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PAPER
143**

Horticultural Innovations to Enhance Exports from India



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Horticultural Innovations to Enhance Exports from India



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Preface

Agricultural diversification is key for future growth and enhancing trade in the sector. India's diverse agro-climatic conditions ranging from temperate to tropical and arid to humid enable the year-round cultivation of a variety of horticultural crops. India is currently the world's second-largest producer of fruits and vegetables, and continues to lead the world in the production and export of spices. Remarkably, despite dedicating only 13% cultivated land (29.5 million hectares) to horticulture, India achieved a record production of 369.1 million tonnes (Mt) horticultural crops in 2024-25, which is almost 4% higher than the previous year and over 8% higher than the quinquennial average of recent years. The production of fruits was 118.8 Mt with an average yield of 16.6 tonnes/ha, while the production of vegetables was 215.7 Mt with an average yield of 18.4 tonnes/ha in 2024-25.

India's horticulture value of production (VOP) contributed 37% share in agriculture in 2023-24. The VOP of horticulture exhibited a cent-per cent increase in the past 12 years (2012-2024) from Rs. 3.80 billion to Rs. 7.60 billion, primarily because of rise in production and prices. In the fiscal year 2024-25, export of horticulture and its products is valued at Rs 1,027.5 billion, and it is projected to reach Rs 9,565.2 billion by 2047-48.

This policy paper "Horticultural Innovations to Enhance Exports from India," aims to present a comprehensive picture of sustainable growth in global trade. By examining existing challenges and opportunities, it seeks to outline strategic initiatives, policy interventions, and innovative solutions that can elevate the status of Indian horticulture to new heights and greater global repute.

To maintain a competitive edge in global markets, India must prioritize high quality standards and brand integrity within its horticulture sector. This requires a need-based basic, applied, and multi-disciplinary research that translates into practical and innovative technologies for growers, thereby improve production efficiency, profitability, and sustainability. India needs to adopt the latest and most innovative technologies to improve its position and presence in global exports. Additionally, the vast comparative and seasonal advantage is largely unexplored for new markets and products. Furthermore, integrating risk management frameworks like Good Agricultural Practices (GAP) and Biodiversity-friendly Agricultural Practices (BAP) are vital for ensuring food safety and sustainability. Enhancing the efficiency of horticulture across the production systems is another key focus to increase the income of farmers, while safeguarding the interests of other stakeholders involved in the supply value chain.

Against this backdrop, the brainstorming session organized by the Academy is indeed timely. I would like to extend my thanks to the Convener (Dr. Sudhakar Pandey), Co-convener (Dr. Sant Kumar) and the participants for their valuable inputs. My sincere appreciation is due to the Reviewers (Dr. D. Prasath & Dr. A.T. Sadashiva) and Editors (Dr. R.K. Jain & Dr. R.K. Pal) for bringing out this policy document. I hope this document serves as a valuable guide for policymakers, other stakeholders, and agricultural leaders to collaborate in strengthening India's position as the world's horticulture hub.

April 2026
New Delhi



(M.L. Jat)
President, NAAS

Horticultural Innovations to Enhance Exports from India

1. INTRODUCTION

India is the second-largest producer of fruits and vegetables in the world, and contributed about 12% (each) of global fruits and vegetables production during the triennium ending (TE) 2023 (FAO, 2025). The sectoral contribution of horticulture to agriculture is approximately 38% by utilising just 13% of the cropped area (Kumar *et al.*, 2025a). Realising the potential of the horticulture sector, the Government of India (GoI) has given greater emphasis since the Eighth Five-Year Plan (1992-97). To promote holistic growth in the horticulture sector, GoI initiated the Mission for Integrated Development of Horticulture (MIDH) in 2014-15, and invested Rs. 376.01 billion over the past 12 years (2014-15 to 2025-26). The productivity of horticulture increased by 7% from 11.7 tonnes/ha in 2015-16 to 12.5 t/ha in 2024-25.

India produced 370.74 million tonnes (Mt) of horticultural produce from an area of 30.14 million hectares (Mha) with 12.30 t/ha productivity during 2024-25 (Fig. 1). The productivity of horticulture increased substantially, from 7.6 t/ha in 1991-92 to 12.3 t/ha in 2024-25. However, in recent years, productivity has stagnated and production is increasing through increase in area. Despite being the global leader in the production of fruits and vegetables, India's share of horticulture exports in global trade stands at 1-2%, which is significantly lower than that of major producing countries. Further, there is a significant import of horticulture products like fresh fruits, cashew nuts, cocoa and spices, accounting for over 94% total horticulture imports over the past decade (2013-14 to 2022-23). Horticulture

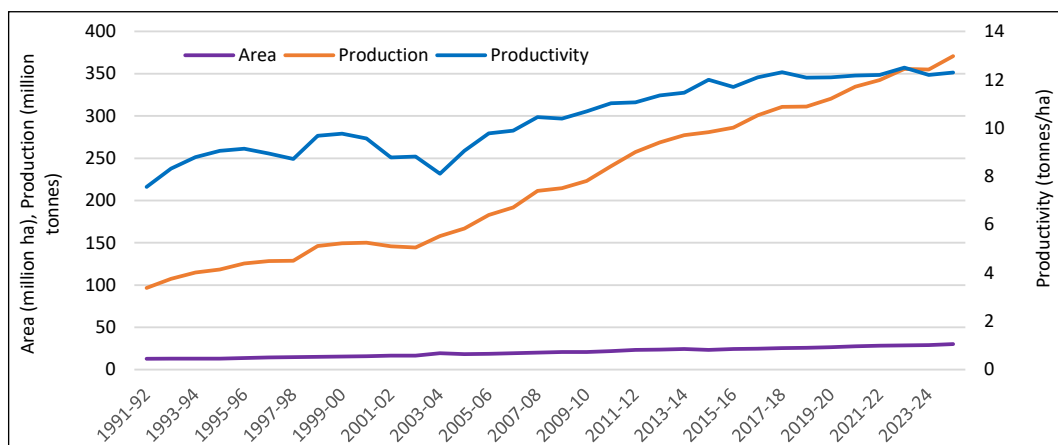


Fig. 1. Trends in area, production and productivity of total horticulture in India, 1991-92 to 2024-25

Source: Horticultural Statistics at A Glance (various years)

imports account for about 18-20% of total agricultural imports. This needs to be addressed as a priority. Moreover, various studies on the fruit and vegetable subsectors in India have indicated large post-harvest losses ranging from 6-15% in fruits, 4.9-11.6% in vegetables and 1.3-7.3% in plantation crops and spices due to inadequate infrastructure for post-harvest handling and value addition in the year 2022 (MoFPI, 2025).

Despite significant progress in the horticulture sector, several challenges accompany with this growing sector. The growing population of India is projected to reach 1.7 billion by 2050, which will substantially increase pressure on the horticulture sector to meet the rising demand for fruits & vegetables and other products. The key production challenges that will come in the way of meeting the domestic demand and export potential include the absence of effective extension services, low productivity, post-harvest losses, changing preferences on quality and global competition, climate change, poor market linkage, and price fluctuations, etc. On the export front, key challenges include product traceability (forward and backward linkage), phyto-sanitary issues like quarantine requirements, pesticide residue limit, poor quality control, lack of certification awareness, varying standards of importing countries, erratic enforcement of domestic phyto-sanitary regulations, both tariff and non-tariff barriers etc.

Horticulture provides a better alternative for the diversification of agriculture, owing to higher returns received than those of traditional crops like rice and wheat (Kumar *et al.*, 2025b). To harness the potential of horticulture, India needs to enhance the adoption of global best technology and practices to improve productivity, develop post-harvest and marketing infrastructure to avoid losses, invest in strengthening the supply chain and value addition activities, and market intelligence to increase the sector's domestic and global market reach and trade share.

In this backdrop, this policy paper attempts to describe the status of horticulture exports and list of innovations vital to boost the potential of the horticulture sector and make India a leading producer and global player in the world markets.

2. STATUS OF HORTICULTURE EXPORT

Despite being the leading producer of fruits & vegetables, India's exports in the global market are low. India exported horticultural products of Rs 925.32 billion during TE 2024-25 (Fig. 2). Spices contributed to about two-fifths of the total export value (38.0%), followed by plantation crops¹ (29.4%), processed horticultural products (13.9%), fresh fruits (8.8%), and fresh vegetables (7.9%). Seeds of horticulture and floriculture crops accounted for about 1% (each) in total export. The major fruits exported include mangoes, bananas, grapes, pomegranates, etc., in 2024-25. Among the major vegetables exported from India are onion, tomatoes, potatoes, beans, garlic, okra, green chillies, and capsicum. Among the spices, chilli, cumin, spice oils and oleoresins, mint

¹ Plantation crops include tea, coffee, cashew, coconut, areca nut and cocoa, etc. Other plantations like Cardamom (small and large) are included in spices. Due to the inadequacy of data, medicinal and aromatic plants (MAP) are not included here.

