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Transforming Horticulture for Sustainable Development: Research and Policy Options*

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ABSTRACT

India's horticulture sector has emerged as a significant growth driver, contributing about 34.45 per cent to the agricultural GDP while occupying only 12.5 per cent of the cropped area. The sector has grown tremendously, with horticultural crop production reaching approximately 349.67 million tonnes in 2021-22, up from 92 million tonnes in 1990-91. This growth is driven by India's diverse agro-climatic conditions, enabling year-round cultivation of over 40 horticultural crops, making India the world's second-largest producer of fruits and vegetables. Despite this progress, malnutrition, climate change, and post-harvest losses persist. India's per capita availability of horticultural crops remains close to the WHO-recommended intake, yet many households cannot afford their daily nutritional needs, leading to widespread malnutrition. As the population grows, the demand for nutritionally secure food will increase significantly, emphasizing the need for sustainable horticultural practices. The paper outlines the sector's growth trajectory across five phases, highlighting the role of policy support and technological advancements. From home gardens in the pre-independence era to large-scale commercial production in the 21st century, the sector has evolved significantly. The paper presents the case studies of widely adopted technologies contributing to the total economic surplus of rural farm households. Regional variations and market vulnerabilities that affect the stability of technologies are also highlighted. To ensure the sector's sustainability, the paper proposes research and policy options focusing on climate-resilient technologies, efficient water use, integrated pest management, value chain integration, and market stabilization strategies. By addressing these challenges, the horticulture sector can enhance its contribution to India's agricultural GDP, food security, and overall sustainable development.

Keywords: Sustainable horticulture, climate-resilient agriculture, technology adoption, crop diversification, agricultural policy

JEL codes: Q12, Q13, Q16, Q18, O33

I

INTRODUCTION

The horticulture sector in India has emerged as a major growth driver in recent decades, thanks to its potential for higher remuneration than food grains and other crops. Total horticultural crop production reached approximately 349.67 million tonnes (MT) in 2021-22, a nearly four-fold increase from 92 MT in 1990-91. By 2012-13, horticultural crop production had surpassed total food grain production and continues to do so, with an anticipated growth rate of 4.8 per cent. Horticulture contributes about 34.45 per cent to the agricultural GDP while occupying only 12.5 per cent of the total cropped area.

India's agro-climatic suitability gives it a unique comparative advantage, allowing for cultivating a wide variety of horticultural crops throughout the year across

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three growing seasons. India is home to more than 40 horticultural crops and is the world's second-largest producer of fruits and vegetables. It leads globally in the production of several horticultural crops, including bananas (26%), mangoes (46%), limes and lemons, papayas (44%), ginger, and okra. India is also the second-largest producer of potatoes, onions, cauliflowers, and cabbages, among other crops, contributing 13 per cent to global fruit production and 21 per cent to global vegetable production (Anonymous, 2021).

Notably, the horticulture sector has demonstrated phenomenal growth potential since the 1950s. However, it only began receiving adequate budgetary and policy support from the VII Plan period. Horticultural crops assure higher profitability compared to other crops, are labour-intensive, and provide opportunities for higher employment generation, nutritional security, increased export earnings, and value addition

However, it is important to note that, despite being the world's largest producer, the per capita availability of horticultural crops in India has been approximately 146 g/day for fruits and about 286 g/capita/day for vegetables, which is close to the recommended standard dose by WHO. Yet, it is a well-known fact that a large number of Indian households cannot afford their daily intake, leading to malnutrition and undernourishment. With the projected population growth, India's malnourished population may reach around 230 million. Based on estimated population growth, the demand for nutritionally secure food is anticipated to grow at 7 per cent. Therefore, the demand for natural nutritional supplements through fruits and vegetable products is estimated to increase by 100-300 per cent in the coming years (ICAR, 2015), not to mention the additional challenges posed by climate change and the changing demand for value-added products.

