultural Research, New Delhi, and printed at M/s Royal Offset Printers, A-89/1, Naraina Industrial Area, Phase-I, New Delhi 110028. *Editing*: Dr Anjani Kumar Jha