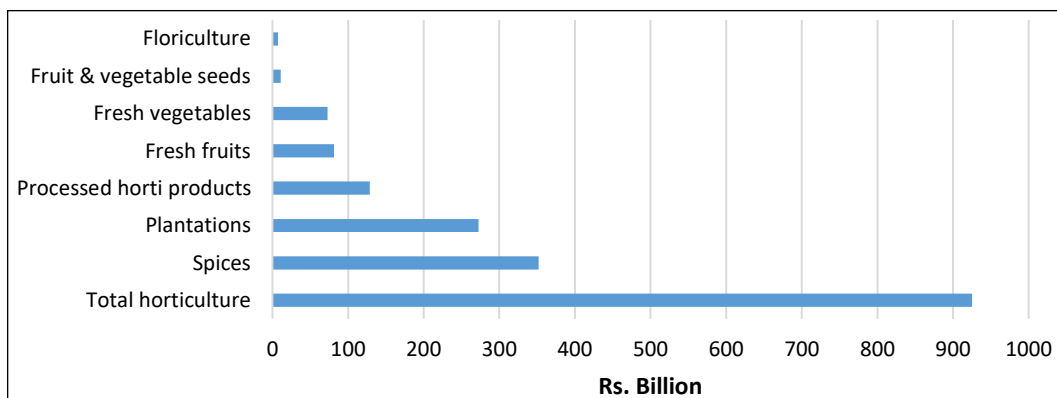


Fig. 2. Export value of the broad group of horticultural products from India during TE 2024-25

Source: GOI (various years); Authors' estimate

products, other spices and curry powder/ paste were the major ones. During the year 2024-25, India exported horti-products to more than 100 countries, including China, USA, Bangladesh, the UAE, Thailand, Malaysia, Indonesia, the UK and Sri Lanka. The major countries where fresh fruits were exported from India in recent years include the Middle East, Europe, and Asia. The major destination countries for fresh vegetables were UAE, Nepal, Bangladesh, Malaysia, Sri Lanka, UK, Oman, Iraq, etc.

Exports of horticultural products from India have shown a modest increase over the past two decades, except for spices (Fig. 3). Total exports increased over 17-fold in the past two decades, from Rs 59.26 billion in 2003-04 to Rs 1,027.45 billion in 2024-25, amounting to an average compound annual growth rate (CAGR) of about 11.7%. Being a key segment of the agriculture, horticulture not only shouldered the responsibility on the production front, but also in export promotion. During the above period, the share of horticulture in terms of value of agricultural export remained between 16-18%. The growth in agricultural exports was about 10%, and horticultural exports constantly backed the agricultural exports at a similar pace (11.7%).

Being the global leader in spices production (40% of the world), its role in horticultural exports remained significant. Within a short span of 5 years, the share of spices exports increased from 26% in 2003-04 to 36% in 2009-10, and 45% in 2016-17. Spices have accounted for over 40% of horticultural exports for the last seven years. Next to spices, plantation crops have been the main items of export and have grown at nearly 13% annually. Other major export commodities are processed fruits and vegetables, which grew at an average CAGR of almost 12% over that time. Annual average growth in fresh fruits and fresh vegetables exports was 9.6% and 8.0%, respectively, during the period.

Despite being a large producer and exporter of horticultural products, India also incurs a huge expenditure on the import of several horticultural products. Data show that India imported horticultural products of Rs 459.56/- billion during TE 2023-24. The country

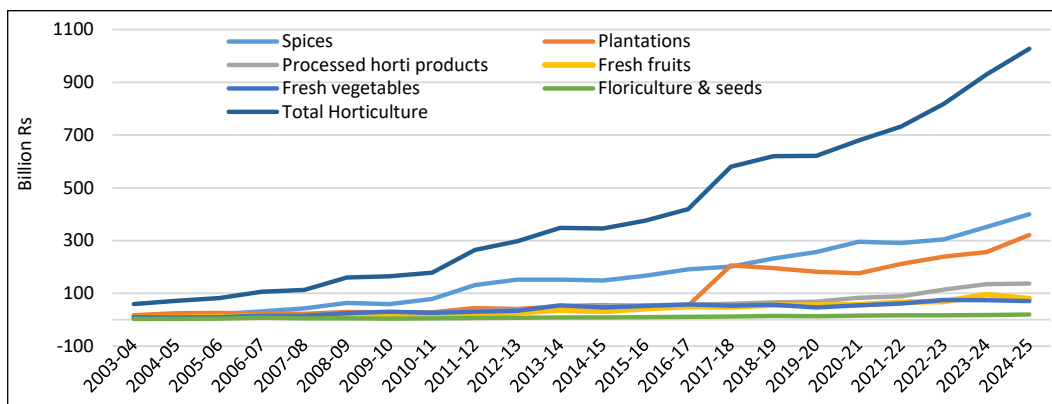


Fig. 3. Trends in the export value of broad group of horticultural products from India

Source: GOI (various years); Authors' estimate

has experienced a substantial increase in imports of horticultural products in the past 10 years (Fig. 4).

Among the imported items, fresh fruits, cashew nuts, cocoa products, and spices are the major ones, and these together accounted for about 94% of total horticultural imports by India. Expenditure on import of fresh fruits alone accounted for about 42-45% share, followed by cashew nuts (29-30%), and spices (20-22%) over the past 10 years. India's fresh fruit imports include apples, oranges, grapes, kiwis, and cherries. Apples are the largest import category by volume, followed by other fruits like grapes and oranges. In recent years, demand has also grown for exotic fruits like avocados and dragon fruit.

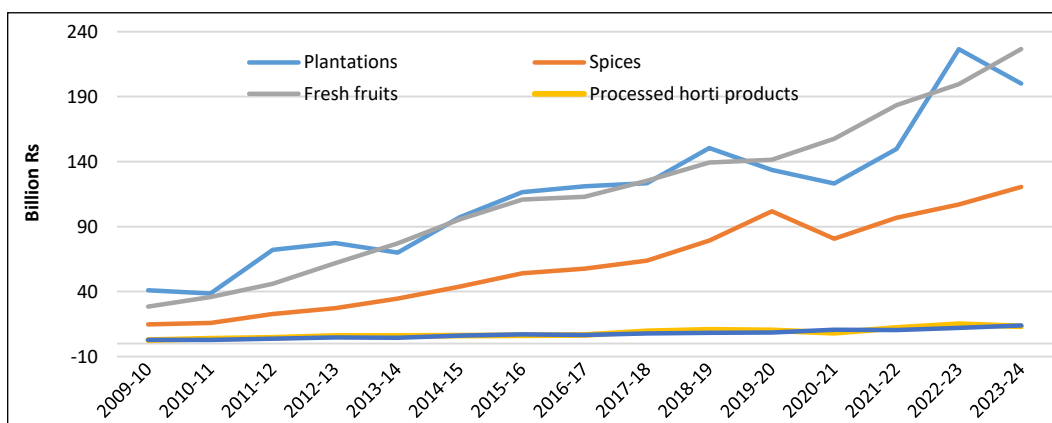


Fig. 4. Trends in the value of a broad group of horticultural products imports by India

Source: GOI (various years); Authors' estimate

Health is a predominant factor driving the preference for consumption of exotic fruits, followed by taste and family preference. Other factors that influenced the consumption were dietary habits and the availability of a wide variety of fruits and in-store promotions/ discounts. Import of spices includes pepper (white, light & black peppers), clove, asafoetida, spice oils & oleoresins, and mint products (menthol, menthol crystal, and other mint oils). These five items together accounted for 53% expenditure on the import of total spices during 2023-24. Other items of spices import include saffron, kokam, vanilla, spices husk and spices nes, spices seeds (celery, ajwan, juniper berry, fenugreek) and ginger (fresh/dry). Moreover, India can minimise large expenditure on the import of spices by utilising the technologies and variable agro-climatic conditions suitable for growing all types of spices. A huge opportunity exists in the production of mint products, and even Uttar Pradesh alone can produce a large quantity of mint products, both for the country's needs and to meet export demand. Among the horti-products imported into India, spices have shown a highest CAGR (15.6%), followed by fresh fruits (13.9%), processed products & seeds of horti-crops (10%, each), and in cashew nuts (9.3%).