In light of the rapidly changing climate, diminishing water resources, and other pressing challenges, it is imperative to ensure that horticulture remains sustainable for the farm, the environment, and the growing population. This paper offers insights into the research and policy strategies needed to make horticulture in India a sustainable endeavour.

II

STATUS AND GROWTH TRAJECTORY OF HORTICULTURE

The growth pattern of the horticultural sector significantly differs from that of the agricultural sector. Post-independence (in the 60s and 70s), India focused on achieving self-sufficiency in food grain production. It wasn't until the late 80s that the need for crop diversification toward other groups like oilseeds, commercial crops, and horticulture was recognized. Economic reforms and policies, such as the liberalization of seed import policies in the 1990s, accelerated crop diversification in favour of horticulture (Chand *et al.* 2008). This shift was driven by increased domestic demand for high-value food commodities and the need to cater to export markets.

The growth and development of the horticulture sector can be divided into five distinct phases:

1. Pre-independence horticulture: characterized by home gardens for aesthetic and social values.
2. Second phase (1948-1980): commercial production systems started for a few commodities, and institutional backing was initiated to support development, although the focus remained on cereal crop production.
3. Third phase (1980-1992): consolidation of institutional support for its role in improving nutritional security.
4. Fourth phase (1993-2000): characterized by the shift from rural confines to commercial production, with enhanced plan allocation and strong institutional support for research and development.
5. Fifth phase (2001 onwards): characterized by innovations and large-scale adoption of technologies like micro-irrigation, protected cultivation, and precision farming—a strategic approach to smart horticulture, integrating skills and knowledge for higher output through innovative methods (Singh, 2014).

This analysis primarily focuses on the fifth phase, mainly covering 2011 to 2020. During this period (2001-02 to 2020-21), the total area under horticultural crops increased from about 16.5 million ha to 27.74 million ha, at an annual growth rate of about 2.39 per cent. Correspondingly, the total production of horticulture commodities increased from 146 million tonnes to 334.60 million tonnes at a yearly growth rate of 4.39 per cent. In comparison, food grain production increased from 213 million tonnes to 308.65 million tonnes during the same period. The production growth in horticulture was led by area expansion, though productivity growth appeared positive at about 1.74 per cent. This indicates a 65 per cent increase in area and a 39 per cent increase in productivity in 2020-21 compared to the base year of 2001-02 (Table 1).

Thus, the growth of the horticultural sector can be termed synergistic, driven by both area expansion and productivity gains. Between 1990-91 and 2014-15, the area under food grains reduced by four percentage points to reach 51.34 per cent, while the area under fruits and vegetables increased from 3.7 per cent to 5.0 per cent, and that of cotton and sugarcane from 4 per cent to 2 per cent and 6.3 per cent to 2.77 per cent, respectively (Jha *et al.*, 2019).

The productivity of horticulture crops showed a substantial increase from 8.8 tons per hectare to 12.3 tons per hectare between 2000 and 2020. This can be attributed to the successful implementation of government-supported schemes like the NHM. During the same reference period, food grain productivity increased from 1.7 tons per hectare to 2.3 tons per hectare (Kumar *et al.*, 2020).

TABLE 1. STATUS OF HORTICULTURE CROPS

Year	Area (million ha)	Production (million MT)	Productivity (MT/ha)
2001-02	16.59	145.79	8.79
2005-06	18.71	182.82	9.77
2010-11	21.83	240.53	11.02
2016-17	24.92	295.16	11.8
2020-21	27.48	334.60	12.2
Increase over 2001-02 (%)	65.6	129	38.8
CAGR	2.69	4.47	1.74

Between 2016 and 2020-21, the increase of 2.5 million hectares in area contributed to a production growth of 39.4 million tonnes, while the productivity growth was 0.39 tonnes per hectare. This indicates that the growth trajectory of horticulture continues to be more area-driven than productivity-driven. It is crucial to understand the underlying factors for sustaining high growth in India's horticulture sector in the future.