3. PROJECTED DEMAND, PRODUCTION AND CONSUMPTION TREND

In the past four decades (1983-84 to 2022-23), fruits & vegetables consumption became more than double, from 4.01 to 9.15 kg/capita/month (BIRTHAL *et al.*, 2025). This has implications for production to meet the rising domestic demand and export potential. The total demand for fruits and vegetables has been projected to 700 Mt (283 Mt fruits and 417 Mt vegetables) in 2047-48 by NITI Aayog (2024). Considering the historical growth (1991-92 to 2024-25), production of fruits & vegetables has been projected to reach 850 Mt by 2047-48 (Table 1). In a business-as-usual situation, the trend in production growth seems to be sufficient to meet domestic demand in the future. However, rising urbanization and per capita income, increasing consumer

Table 1. Current (2024-25) and projected area, production and yield of horticultural crops

Commodity	TE 2024-25			Projected* (2047-48)		
	Area (Mha)	Production (Mt)	Productivity (t/ha)	Area (Mha)	Production (Mt)	Productivity (t/ha)
Fruits	7.11	113.98	16.03	14.03	296.27	21.12
Vegetables	11.42	211.81	18.56	21.88	554.11	25.32
Flowers	0.33	3.55	10.79	1.34	29.14	21.75
Medicinal & aromatic plants	0.87	0.71	0.81	3.63	3.04	0.84
Plantation crops	4.53	17.29	3.82	6.93	31.42	4.53
Spices	4.74	12.27	2.59	7.88	43.05	5.46
Total	29.00	359.76	12.40	55.69	957.04	17.19

Source: <https://agriwelfare.gov.in/en/StatHortEst>; *Authors' estimate

awareness about health and quality, changing dietary patterns and potential export demand, require stepping up the yield level as the scope for area increase is limited due to competing demand from other sectors.

4. EXPORT COMPETITIVENESS

In the context of a cohesive global network of markets and value chains, horticultural products from India face tough competition from other countries worldwide (Table 2). Meeting the demand and regulatory issues, such as consumer preferences, quality and certification, branding & packaging, and market intelligence can help to improve India's global ranking in export markets. However, most Indian horticulture products have comparative, strong seasonal, and partial seasonal advantages (Saxena *et al.*, 2024). Many Indian fruits, such as pineapple, fresh melons, oranges, and grapes (dried) have an untapped export potential of over 70% of global export. The grapes have strong seasonal advantages with over 50% unexplored markets.

Additionally, India is a leader in the export of spices (40% of the globe). The major import destinations of spices, in general, are spread over North America and Europe (NAAS, 2025). This offers the advantage for the producing countries to have commodity boards to offer a fair price to the primary producers, while providing a stable market, conducive for sustainable growth and development.

Besides trade competitiveness, another crucial factor is a planned and stable export policy for the products. The existing trend in horticultural exports shows that it is highly skewed and concentrated in a few countries. This reflects the risk for the major exporting country, owing to economic and geopolitical reasons and requires diversifying export destinations. The current customs imposition by the USA on imports from India is a burning example, and suggests that diversification of export sources must be pursued to avoid such risk elements. Several other factors to be kept in view, while pursuing a stable trade policy require quality standards, licensing system, quotas, SPS issues, local needs, etc.

Export competitiveness of a commodity does not depend only on production or cost efficiency alone. The price discovery of a product depends on several other factors, like preferred quality, geographical origin, product uniqueness, and marketing strategy followed individually or as a group. To examine the export competitiveness of a commodity, mostly indices like Revealed Comparative Advantage (RCA) and Revealed Symmetric Comparative Advantage (RSCA) are employed based on actual trade data to identify a country's strong and weak export sectors/ commodities. It empirically "reveals" which products a country can produce and export most competitively relative to the rest of the world. Considering RCA, Saxena and his associates (2024) have examined India's export competitiveness of key vegetables like cucumbers and gherkins, preserved (29.45), dried onion (15.94), and several others for the year TE 2020 (Fig. 5).

Among the fruits, fresh coconut, cashew nut, shelled (6.34), guava, mango, and others have found having export competitiveness from India. Among the major spices, chillies, cumin, mint products, turmeric, coriander, and ginger were found to have very strong export competitiveness during 2022-23 (NAAS, 2025). A study by TPCI (2021) on exports of

Table 2. India's competitor in the global horticulture export

Fruits	India's competitor for export	Spices	India's competitor for export
Mango	Mexico, Brazil, Thailand, Pakistan, Peru	Black peeper	Vietnam, Sri Lanka, Brazil, Indonesia
Guava	Thailand, Mexico, Brazil, Egypt, Vietnam	Ginger	China, Nepal, Nigeria
Banana	Ecuador, Philippines, Costa Rica, Colombia	Turmeric	Vietnam, Myanmar, Nigeria, China, Bangladesh
Grape	Peru, Chile, China, South Africa, USA	Chillies	Vietnam, Thailand
Pomegranate	Iran, Spain, Turkey, Egypt	Nutmeg	Indonesia, Vietnam
Oranges	Spain, South Africa, Egypt, USA, Brazil	Cumin	China, Turkey, Syria
Tamarind	Vietnam, Thailand, China	Coriander	Russia, Italy, Morocco, Bulgaria
Pear	China, South Africa, Belgium, Netherlands	Fenugreek	Pakistan, Egypt, China
Vegetables	MAP		
Onion	China, Netherlands, Mexico, Egypt	Ashwagandha	China, USA, Brazil
Potato	Netherlands, France, Germany, Canada	Turmeric	China, Myanmar, Vietnam, Thailand, Indonesia, Peru
Tomato	Mexico, Netherlands, Turkey, Spain	Ginger	China, Nigeria, Thailand,
Cabbage	China, Uzbekistan, Mexico, Netherlands	Neem	China, Sri Lanka, Australia, Germany, USA
Beans	Canada, Australia, Myanmar, Malaysia	Aloe Vera	China, Thailand, USA, Mexico
Okra	China, Mexico, Honduras, Malaysia	Tulsi	China, Singapore
Flori-products	Plantations		
Rose	Netherlands, Colombia, Ecuador, Kenya	Tea	China, Kenya, Sri Lanka
Carnation	Netherlands, Colombia, Kenya	Coffee	Brazil, Vietnam, Colombia
Chrysanthemum	Netherlands, Vietnam, Tanzania	Cashew nut	Vietnam, Brazil, Ivory Coast
Gerbera	Netherlands, China, Lithuania, Ecuador	Coconut	Philippines, Indonesia, Thailand

Sources: <https://apeda.gov.in/>

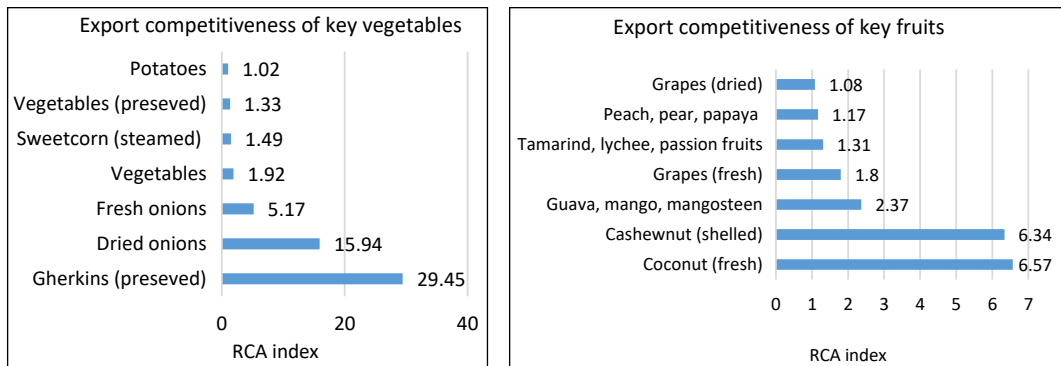


Fig. 5. Trade competitiveness of major fruits and vegetables from India (Source: Saxena *et al.*, 2024)

horticultural products from India has also reported similar findings. Cost-efficient production, quality, and traceability mechanisms, including a stable trade policy to help India become a global player in horticulture trade. Thus, to make Indian horticulture trade competitive in global markets, it is essential to promote and give financial assistance to this sector.

Trade competitiveness (TC) of spices depends on various factors like perceived quality, geographic origin, intrinsic quality profile and uniqueness of the product and marketing strategies adopted by the firms and producers, either individually or as a group (NAAS, 2025). TC is one of the indices and it varies from -1.0 to +1.0. An index value between -1.0 to -0.5 indicates very poor export competitiveness while a value between -0.5 and 0.0 indicates poor competitiveness (Long, 2021). Similarly, TC value between 0.0 and 0.5 indicates strong export competitiveness while values above 0.5 is indicative of a very strong export competitiveness of the commodity. The TC value of major spices, such as chillies, cumin, mint products, turmeric, coriander and ginger were found to have very strong export competitiveness during 2022-23 (Fig. 6), while cardamom had a strong

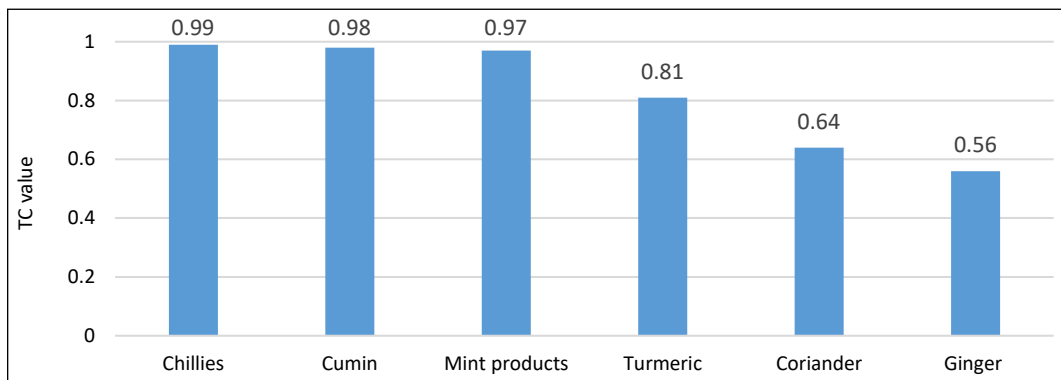


Fig. 6. Trade competitiveness of major spices from India

Source: NAAS (2025)

export competitiveness with a trade competitiveness index value of 0.36 (NAAS, 2025). The TC of black pepper, once a major item of the spice export basket was found to be poor (-0.30). Nutmeg and mace, as export items, had very poor competitiveness during 2022-23. The analysis of TC indicates the urgent need to improve the efficiency of the production ecosystem in crops like black pepper and nutmeg. It also points out the need to consolidate gains in crops like coriander, ginger and cardamom, where there is considerable scope for improving export competitiveness. However, it should be borne in mind that the calculation depicted above is for a particular year alone. A comprehensive picture of TC needs to be constructed based on price, trade volume and other non-price factors.