Between 2001-02 and 2020-21, the horticultural crop sector gained over 11.8 million hectares and contributed 184.8 million tonnes. Vegetable crops gained 4.7 million hectares, contributing to 11.7 million tonnes, followed by fruits in terms of area and spices in terms of production. However, regarding percentage change in area and production, flower crops (commercial floriculture) showed substantial gains, followed by spices and vegetables. The compound annual growth rate (CAGR) for the same period also indicates significant signals of crop diversification towards flowers and commercial crops like spices (Table 2). This can be attributed to the growing awareness of the commercial value of horticultural enterprises. The National Horticulture Mission (NHM) has also emphasized enhancing flower cultivation.

TABLE 2. CHANGING PROPORTION OF HORTICULTURAL CROPS FROM 2001-02 to 2020-21

Crop Group	Increased Area (Mill Ha)	Percent Change	CAGR (2001-02 to 2020-21)	Increased Production (Mill M tones)	Percent Change	CAGR (2001-02 to 2020-21)
Fruits	2.803	67.9	2.77	59.366	137.69	4.66
Vegetables	4.703	76.4	3.03	111.783	126.08	4.39
Flowers	0.216	203.8	6.02	2.445	457.01	9.46
Spices	1.957	78.3	3.09	8.094	267.75	7.09
Plantation	1.393	48.7	2.11	7.171	75.82	3.01
Total Horticulture	11.781	75.1	2.99	184.406	122.78	4.31

III

REGIONAL VARIATIONS AND CONTRIBUTION OF STATES TOWARDS HORTICULTURE

Expanding area under horticultural crops suggests a positive shift in crop diversification from traditional non-horticulture crops. Crop diversification should be viewed from two perspectives: horizontally, where crops are shifted to more remunerative ones, and vertically, where value addition is emphasized. Diversification also includes the introduction of new crops that have not been grown in the region. The pattern of diversification has shown significant changes across states.

It is generally believed that the diversification pattern based on the area allocated under different crops indicates that the northern region (states like Punjab, Uttar Pradesh, and Haryana) specializes in traditional crops such as rice and wheat. The high yield of these crops and favourable rainfall contribute to this specialization, reducing the incentive to diversify. Moreover, the minimum support price for traditional crops incentivizes farmers in these areas to produce rice and wheat instead of diversifying towards horticulture crops.

TABLE 3. STATE-WISE CHANGES IN THE AREA AND PRODUCTION OF FRUITS DURING 2011-12 TO 2020-21

States	Area in 2020-21 ('000 ha)	CAGR (2011 to 2020)	Production in 2020-21 ('000 MT)	CAGR (2011 to 2020)
Andhra Pradesh	737	0.943	17708	6.05
Assam	147	0.297	2251.9	1.98
Bihar	365.94	2.041	4636	1.62
Chhattisgarh	222	1.840	2483	4.70
Gujarat	426	1.897	8243	0.92
Haryana	71.26	4.250	1231.6	9.97
Himachal Pradesh	234.7	0.928	624	5.29
J&K	335	-3.030	2237	-0.41
Jharkhand	105.28	2.320	1285	4.22
Karnataka	425.7	1.363	7995	2.21
Kerala	308.14	0.403	1922.18	-2.59
MP	411.07	9.964	8478	9.59
Maharashtra	827	-6.149	1178	-19.68
Odisha	366.5	1.116	2782	2.59
Punjab	102.7	3.692	2202	4.49
Tamil Nadu	311	-0.648	5433	-4.42
Uttar Pradesh	504	4.107	11231	6.84
West Bengal	282	2.702	3658	1.82

An earlier study (Jha *et al.*, 2019) suggested positive and significant growth in the area and production of horticultural crops across states, especially when the NHM was active (between 2003/4 and 2016/17). However, some variations can be observed between 2011 and 2020 (Table 3). This table provides a detailed overview of the changes in area and production of vegetables across different states in India during the period 2011-12 to 2020-21, highlighting both the area ('000 ha) and production ('000 MT) along with their respective Compound Annual Growth Rates (CAGR).

From 2011 to 2020, Andhra Pradesh (AP) led in terms of the highest area and production of fruits, followed by Gujarat and Bihar. AP also led in fruit production, followed by Uttar Pradesh and Gujarat. However, the compound annual growth rate (CAGR) for this period indicates that Madhya Pradesh (MP) registered nearly double-digit annual growth in the area under fruits, followed by Haryana, Uttar Pradesh, and West Bengal. Both Haryana and MP showed roughly double-digit growth rates in fruit production during this period. In contrast, Maharashtra showed a negative growth rate in production and area, requiring further investigation.

TABLE 4. STATE-WISE CHANGES IN AREA AND PRODUCTION OF VEGETABLES DURING 2011-12 to 2020-21

States	Area in 2020-21 (‘000 ha)	CAGR (2011 to 2020)	Production in 2020-21 (‘000 MT)	CAGR (2011 to 2020)
Andhra Pradesh	227	-10.14	6585	-5.84
Assam	301	1.24	3628	1.77
Bihar	912	0.62	17849	1.39
Chhattisgarh	491	3.40	6865	4.13
Gujarat	731	3.51	14505	3.74
Haryana	334.7	-0.62	5883	1.50
Himachal Pradesh	91.78	0.77	1875	1.85
J&K	60	-0.49	1339	-0.41
Jharkhand	310	1.74	3792	-0.29
Karnataka	490	0.77	7846	0.24
Kerala	98	-4.10	3052	-1.71
MP	1090	7.98	21329	7.78
Maharashtra	962	4.99	14212	4.94
Odisha	673	-0.25	9422	-0.10
Punjab	287	4.89	5856	4.77
Tamil Nadu	322	0.51	8519	-0.62
Uttar Pradesh	1307	4.37	29160	4.62
West Bengal	1511	1.28	30330	2.62

Regarding vegetables, West Bengal showed the highest area and production during 2020-21, followed by Uttar Pradesh and Madhya Pradesh (MP). Bihar, typically

considered an important state for vegetable production, ranked fifth in area and fourth in production. MP once again demonstrated comparatively larger area and production and, notably, the highest annual growth rate in both area and production of vegetables from 2011-12 to 2020-21 (Table 4).

IV

EXPORT PERFORMANCE

The horticultural sector accounts for about 37 per cent of the total exports of agricultural commodities from India. Exports of horticultural commodities have increased eightfold since 2001, reaching ₹14,856 crore in 2015-16 and further to around ₹25,000 crore by 2021-22. A closer examination of the pattern and direction of exports over the years reveals a consistent trend, indicating that the country has yet to promote large-scale value addition.

Fresh onions represent a significant share of exports, accounting for around 15 to 20 per cent. Mango pulp leads among fruit products, while other processed products, such as dried and preserved vegetables, constitute about 25 to 30 per cent. Notably, the export basket largely comprises fresh produce and minimally processed products.

Regarding export destinations, India largely relies on countries like Bangladesh, Nepal, and the UAE, with some exports of fresh mangoes to the USA. Despite the harmonization processes led by the WTO, major export breakthroughs have yet to be achieved.

V

POLICIES AND GOVERNMENT SUPPORT FOR HORTICULTURE DEVELOPMENT

Based on the analysis thus far, it can be inferred that one of the significant contributors to horticultural development over the decades is the ever-expanding budgetary support, which grew from a mere ₹20 million in the IV plan period to over ₹14,500 million by the IX plan period, along with around 10 per cent of the budget allocated for focused research on horticulture (Singh, 2014). The increasing thrust of the government towards the horticulture sector is also evident from its share in the plan outlay for the agriculture sector, which increased from 3.9 per cent in the Ninth Plan to 4.6 per cent during the Twelfth Plan. Horticulture development was an integral part of the agricultural sector and did not receive special impetus until the end of the IV five-year plan. It was only since the VI plan that ₹24 crore was allocated for horticulture development, which increased to ₹1000 crore in the VII plan, ₹1400 crore in the VIII plan, and ₹16,000 crore in the XI plan. Besides the budgetary allocation, horticulture also received specific policy changes.