The expansion of multilateral trade agreements has significantly enhanced trade opportunities and market access for plantation crops. However, the emergence of low-cost producers in Latin America, Asia, and Africa, coupled with non-tariff trade barriers, threatens the competitiveness of India's plantation exports. Desai and Manoj (2025) utilized the RCA index and TC index to evaluate the competitiveness and export potential of Indian plantation crops in the European Union (EU) and the North American Free Trade Agreement (NAFTA). Their study identifies a robust complementary trading structure for tea, coffee, and pepper, suggesting substantial trading potential and benefits with NAFTA. Tea exports to NAFTA and pepper exports to the EU demonstrate moderate competitiveness and a high degree of complementary trading structures. Conversely, coffee exports show low to negligible competitive strength in both trading blocs, although the trading competitiveness ranges from medium to high between the EU and NAFTA. The study highlights the EU as the primary export destination for Indian tea and NAFTA for pepper, while India is experiencing a decline in competitiveness in coffee exports both globally and in these specific markets.

5. INNOVATIONS TO ENHANCE HORTICULTURAL PRODUCTION AND EXPORTS

To promote the holistic development of the horticulture sector, India has undertaken several initiatives to revolutionise the horticulture industry. These initiatives can be grouped into technological, infrastructure & management, and policy & market support.

5.1 Technological Innovations

5.1.1 Export-oriented and climate-resilient varieties : The advancements in research have led to the development of several improved varieties/ hybrids/chemotypes over the years. In India, more than 440 horticultural varieties have been developed, released, and notified between 2014 and 2024, of which 112 varieties have exhibited strong export competitiveness. Some high-value export-oriented varieties include spices such as turmeric (IISR Pragati, Rajendra Sonia) and cumin (Gujarat Cumin 4); fruit crops such as mango (Alphonso, Kesar), grapes (Sharad seedless) and banana (Grand Naine); and vegetables such as okra (Arka Nikita, Kashi Sahishnu). Despite this progress, there is a continued need to breed market-demand-driven varieties for specific export destinations. Importing countries require their own quality specifications for horticultural products and the export specifications for major fruits are presented in Table 3.

Table 3. Export specifications of fruits for specific regions

Fruit	Exported variety	Regions/ Country	Size/ weight of fruit	Colour	Packing	Storage temperature	Transport
Grapes (Seedless)	Sharad, Flame	Mid-East, Holland/UK, Germany	15-18 mm	Amber, Black, Pink	1 kg, 4.5/9 kg	0-1°C	Sea (Europe), Air (Others)
Mangoes	Alphonso, Kesar	Mid-East, Netherlands/ Germany, UK, Japan, USA	200-300 g	-	1 Doz/ 2.5-3.5 kg	13°C	Sea (Mid-East), Air (Others)
Pomegranate	Ganesh, Bhagwa, Arakata, Mrudula	Mid-East, Holland, UK, Germany	300-500 g	Red/ Deep Red	5 kg (Mid-East), 3 kg (Others)	5°C	Sea
Papaya	Taiwan Solo	785/786, Mid-East, Europe	1-1.25 kg, 400-500 g	Pale Green	8 kg, 5 kg	10-13°C	Sea
Sapota	Cricket Ball, Kalipatti	Mid-East	125-150 g or higher upto 400 g depend upon the variety	Dull brown or Light brown	3 kg	15-20°C	Sea
Mandarin	Nagpur Mandarin	Mid-East	150 - 175 g, Grades: 65 - 70 mm & 40 - 45 mm	Light orange	65 mm - 7 kg; 40 mm - 2.5 kg	5-7°C	Sea
Banana	Grand Naine Cavendish	Mid-East	2.5 kg (Bunch)	Green/ preferably straight	13 kg	13-14°C	Sea
Lime		Mid-East	20-25 mm	Green	5 kg (Gunny bags)/ 20 kg (Wooden boxes)	2-5°C	Sea Air

Source <https://www.msamb.com>

Export of fresh vegetables to Middle East countries has traditionally been air-shipment based, but in recent years, sea container exports have increased significantly. The required export specifications for vegetables are given in Table 4. These export needs provide a framework for export-oriented breeding, post-harvest handling, and supply chain standardization.

5.1.2 Good agricultural practices and quality assurance : The NHB, in collaboration with ICAR and the Quality Council of India, has developed the Bharat Good Agricultural Practices (Bharat GAP), a farming-system–centric framework that adapts global best practices with local feasibility and affordability. Additionally, ICAR has formulated GAP-compliant packages of practices for 39 major fruits, vegetables, flowers and 28 medicinal and aromatic crops, enabling farmers to adopt safe and export-oriented cultivation protocols. In spices, GAP was developed for black pepper, cardamom, turmeric and cumin in collaboration with the Spices Board, State Department and SAUs. The GAP on black pepper was adopted in Paderu Mandal of Alluri Sitharama Raju district (formerly in Vishakhapatnam), Andhra Pradesh in collaboration with Spices Board through STDF-FAO partnership for strengthening the spice value chain and improving market access through innovative intervention for the production and export of certified black pepper. The farmers’ groups could produce and market 55 tonnes of black pepper that are certified by EuroGAP and CODEX standards.

Quality assurance for export-oriented horticulture in India has been significantly strengthened through coordinated initiatives focusing on GAP, traceability, and

The ICAR Institutes have developed 18 bio-fortified varieties in various horticultural crops such as pomegranate, grapes, okra, potato, etc. for commercial production and over 100 climate-resilient varieties during the last five years. These varieties would be in high demand for export due to their nutritional quality and higher production under stress conditions.

Table 4. Exportable quality of vegetables for Middle East

Commodity	Parameters	Packing
Okra	3-5 inch length, green tender	5 kg
Ivy gourd	1-2 inch length, green tender	5 kg
Bottle Gourd	12 inch length, greenish tender and straight	5 kg
Peas	5-6 inch length, green tender and straight	5 kg
Elephant foot yam	Cleaned, weighing around	5-10 kg
Green Chilli	3-4 inch length, green	5 kg
Drumsticks	24 inch length, straight and thick	5 kg

Source: <https://apeda.gov.in/>

internationally compliant residue monitoring. Pesticide and chemical residues remain a major barrier to India's export growth, with shipments often rejected in global markets when residues exceed the prescribed Maximum Residue Limits (MRLs). This issue arises due to limited farmer awareness and inadequate training on the judicious and timely use of agrochemicals, leading to frequent non-compliance with international safety standards.

To ensure food safety and traceability, the HortiNet digital system facilitates certification and traceability of diverse horticultural crops, including grape, pomegranate, mango, vegetables, etc., throughout the process of farm registration, sampling, residue analysis by laboratories, AGMARK and Phyto-sanitary certification for compliance with the requirements of export. The ICAR-NRC Grapes has NABL accredited National Reference Laboratory (NRL) and facilitating the residue analysis of 779 pesticides across different horticultural and other crops.

5.1.3 Precision horticulture for better output with less inputs : Precision horticulture is an effective approach not only for large farms but also for smallholder horticulture farmers facing resource constraints and climate variability. By integrating sensors, GIS, drones, drip fertigation, protected cultivation, and data-driven advisories or decision-support systems, it enhances productivity while improving resource-use efficiency, sustainability, and farmer incomes. Precision horticulture enables site, crop, and growth stage-specific management of water, nutrients, and plant protection. Its integration with specialty fertilizers, such as water-soluble, micronutrient, controlled-release, and bio-enhanced formulations, further improves nutrient efficiency, crop quality, and environmental resilience. Adoption of the drip irrigation system in India has increased water productivity by 42-255% for crops like banana and sweet potato, and the use of the drip irrigation system for tuber crops enhance yield per unit area, improve tuber size and uniformity and support export quality produce.