The introduction of appropriate development schemes such as the Mission Mode Integrated Development of Horticulture (MIDH) and adopting an end-to-end approach for increasing horticulture crop production and reducing post-harvest losses

appears to have substantially paid off in the sector's development. The horticulture sector focused on developing and disseminating improved technologies through integrated research and development approaches.

Ensuring the quality of seed and planting materials and enacting and revising the Seed Bill of 1984 marked the initial policy-level focus on horticulture. The Seed Policy 1988 focused on liberalizing the import policy, allowing high-quality planting material into the country. Furthermore, the union government concentrated on technological advancements, such as promoting high-density planting, integrated nutrient management strategies, organic farming, plasticulture, greenhouse/protected cultivation of flowers, and other high-value horticulture crops through appropriate financial incentives.

As a means of institutional support for promoting horticulture development, the Union government established the National Horticulture Board (NHB) in 1984, aiming at the comprehensive development of the horticulture sector. NHB is a pioneer institution providing technological, financial, and market intelligence services to farmers, processors, and consumers.

The National Horticulture Mission (NHM), a centrally sponsored scheme, was launched in 2005-06, with one of its major objectives being to increase horticulture production and double farmers' income. Before the NHM's launch, horticulture crop production was about 167 MT, from 9.7 per cent of the cropped area (18.5 million hectares); total food grain production was 198 MT, covering 63 per cent (120 million hectares) of the gross cropped area of the country. Post-NHM, horticulture registered a sharp rebound in production and acreage, far outpacing food grain production since 2012-13. Notably, horticulture productivity increased from 8.8 tonnes per hectare (TPH) in 2001-02 to 12.1 TPH in 2020-21, while total food grain productivity increased from 1.7 TPH to 2.5 TPH during the same period.

Other important policies include:

(i) National Mission for Sustainable Agriculture (NMSA): Aimed at defining strategies for climate adaptation and mitigation within the agriculture sector, focusing on rainfed areas. (ii) Promotion of Organic Farming: Environment-friendly, non-chemical-based farming that follows sustainable crop rotations using biological pesticides like neem, green manures, and decomposed organic matter. Despite the benefits, the total area under organic farming is much less than the net sown area of 140 million hectares.

- Paramparagat Krishi Vikas Yojna: Launched under NMSA to support organic farming via a cluster approach, encouraging farmers to reduce their dependence on chemical-based fertilizers and increase the use of more environmentally friendly cultivation methods to improve yield.
- Pradhan Mantri Krishi Sinchayee Yojana (PMKSY): Launched in 2015 to promote efficient irrigation practices and resource allocation in agriculture.

(iii) National Initiative on Climate Resilient Agriculture (NICRA): Launched in February 2011, aimed at making farmers self-reliant in climate change adaptation by improving soil health, livestock, natural resource management, and crop production. (iv) Mission for Integrated Development of Horticulture (MIDH): Launched during the 12th Plan for the holistic development of the horticulture sector in the country. MIDH integrates ongoing schemes such as the National Horticulture Mission (NHM), National Bamboo Mission, Horticulture Mission for Northeast and Himalayan States, National Horticulture Board, Coconut Development Board, and Central Institute for Horticulture, Nagaland.

Additional policies include:

- Crop Insurance: Launched in January 2016 as the Pradhan Mantri Fasal Bima Yojana to minimize risk and maximize insurance for farmers.
- Rashtriya Krishi Vikas Yojana (RKVY): A special Additional Central Assistance Scheme launched in August 2007 to orient agricultural development strategies. RKVY covers all sectors, including horticulture, fisheries, forestry, wildlife, plantation, agriculture marketing, research, and education. Some sub-schemes under RKVY include Bringing Green Revolution to Eastern India (BGREI), Integrated Development of 60,000 Pulses Villages in Rainfed Areas, Promotion of Oil Palm Initiative, and National Mission for Protein Supplements.
- Soil Health Card Scheme: Launched in 2015 to issue soil cards to farmers, helping them achieve good harvests by studying soil quality. The scheme aims to issue soil cards to about 14 crore farmers across India, providing a printed report every three years. However, only about one crore soil health cards have been issued so far, making it unlikely that the agriculture ministry's target of providing soil health cards to all 14 crore farmers by the end of 2017-18 will be met without proper planning.

5.1 Technology Dissemination, Spread, and Impact

Significant changes in the outlook of the Union Government and ICAR towards technology development, dissemination, and spread can be seen from 2006 onwards. There has been a paradigm shift in government policy towards Science & Technology (S&T). As a direct result of India being a signatory of the World Trade Organisation (WTO), the Trade Related Intellectual Property Rights (TRIPS) came into force. Consequently, ICAR adopted a technology development, production, and commercialization policy. In 2008-09, ICAR set up a three-tier system of technology commercialization through the World Bank-supported National Agricultural Innovation Programme (NAIP) and the subsequent Agribusiness and Incubation (ABI)

program in 50 out of 110 research institutions, focusing primarily on technology transfer through commercial licensing.

Since then, ICAR and its research institutions have commercialized over 2000 market-ready, regulatory-compliant technologies across the entire agriculture/horticulture value chain to entrepreneurs who ensure mass production and supply of these technology products to end users. Technology dissemination now follows a new format through technology transfer via KVKs, FPOs, individual entrepreneurs, or companies.

A variety of technologies, including improved varieties, hybrids, planting material, protected cultivation techniques, precision technologies, bio inputs, biofertilizers, biopesticides, and post-harvest value-added products, have all been disseminated for adoption by stakeholders along the value chain. The widespread adoption of these technological innovations in different horticultural crops has demonstrated a lasting impact on farm income and welfare.

Between 2009 and 2020, a total of 288 improved varieties/hybrids in horticulture (23 fruits, 155 vegetables, 38 spices, and 72 others) were developed and released by various ICAR research institutions (Malhotra, 2021). Budgetary support, backed by institutional reforms, has helped bring innovative technological outcomes that have revolutionized Indian horticulture. ICAR has also undertaken economic impact assessments of specific widely adopted technologies to capture the overall impact of technology dissemination across crops. Some successful case studies highlight the significance and sustainability of technologies in horticulture across the country.

Case 1: Technology Standardization for the Production of 'True Seed in Potato' (mid-1980s)

- The impact of potato technologies developed by ICAR-Central Potato Research Institute has been phenomenal. The crop has witnessed a 9.61-fold increase in area, a 35.15-fold increase in production, and a 3.66-fold increase in productivity from 1949-50 to 2020-21. In 1949-50, the area, yield, and production were 0.234 million ha, 6.59 t/ha, and 1.54 million tonnes, respectively. By 2020-21, the country produced 54.23 million tonnes of potatoes from 2.25 million ha with an average yield of 22.12 t/ha (NHB, 2019).
- Potato varieties developed by ICAR-Central Potato Research Institute are popular among farmers, covering nearly 95 per cent of the total area under potato. India produced approximately 45.87 million tonnes of potatoes annually during the triennium 2014-17, contributing ₹57,512 crore annually to the Gross Value Added (GVA) at current prices. The varieties developed by ICAR-CPRI contributed ₹54,636 crore annually during this period. Four varieties—Kufri Jyoti, Kufri Bahar, Kufri Pukhraj, and Kufri Chipsona 1—

covered around 75 per cent of the total area under potato (Kumar and Pal, 2020).