In India, approximately 1.25 lakh ha area is under 'protected cultivation', which includes greenhouses (permanent structures) and other temporary protected structures. The exportable quality produce of vegetables and flowers are produced under protected condition and their productivity is very high due to real time monitoring of inputs and plant health. Most commonly grown crops under protected conditions are cucumber, capsicum and tomato, in addition blueberry and strawberry are emerging crops under this system. Further, there is a need to convert 10% of the greenhouses into hydroponics/aeroponics with a controlled environment, which can save approximately 15-20% fertilizer and water requirements. To attain the sustainable food system by 2047, our target may be to cut nutrient losses by 50% and reduce fertilizer use by at least 20% by using the precision horticulture.

e-Crop Based Smart Farming (e-CBSF) developed by the ICAR-CTCRI is an IoT-enabled precision nutrient and water management technology for cassava, sweet potato, elephant foot yam and banana for open field condition, which reduces the yield gap from 50% to 5%, saves 25–50% water and nutrients and improves quality suitable for export-oriented value chains.

The Smart Precision Horticulture Programme under the Mission for Integrated Development of Horticulture (MIDH) has allocated Rs. 60.0 billion to cover 15,000 acres and benefit 60,000 farmers between 2024 and 2029.

Decision Support Systems (DSS) are computer-based tools that integrate weather, soil, crop, and disease data with predictive models to generate timely alerts, assess risks, and recommend treatments for the management of plant diseases and pests. They support evidence-based decisions under IPM, reducing pesticide use, production costs, and yield losses. For example, ICAR-Central Potato Research Institute has developed Indo-Blightcast model for accurate prediction of the appearance of late blight across agro-ecologies. Accordingly, agro-advisories are issued for the management of late blight disease. Scheduling fungicides based on the Indo-Blightcast model has resulted in a reduction of fungicide usage by 33% and saving on fungicide cost Rs. 3,500.0/ha, thus, a net saving of Rs. 7.70 billion per annum, besides saving the environment. This model is operationalized across the country covering 2.3 Mha area. Even at the current potato production scenario of 60 Mt, the average reduction in crop losses (15%) would amount to 9 Mt of potatoes that would be worth Rs. 900.0 billion annually. A similar model has been developed in grapes for mildew management. This type of DSS should be developed for the management of major pests and diseases of horticultural crops.

In precision farming, the use of 'high-quality seeds and planting materials' is equally important to enhance the yield per unit area and quality to scale up the horticultural commodity export. Over the past five years, 4,240 quintals of breeder/truthfully labelled seeds of improved vegetable varieties and spices, 11,455 tonnes of seed tubers (including potato, onion, and other tuber crops), 11.446 million fruit crop plants, and 2,373 quintals of mushroom spawns have been produced. Additionally, more than 40 million virus-free mini-tubers of potato have been generated through aeroponic technology by forty units licensed by ICAR-CPRI, Shimla, fully meeting the national demand for nucleus seed tuber production in potatoes. These advancements in clean planting material and seed systems significantly enhanced the quality, reliability, and export potential of horticultural produce. Further, the aeroponic system and apical rooted cuttings (ARC) techniques for disease-free quality seed potato production open new opportunities for seed export.

5.1.4 Processing and value-addition : India's horticulture export basket is evolving beyond traditional high-demand commodities such as dehydrated onion and frozen gherkins. There is a significant scope to promote indigenous value-added items, including frozen fruit pulps (Custard Apple, Jamun), fruit juices and beverages (Custard Apple, Litchi, Guava, Mango), and osmo-dried products such as jackfruit slices, amla slices, bael candy, pomegranate dried arils, and karonda. The products like jamun bars, cashew apple fruit bar and nutrient-rich powders including dried jamun seed powder, dried jackfruit seed powder, and moringa powder offer strong potential for

export markets. Further, vacuum-fried vegetables such as beans, okra, bitter gourd, and jackfruit represent an emerging segment.

India is rapidly strengthening its value-added horticulture sector through the development of specialised processing varieties. In potato, cultivars such as Kufri Frysona for French fries and Kufri Chipsona-3 for chip-making have enabled a major transformation, increasing the share of processing from 2% in 2000 to nearly 10% at the current level of production. As a result, India has shifted from being a net importer of French fries to becoming a net exporter. Similarly, India exporting high valued spice oils/oleoresins, mint and mint products and it is supported by the improved cultivars of spices, flowers, medicinal and aromatic crops developed by the ICAR. Special emphasis should be placed on the development of the processing varieties of vegetables and fruits with high nutrient content; spices, flowers, medicinal and aromatic crops for high oleoresins, essential oils and natural colourants.

Further, there is tremendous scope for extraction of high value bioactive compounds from otherwise unmarketable fruits and vegetables in their fresh form. These high value bioactive compounds viz. Punicalagin and virgin pomegranate seed oil from pomegranate, flavonoids from citrus, edible fat from mango stone, xiloto from banana pseudo stem, lutein from marigold etc. have great potential for their use in food, pharmaceutical and cosmetic industries globally. Hence, total utilization concept of the harvested horticultural produce through appropriate value chain activities, generating data on their specific demand by the end users and creating awareness among the FPO's will go a long way improving farmers' income through marketing of these high value products both in domestic as well as export market.

5.1.5 Organic farming : Organic farming is an agricultural approach that preserves the soil's reproductive and regenerative capacity, good plant nutrition, and promotes sustainable soil management, resulting in nutritious and high-vitality food. Globally, India ranks second in terms of organic agricultural land and first in the total number of organic producers. In the financial year 2024, India produced approximately 3.6 Mt of certified organic products, including a wide range of food products. India exported 0.261 million Mt of organic food, earning Rs 40.08 billion in 2023-24 and mainly exported to the USA, the European Union, Canada, Switzerland, Vietnam, Australia, Thailand, New Zealand, Japan, etc.

Organic production protocol has been developed for black pepper, ginger, turmeric, fennel, coriander, cabbage, pea, bottle gourd, leafy vegetables, fruit crops and medicinal plants. The innovative biocapsule technology for the encapsulation and delivery of beneficial microorganisms enhances the shelf life, survival efficiency, and field performance of bioinoculants while enabling easy transport and application by farmers. Biocapsules have significantly reduced the dependence on chemical fertilizers and pesticides in spice cultivation, promoting organic and eco-friendly farming practices and improving soil health. *Lecanicillium psalliotae* granular formulation developed for biocontrol of cardamom thrips rationalizing the use of pesticides to produce residue-

free cardamom for export promotion. India is bestowed with varied agro-climatic conditions and a strong tradition of organic farming in many regions, has significant potential to expand organic production. This provides opportunities for producers to tap into the steadily growing domestic and export markets.

The organic production in horticulture needs to be promoted along with its certification mechanism for trusting the quality of produce, harnessing environmental and economic benefits, and branding Indian horticulture products. But the existing certification system is complex and costly for small and marginal farmers. To make it easier and affordable, the certification system should be simple and accessible to marginal and small farmers to adopt certification and sell produce in the market. Several initiatives have been taken to promote organic farming in India, such as *Paramparagat Krishi Vikas Yojana* (PKVY) in 2015, *Mission Organic Value Chain Development for North East Region* (MOVCDNER) 2015-16, *Jaivik Kheti organic e-commerce portal*, and the *National Programme for Organic Production* (NPOP) in 2001.

The domain of organic seed production and export presents a significant opportunity. Current regulations in Europe and the USA mandate that organic producers must utilize organically-grown seeds unless suitable options are unavailable in the market. Organic seed production demands specialized knowledge and meticulous care, emphasizing non-chemical methods for cultivating seed crops. It is imperative to invest in organic seed production and establish robust frameworks and mechanisms for certification that align with international standards or those of destination countries.

5.2. Infrastructure and Management

Several schemes and programmes have been initiated to develop infrastructure for boosting the production and export of horticultural products by Gol. The major programmes are noted below:

5.2.1 Cluster development programme : The Cluster Development Programme (CDP) was initiated by Gol in 2021 to make potential horticulture crops globally competitive. The programme is implemented through State/ UT governments' identified development agencies, and the National Horticulture Board (NHB) is the nodal agency to monitor at the national level. Initially, on pilot basis, the programme is implemented for 7 crops in 12 clusters (Table 5). The pilot phase mid-term evaluation by the Asian Development Bank has revealed the successful implementation of the programme across diverse agro-climatic zones of India. Accordingly, the implementation guidelines have revised before its full-scale launch. Peri-Urban Vegetable Cluster (PUVC) launched for a period of five years has been merged with CDP. The PUVC aims to mitigate price volatility in fruits and vegetables and will be rolled out in phases. These clusters to provide development prospects to stakeholders involved viz., farmers/producers, traders, aggregators, agribusiness enterprises, logistic players, retailers, processors, exporters, and others. The CDP is expected to benefit 10 lakh farmers and related value chain. Through CDP, India aims to improve exports of targeted

Table 5. Details of clusters identified under cluster development programme

Crop	Identified clusters	State
Apple	1. Sopian	Jammu & Kashmir
	2. Kinnaur	Himachal Pradesh
Mango	1. Lucknow	Uttar Pradesh
	2. Kutch	Gujarat
	3. Mehbubnagar	Telangana
Banana	1. Anantpur	Andhra Pradesh
	2. Theni	Tamil Nadu
Grapes	1. Nasik	Maharashtra
Pineapple	1. Siphahijala	Tripura
Pomegranate	1. Solapur	Maharashtra
	2. Chitradurga	Karnataka
Turmeric	1. West Jaintia Hills	Meghalaya

Source: NHB (2025)

crops by 20% and create cluster-specific brands to enhance competitiveness. The program has huge potential to transform the horticulture ecosystem, improve its global competitiveness by building last-mile connectivity, and timely evacuation and transport of horticulture produce.

Besides cluster development, India has delineated a total of 60 Agri Export Zones of different horticultural crops includes mango, vegetables, flowers, potatoes, onions, litchi, grapes and grape wine, ginger, oranges, gherkins, medicinal plants, banana, pomegranate, apple, walnuts, cashew nut, turmeric, chilli, coriander, cumin, vanilla, pineapple, seed spices, honey and Darjeeling tea.

5.2.2 Pre-and post-harvest management : India is a leader in horticulture production, but it faces challenges with pre-and post-harvest losses and infrastructure. Pre-harvest practices such as harvesting and picking at the proper maturity stage in different crops, along with operations like precooling to remove field heat, curing, washing, drying, sorting and grading, help to increase the shelf life and maintain quality. Initiatives like MIDH and the Cold Chain Scheme aim to improve infrastructure and reduce losses from farm to consumer. The horticulture is covered in the component –Operation Greens of PM Kisan Sampada Yojana (PMKSY). Horticulture has significant potential due to a large domestic market and increasing export demand, but it requires investment in infrastructure and technology. Developing processing units of various sizes involving small industries, SHGs, FPOs, and others is crucial, along with addressing operational issues and quality. Besides strengthening the processing sector, there is a need to explore new markets and diversify product demand. Uneven distribution of processing industries is noted, with high focus in southern and western states. The location of

processing units should consider raw material availability and potential growth rather than just location.

5.2.3 Food irradiation facilities : The controlled ionizing irradiation facilities are required to minimise the post-harvest losses. This process helps reduce the post-harvest losses in bulbs (onions), tubers (potato), and ensures microbial decontamination of dried herbs and spices. It also provides phyto-sanitary treatment of fruits and vegetables, enabling them to meet quarantine requirements for international trade. This technology has been Gazette-notified by the Government of India and endorsed by the Food Safety and Standard Authority of India (FSSAI); and many international statutory bodies including WHO, FAO, IAEA, USFDA and FSANZ. Globally, food irradiation is practiced in more than 70 countries. As of 2025, 31 food irradiation facilities (seven in the government sector and 24 in the private sector) are operational in India, supporting export-grade post-harvest management and compliance with global market requirements.

5.2.4 Development of sea protocol : Sea protocols play an important role in horticultural exports because they facilitate cost-effective, large-volume, long-distance transportation, while retaining produce attributes during the transit period. ICAR-Central Institute of Subtropical Horticulture (CISH), Lucknow has developed specialized sea protocols for mango and banana using innovative organo-peptides and lipids. CISH METWASH, an organic wash formulation was developed to increase the shelf life of mango upto 32 days and banana upto 47 days at 17°C and 13°C according to the container. This innovation resulted in the removal of chemicals such as Bavistin and Sodium hypochlorite traditionally used in the export protocols of the above fruit crops. This protocol has been successfully validated in banana and mango for large-scale sea-route export.

Similarly, the export of pomegranate from India to the USA resumed through successful trial shipments by both air and sea after a 2018 ban, following the new USDA-APHIS operational work plan that mandated surfactant wash, surface disinfection, irradiation, and proper packaging. The fruits were pre-cooled, graded, crown-cleaned, and subjected to mite wash with surfactant, a second wash with sodium hypochlorite (100 ppm), normal water wash, drying, packaging in CFB boxes, and they were irradiated at a minimum absorbed dose of 400 Gy before air shipment. Since air shipment costs are high, a dedicated sea-shipment protocol was developed by ICAR-National Research Centre for Pomegranate (NRCP), Solapur to facilitate economical export to distant markets, which reduces transportation costs by one-third and enhances the export competitiveness of pomegranate from India.

To expand this success, developing commodity-specific sea protocols for other horticultural crops must be prioritised, as sea freight reduces costs compared to air shipment. Such protocols can be developed in collaboration with shipping lines, reefer container service providers, ICAR and APEDA, which will help to determine ideal harvest maturity and handling conditions. Rapid trials at strategically important Indian ports are urgently required, as wider adoption of sea-shipment protocols will significantly

enhance India's horticultural trade competitiveness and enable the country to compete more effectively in global markets. This will go a long way in promoting trade.

5.2.5 Micro irrigation : Agriculture is the main user of about 80% of the total freshwater in India. Growing population, urbanisation, industrialisation and economic progress are the main reasons for diversion of water to non-farm sectors. Rising cropped area, cropping intensity, climate change, etc., further pose pressure on groundwater, and availability is declining. Micro Irrigation (MI) is a suitable option to enhance water use efficiency, thereby increasing yield and promoting sustainability.

With the launch of PM Krishi Sinchayee Yojana (PMKSY) from 2015-16, significant progress has been made to cover the area under MI and horticulture crops. Presently, a total of 16.73 Mha area is under MI in 2023-24. In the past 10 years, preference has been given to cover a large area under horticulture. Data show that over the year substantial area under horticulture crops has been brought covering 685 thousand hectares (62% of total MI) in 2022-23, from merely 1.9 thousand hectares (0.33%) in 2015-16 (Table 6).

Survey findings have shown that MI technology has the potential to reduce irrigation cost by 20-48% with an average of 32.3%. The average electricity consumption is reduced by 10-17%. Fertiliser saving is also noticed from 7-42% with an average of 28% (GAPL, 2014). The average yield of fruits and vegetables increased about 42.3% and 52.8%, respectively, mainly due to crop spacing, judicious use of water and other inputs, etc. The overall benefits accrued from the MI are reflected in the income increase of the farmers. Adoption of MI across surveyed states reported an increase in income by 20-68% with an average of 48.5%.

Table 6. Area under micro irrigation in horticultural crops

Year	MI area under horticultural crops (thousand ha)			
	Drip	Sprinkler	Total	Per cent of total MI area
2015-16	1.434	0.414	1.848	0.33
2016-17	151.482	8.580	160.62	19.06
2017-18	195.160	34.781	229.941	21.92
2018-19	173.396	21.250	194.646	16.80
2019-20	436.754	151.200	587.954	50.08
2020-21	72.945	118.317	191.262	20.40
2021-22	233.230	125.954	359.184	35.38
2022-23	425.711	259.191	684.901	62.14
2023-24	368.244	276.513	644.757	56.49

Source: GAPL (2014) <https://pmksy.gov.in/microirrigation> (accessed on 22 October 2025)

5.2.6 Cold storage and cold chains : Cold storage and cold chain infrastructure play a crucial role in reducing post-harvest losses and ensuring the quality of perishable produce. These facilities are supported mainly through government schemes by providing credit-linked subsidies in India. The “Integrated Cold Chain and Value Addition Infrastructure (ICCVA)”, commonly called the Cold Chain Scheme (2008) has been playing a major role in the development of cold chains in the country. The cold chain scheme has now become a component of Operation Greens of PMKSY from 2022. In addition, the National Centre for Cold-chain Development (NCCD) continues to play a vital role in creating frameworks for public-private partnerships and ensuring sustainable growth in cold chain infrastructure. Additionally, the government has allocated Rs 65.20 billion (till March 2026) for building 50 Multi-Product Food Irradiation Units under the ICCVAI. The significant allocation reflects the government’s commitment to expanding the cold chain infrastructure. Besides, the government has helped in creating cold storage across states of India. These cold storages have benefited in avoiding post-harvest losses in potatoes and many horticultural crops and assured a regular supply of horti-products throughout the year.

5.2.7 Export market opportunities for GI products : The Geographical Indication (GI) tags can safeguard products possessing unique qualities, reputation, and characteristics attributed to their geographical origin. By granting a GI tag, the law not only secures products against misuse or false claims but also motivates farmers to preserve traditional cultivation methods and maintain quality standards (WIPO, 2019). This, in turn, enhances economic value, supports livelihoods and agricultural heritage (Devi *et al.*, 2021). Thus, GIs in agriculture function as both an economic tool and a cultural safeguard, ensuring the community benefits from the reputation they have built over centuries. India, with its diverse agro-climatic zones, has a rich repository of GI-tagged horticultural crops. A total of 148 horticultural crops/products have been provided with GI tags, of which 61 are for fruits, 15 for vegetables, 30 for spices including chillies, 7 flowers, 19 plantation crops, and the remaining are for MAPs (CGPDTM, 2025). The government has placed significant emphasis on connecting FPOs, FPCs and exporters with international business communities to establish an export hub. Several virtual buyer-seller meetings have been organised in the past years to brief about GI products from India. This meeting on GI products serves as a platform for interaction between Indian exporters and importers from importing countries.