Case 2: Introduction and Standardization of Rootstock Use in Grape Cultivation (mid-1990s)

- The Dogridge (*Vitis champinii*) rootstock proved promising due to its ability to overcome drought and salinity's adverse effects, improve the yield and quality of major commercial varieties, and facilitate higher raisin/wine recovery by 25 per cent compared to own-rooted vines (Prakash & Satish, 2017). Over 85 per cent of the total area under grape cultivation uses this rootstock, indicating significant adoption.
- Economic impact assessments of adopting rootstock technology estimate a range from ₹8,800 crore to ₹15,000 crore (1996-97 to 2017-18), with export quantities and values from fresh grape exports, raisins, and wine at US$360 million in 2017-18 (Mysore *et al.*, 2014; Kumar and Pal, 2020).

Case 3: Introduction and Popularization of Flowers for Crop Diversification & Increased Income

- Introducing improved cultivars/hybrids of seasonal flowers like tuberose and marigold into crop rotations has proven highly remunerative for farmers. In tuberose, an improved variety, Arka Prajwal, was released in 2006 with double the yield potential of the locally popular cultivar, Mexican Single. Detailed economic impact analysis covering the important tuberose growing areas like Madurai and Krishnagiri in Tamil Nadu, Meerut in UP, and Kalyani district in West Bengal showed that Tuberose (Arka Prajwal) occupied nearly 38 per cent of the total tuberose area in the country between 2006-2016, helping increase farmers' income across growing regions.
- Daily harvest assured employment for farm women and also fetched at least Rs.1000 as net income for meeting home expenses (85%).
- At present, it is spread in > 38 per cent tuberose area, i.e., 2805 ha.
- Economic impact assessment indicated a net total aggregate economic benefit of Rs. 880 crores (2009-2015) (Rs 140 crores/annum) across growing regions (Mysore, 2017).
- At present, the annual valuation of this technology is about Rs Rs 280.5 crores.

Case 4: Tomato – Triple Resistant Arka Rakshak Hybrid (2010)

- Released in 2010, Arka Rakshak is resistant to Bacterial Wilt, Leaf Curl Virus, and Early Blight. With a yield capacity of over 90 t/ha in farmers' fields, the hybrid assured a net return of more than 35 per cent over other hybrids under similar conditions. Spreading to over 4,900 ha annually, including NE regions, and accruing total benefits of ₹661.5 crore per year, the hybrid's parental lines have been licensed to 11 private and public sector organizations/companies.

Presently, only IIHR produces seeds on its own, with a capacity to spread to over 5,000 ha and a yield potential of 75 t/ha, which is projected to increase by 10 per cent annually. Further upscaling via PPP mode for seed production and the involvement of NSC, SSC, and KVKs is necessary (Mysore, 2017).

Case 5: Biofertilizers: Arka Microbial Consortium

- Concerted research efforts into developing biofertilizers like Rhizobium, Azotobacter, Acetobacter, Azospirillum, Phosphate/potash mobilizing bacteria, and PGPR microbial consortia have been crucial for horticultural crops. Bio-based input use, such as biofertilizers and biopesticides, has proved highly beneficial in cultivating fruits, vegetables, and commercial flowers. Without regular use of these products, cultivating commercial polyhouse-grown flowers like roses and carnation becomes uneconomical.
- The Arka Microbial Consortium is crop-neutral and applicable across geographical regions. Comprising N-fixing, Phosphate & Zn-solubilizing, Phosphate Mobilizing, and Plant Growth Promoting Bacterial Strains, it can reduce N and P fertilizer requirements by 25 per cent and enhance yields by 10-15 per cent in most crops. The estimated annual benefit to the nation from this technology is ₹138 crore. With 676 tons of produce, 60,000 ha covered, and over 146,000 farmers benefited, the consortium is licensed to more than 30 entrepreneurs and government agencies (Mysore, 2017).