5.3 Policy and Market Support

5.3.1 Mission for Integrated Development of Horticulture (MIDH) : The MIDH is a centrally sponsored scheme for the holistic growth of the horticulture sector in India. While the GoI contributes 60% of the total outlay for developmental programmes, states contribute the remaining share (40%). In the North Eastern and Himalayan States, the central contribution is 100%. Similarly, for the development of bamboo and programmes of NHB, Coconut Development Board (CDB), Central Institute for Horticulture (CIH), Nagaland and the National Level Agencies (NLA), GOI contribution is 100%. The

MIDH also works closely with the National Mission on Sustainable Agriculture (NMSA) towards the development of MI for all horticulture crops and protected cultivation on farmers' fields.

5.3.2 Clean plant programme (CPP) : Despite being a leading producer of fruits like bananas, mangoes, pomegranates, and papayas, India has been struggling to meet global standards for export. One of the key factors behind this disparity is the diseased and substandard quality of planting materials. In a transformative move to maximise export potential, the GoI approved CPP in 2024. Under the programme, nine Clean Plant Centres (CPCs) have been approved with a sanctioned budget of Rs 17.66 billion. Funded under MIDH with ADB support, 3 CPCs have been established in Maharashtra with a cost of Rs. 3 billion in Pune (grape), Nagpur (oranges), and Solapur (pomegranate). This initiative is set to revolutionise the horticulture sector in India and to set new standards for excellence and sustainability. The programme is to address critical issues in horticulture and provide access to high-quality, virus-free planting materials and 8 crore disease-free seedlings to farmers annually. This will not only enhance productivity but also improve the quality of harvested produce and fetch better market prices and income for farmers.

5.3.3 Mechanisation of horticulture : Horticulture mechanisation is aimed at improving farm efficiency, reducing the drudgery of the farm workforce, and making quality production on a sustainable basis. Under the Sub Mission on Agriculture Mechanisation (SMAM), sufficient provision should be made to provide financial assistance for the purchase of machine/developing of a custom hiring centre in favour of the horticulture sector. Assistance for horticulture mechanisation should be available to farmers, SHGs, and women farm groups, who are engaged in the cultivation of horticultural crops. State Horticulture Mission (SHM) can enter into MoU with such associations/groups to ensure proper upkeep and maintenance of the machines and tools.

5.3.4 Market linkage and price fluctuations : The horticulture marketing chain encounters significant challenges primarily due to the perishable nature of its products, complicating efficient storage and transportation. Inadequate logistics and insufficient storage facilities exacerbate delays and wastage. Cold storage units are predominantly located in Uttar Pradesh, West Bengal, Punjab, and Gujarat, leaving major horticultural regions such as the southern states and the North East with a shortage of these essential facilities. Crops like tomatoes, potatoes, and onions (TOP crops) have a limited shelf life, and the lack of adequate storage solutions leads to annual price volatility. To address these issues, there is a need to establish multipurpose cold storage facilities across India. While the initial investment for such infrastructure is substantial, the potential long-term benefits are significant. Besides, the horticulture sector is hindered by underdeveloped Farmer-Producer Organisations (FPOs), which are crucial for connecting farmers with markets, financing, and technical support. These deficiencies restrict farmers' ability to fully capitalise on available opportunities.

5.4 Strategy to Reduce Import Dependency

A peculiar shift has been occurring in the horticultural trade. Despite rising production of horticultural products, imports of fresh fruits and spices have shown a rise in the past few years. For example, the spice imports increased almost 18% within the past five years, from Rs 101.87 billion in 2019-20 to Rs 120.51 billion in 2023-24, showing a CAGR of 6.4%. The key items of import include pepper, clove, spice oils & oleoresins, and mint products. The import budget on fresh fruits (consisting of apples, oranges, grapes, kiwis and cherries, etc.), increased 8-fold in the past 15 years from Rs 28.43 billion in 2009-10 to Rs 226.64 billion in 2023-24. This divergence between demand and actual production encapsulates the core of horticulture's production paradox. An attempt should be made to reduce import dependency through boosting domestic production, reducing post-harvest losses, and providing support to farmers under various schemes to build a capacity for Atmanirbhar Horticulture.

To reduce fruit and vegetable import dependency, India can boost domestic production through better technology and irrigation practices, cutting post-harvest losses, improving marketing infrastructure, and focusing on schemes for infrastructure development. Schemes like PM-KISAN can be used to promote growing more fruits & vegetables to reduce reliance on specific imports. Price assurance for crops, providing subsidies (seeds, machinery) and offering crop insurance can be useful strategies. Developing better domestic marketing systems, quality control and standardisation and raising consumer awareness about their own fruits and vegetables could be other meaningful options. These strategies could be adapted for reducing imports for other commodities like spices, MAP and other products.

5.4.1 Crop group-wise strategies to reduce import

Fruits: India has often been importing fresh and processed fruits, especially apples, oranges, almonds, kiwis and walnuts in the past few years. The reduction in imports requires boosting domestic production of high-demand temperate and subtropical fruits through high-yielding and climate-resilient varieties, improved orchard systems and efficient post-harvest logistics. Strengthening cold-chain and controlled-atmosphere storage for apples, walnuts and kiwis will reduce seasonal import dependence.

Vegetables: Reducing imports of processed and selected fresh vegetables requires improved processing-grade varieties, strengthening processing infrastructure and efficient value chains, particularly for onion and other processing vegetables. Enhancing domestic vegetable-processing capacity will directly reduce imports of vegetable-based products.

Spices: Despite being a leading producer and exporter, India imports (over ₹100 billion annually) several spices like black pepper, clove, asafoetida, cinnamon/cassia, cumin and cardamom. Import reduction should focus on increasing area, augmenting productivity, adopting improved varieties and quality planting material and better post-harvest practices. For spice oils/ oleoresins, mint and mint products, emphasis

should shift to processing-oriented cultivation, quality standardization, and value addition. Asafoetida and saffron require crop-specific strategies due to their total import dependence.

Plantation Crops: India incurs huge foreign exchange on imports of cashew and cocoa products. The import substitution strategy requires area expansion, adoption of high-yielding planting material, and strengthening domestic processing. Contract farming and industry partnerships can accelerate production growth and secure supply chains.

Medicinal & Aromatic Plants (MAPs): Continuance of imports of medicinal and herbal plant products highlights rising domestic demand. Reduction strategy should focus on increasing domestic production through cultivation of quality planting material, cluster-based production, and ties with herbal, pharma and nutraceutical industries, thereby strengthening bio-economy.

Flowers: To reduce imports of temperate bulbous crops, annual flowers and potted plants, India should expand greenhouse and controlled-environment cultivation of high-value flowers, supported by superior planting material, efficient post-harvest handling and a strengthened domestic supply chain. Research should be strengthened to develop flower crop varieties as per market demands.

6. CHALLENGES TO ENHANCE HORTICULTURE PRODUCTION AND EXPORTS

The horticulture industry is globally experiencing a major shift across production, processing and value addition fronts driven by technical change, rising income, shifting consumer preferences, increased health awareness and export opportunities. Additionally, India's growing population is projected to reach about 1.7 billion by 2050, resulting in substantial pressure on the horticulture sector to meet the rising demand. This demand is expected to be 700 Mt (i.e. 283 Mt fruits and 417 Mt vegetables) in 2047-48 by NITI Aayog (2024). Furthermore, the rising demand for processed products, where 1% increase in processing equates to an extra 2.5 to 3.0 Mt of fruits and vegetables, combined with rising export demand, will further push total demand to about 900 Mt by 2047-48. Subsequently, the challenge over the next three decades is to almost double fruit & vegetable production from the current level. Having the wide diversity of horticultural flora, agro-climatic conditions, low cost of labour and geographic condition, India has an edge over other producing countries to expand its export basket and exploit the hitherto untapped potential of its indigenous germplasm. Moreover, the horticulture sector is facing the following challenges related to production and export.

6.1 Low Productivity

Despite being a global leader in production, the productivity of horticultural crops in India is low compared to many leading producing countries. In 2023, the average productivity of fruits was 15.1 t/ha in India as compared to major fruit-producing

countries [(Indonesia (27.1 t/ha), USA (20.9 t/ha), Turkiye (20.3 t/ha), Brazil (18.4 t/ha)]. A similar gap exists in vegetables, where India's yield 15.8 t/ha falls far short of many leading countries [Turkiye (41.7 t/ha), USA (36.6t/ha), Russian Federation (29.4 t/ha), China (20.1 t/ha)] (Gol, 2023). These disparities in yield are mainly due to poor quality planting materials/ seeds, low adoption of modern technologies, and degraded natural resources. Addressing these issues needs a strategic approach to enhance the yield of marginal and small farmers engaged in horticulture production. Other reasons for low yield are low organic matter in the soil and a lack of proper irrigation facilities.

6.2 Post-harvest Losses

Post-harvest losses in India's horticulture sector remain significant, with an estimated 10-40% of total production lost between production and consumption. These losses occur due to a combination of factors like inadequate infrastructure, poor technical knowledge in production management, and market failures. The existing cold storage facilities (about 75% of total) are primarily suitable for potatoes, limiting their utility for diversified horticultural crops. About 20-30% post-harvest losses have been reported in onion storage. Besides the economic loss to farmers, these losses threaten national food security and environmental degradation.

6.3 Value Addition

Horticultural crops possess an inherent advantage for value addition due to their high degree of processing ability, profitability and potential for trade. However, a significant gap remains between production and processing. While developed countries process 40-80% of their horticultural production, India's processing levels remain below 10%. This disparity is caused by a combination of factors such as fragmented supply chains, limited processing-grade raw materials, and a high degree of both physiological spoilage and pathological spoilage.

6.4 Changing Quality Focus and Global Competition

Horticultural crops are crucial for health and nutrition as being rich in essential nutrients and minerals. With the rising per capita income, consumers are becoming health-focused and quality-conscious. Also, there is a growing demand for high-quality processed products. With changes in global trade, India must produce horticultural crops that meet global standards.

6.5 Climate Change

Climate change poses a formidable challenge to the horticulture sector, with greenhouse gas-driven temperature increases, triggering heat stress, erratic rainfall, and novel pest outbreaks. Shift in seasonal temperatures could alter agro-ecological zones,

creating new regions suitable for horticulture. Some effects of climate change noticed in horticultural crops such as fruit fly in guava, mealy bug in papaya and vegetables is becoming alarming. Crops like apple, peach, plum, and apricot, which need low chilling temperature also showing signs of decline in yield in their natural growing areas due to rise in temperature during the critical growth period.

6.6 Market and Economic Factors

Information asymmetry significantly hamper the horticulture sector, as growers often needed the required information for crop selection. This leads to localized gluts and shortages. The traditional marketing system, burdened by excessive intermediaries, further erodes the farmer's share of export value while increasing transaction costs. In the absence of procurement guarantees, the farmers remain highly vulnerable to market volatility. This instability is compounded by government-imposed export bans/restrictions designed to curb domestic inflation, which undermines the reliability of Indian suppliers and long-term trade partnerships.

6.7 Backward Linkage

Backward linkage for perishables horticultural crops remains fragmented and inefficient, leading to inconsistent quality and suboptimal management. This structural weakness is increasingly problematic as importing nations tighten their regulations over the years. There is now an increasing global emphasis on production norms and farm-level traceability –standards that India's unorganized production base currently struggles to meet.

6.8 Training and Skill at Farm Level

Horticulture exports face significant problems due to farmers' limited familiarity with GAP, proper input management and other management practices. The unregulated use of pesticides is particularly problematic, often leading to chemical residues that block international trade. To overcome these, training and capacity building of farmers on GAP, safe pesticide usage, nutrient management, and key pre-harvest practices are required to ensure quality produce.

6.9 Phytosanitary Challenges

Sanitary and phytosanitary measures are fundamental to protect public health, food safety and biodiversity. However, the Indian horticulture industry continues to face systemic hurdle that impede international trade of fruits & vegetables. The key primary challenges include inadequate pest management, excessive pesticide residues, and a lack of post-harvest infrastructure. Besides, limited traceability, low certification awareness among smallholders, and inconsistent domestic enforcement remain barrier to global market integration.

7. RECOMMENDATIONS

1. Strengthen the breeding programme of the horticultural crops, for which seeds and planting materials are imported in high quantity, and minimize the burden of royalty through specific licensing

- ◆ Emphasize the development of improved varieties and hybrids in import-dependent horticultural crops — vegetables: coriander, carrot, beetroot, gherkins, parthenocarp cucumber; fruits: papaya, apple, walnut, hazelnut, kiwifruit, olive, oil palm, date palm, blueberry; flowers: tulips, liliun, annual flowers, and potted plants.
- ◆ Introduce a streamlined, one-time licensing mechanism for globally competitive horticultural crop varieties/hybrids currently being imported, to make them freely accessible to farmers and reducing repeated imports and ongoing royalty burdens.
- ◆ Emphasis should be on the development of exportable varieties targeting the destination countries considering consumer preferences, nutrition value and shelf-life.

2. Promote a sustainable, efficient and safe production system aligned with global concerns for food safety and traceability

- ◆ Promote adoption of Bharat GAP-compliance packages (good agricultural practices) in horticultural crops to improve field-level compliance and enhance export readiness.
- ◆ Develop production protocols for organic/natural farming and facilitate the certification to the growers.
- ◆ Strengthen the traceability systems across the value chain, including organic produce to assure food safety and sustainability.
- ◆ Develop sea route protocols for long duration consignments of important fruits such as banana, pomegranate, mango etc., to minimize the export cost.

3. Focus on the development of processing and value-added products with high export demand

- ◆ Develop processing-specific varieties in major horticultural crops such as tomato (paste/concentrate), onion (dried flakes/powder), potato (chips, French fries), chilli (high oleoresin), turmeric (high curcumin) and marigold (high lutein and zeaxanthin).
- ◆ Promote the production of nutraceuticals, cosmeceuticals and high-value bioactive compounds derived from horticultural crops *viz.* unmarketable fruits, processing wastes, spices, medicinal & aromatic crops, flowers.
- ◆ Promote linkages with food, pharmaceutical and cosmetic industry partnership for developing innovative uses of horticulture-based processed and value-added products.

4. Streamline the registration and regulation of pesticides to address the limited options for plant protection in medicinal & aromatic plants, spices, fruits and vegetable crops to have a more label claim pesticide

- ◆ Generate crop specific data on pesticides for effective management of insects and pests.
- ◆ Facilitate the Central Insecticides Board & Registration Committee's (CIBRC) for providing the data on new and safer agrochemicals for registration.
- ◆ Crop grouping approaches may be implemented to streamline label claims for maximum crop groups for inclusion in CODEX norms. This will facilitate to optimizing residue testing and standardize maximum residue limits (MRLs).

5. Promote cluster-based export development, public–private partnership (PPP) models and institutional support

- ◆ Promote production aggregation through FPOs and cooperatives and develop crop-specific, cluster-based export roadmaps for the top 20 horticultural crops with integrated logistics support. Encourage PPP models to bridge infrastructure and technical knowledge gaps.
- ◆ Facilitate the establishment of procurement and collection centres in major horticultural production clusters to streamline aggregation and export of produce, similar to organized marketing arrangements adopted in countries such as Taiwan
- ◆ Provide targeted awareness, extension and training programmes on GAP, pre-and post-harvest management and export compliance, along with government financial support (incentives/subsidies, low-interest loans and insurance coverage) for farmers and exporters to enable technology adoption and infrastructure creation.

6. Strengthen infrastructure, logistics and digital traceability to minimize the post-harvest losses and improve supply chain efficiency

- ◆ Promote modern pack-houses, cold storage, refrigerated transport, reefer vans and cargo infrastructure/facilities to reduce pre- and post-harvest losses and extend shelf life of produce reaching domestic and export markets.
- ◆ Adopt digital traceability systems such as RFID (radio frequency identification), AI and blockchain-based sensors for temperature, ethylene and humidity monitoring, integrated with QR systems and *PM Gati Shakti* digital infrastructure to ensure seamless farm-to-market tracking, food safety compliance and improved multimodal connectivity for horticulture exports.

7. Exploration of new destinations for horticultural export to reduce the dependency on traditional destinations and future risks

- ◆ Build a robust national and region-level market intelligence system through inter-ministerial collaboration to provide real-time data on demand, prices, consumer

preferences, SPS/MRL requirements, seasonality and emerging risks. Use this intelligence to new export markets beyond traditional destinations, particularly for high-value, niche, organic and GI-tagged produce.

- ◆ As hybrid seed production is costly in many countries, India can serve as a key supplier for importing countries. Leverage India's strength as a major hub for vegetable hybrid seed production particularly for solanaceous vegetables and cucurbits by simplifying export policy to promote seed exports.
- ◆ Establishment of a national framework and mechanism for organic seed production and certification aligned with international standards/requirements (EU and USA) to tap the growing demand for organically produced seeds in the global markets.
- ◆ Showcase of high value commodity in emerging destinations during International trade fair such as pomegranate, litchi, jamun, mangosteen, guava, brinjal, okra, bitter gourd, bottle gourd, pointed gourd, sponge gourd, teasel gourd, spices, drumstick, green chilli, fox nut, and value-added products based on jack fruits, bael, tamarind, aonla etc.

8. Enhancing functional collaboration among stakeholders in the horticultural research and development sectors to boost exports

- ◆ Build a platform of information exchange among different ministries, commodity boards (i.e. spices board, turmeric board, coconut development board, tea board, coffee board, etc.), APEDA, National Horticulture Board (NHB), CSIR institutes, Agricultural Universities, private institutions, FPOs/FPCs etc.
- ◆ Promote vertical information among producers, manufacturers, exporters along with horizontal collaboration among farmers through FPO, SHG and cooperative societies to achieve the required quantity as per the international demand.

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