5.2 Total Factor Productivity Analysis

The horticultural sector in India has shown a unique growth trajectory with a distinct pattern over the years. The sector consolidated its progress between 2002-03 and 2018-19. During this period, numerous government policy initiatives through technology and budgetary support were extended to the sector, making it highly viable and economically feasible. Studies have shown that the productivity of horticultural crops increased from 8.8 t/ha to 12 t/ha, significantly higher than the productivity increase of field crops. Horticultural crop production has continuously surpassed food grain production since 2012-13. However, the question remains: how sustainable is this growth pattern?

Partial measures of productivity involving traditional inputs like labor and capital do not provide satisfactory inferences. Therefore, estimating the Total Factor Productivity (TFP) for the sector is appropriate. However, due to a lack of required data, TFP analysis in the horticultural crop sector is yet to be undertaken. A review of the literature indicates that Thorat *et al.* (2006) conducted one attempt for the Konkan region of Maharashtra from 1990 to 2000. A more recent study by Jain *et al.* (2017) included the horticultural sector in estimating TFP for the agricultural crop sector using the TD index method.

EMERGING CHALLENGES

Despite focused efforts, horticulture faces many challenges that need to be addressed. The most pressing challenge is enhancing production by nearly 100 million tonnes within five years. For context, it took the country four decades to add 75 million tonnes from 1950-51 to 1991-92. The main challenge for horticulture was crop production and productivity, which was at 25 million tonnes during the post-independence period of 1950-51. This increased to 98 million tonnes by 1991-92, nearly quadrupling over four decades through relentless research (public and private). By 2001-02, production reached 145 million tonnes, and 320 million tonnes within the next decade. The following 100 million tonnes were achieved within a decade, attributed to the impact of liberalization, enhanced budgetary and policy support, and schemes like NHM and TMNE in horticulture (from 2000-01 to 2011-12).

6.1 Encompassing Climate Resilience

With the rapidly changing climate, India's comparative advantage in producing numerous crops seems to be at stake. Analysis of past trends and current status shows that productivity growth already shows signs of decline. The unwarranted extremes of weather over the last two years have impacted production. Reports indicate a recent decrease in vegetable production, emphasizing the urgent need to shift research focus toward developing climate-resilient varieties and production packages for maintaining horticulture sustainability.

6.2 Addressing Large Post-Harvest Losses

Being highly perishable and seasonal, horticultural crops are subject to significant harvest and post-harvest losses, reaching up to 40 per cent or more. Continued research and dissemination efforts have led to some improvement in post-harvest losses. A recent study by the Central Institute of Post-Harvest Engineering and Technology (CIPHET), Ludhiana (2015), reported that about 16 per cent of fruits and vegetables are lost post-harvest. Despite all efforts, the TOP crops (Tomato, Onion, and Potato) still register post-harvest losses of 25 to 40 per cent, and the producers' share of the consumer rupee remains low.

6.3 Managing Market Imperfections and Seasonal Price Volatility

Price volatility and market imperfections are significant threats to horticultural crops. Without instruments like MSP for these crops, producers face seasonal gluts and end up in distress sales. The producers' share of the consumer rupee remains very low, at 35 per cent for some highly perishable crops. Fragmented production regions, high price volatility, and low levels of processing characterize horticultural markets in India. Unlike cereals and dairy, where procurement and marketing are well-developed, a decent value chain in fruits and vegetables is missing. The perishable nature of the crops, regional and seasonal concentration, associated losses, and lack of storage facilities complicate horticultural crop marketing.

6.4 Creating and Fostering a Price Stabilization Fund

A Price Stabilization Fund (PSF) is constituted to contain extreme volatility in the prices of selected commodities. The fund amount is generally utilized for activities aimed at regulating high/low prices, such as procurement and distribution of products to keep prices within a lucrative range and avert distress sales. India first created a PSF for some export-oriented plantation crops in 2003, which ceased to exist in 2013. Prices of horticulture crops are highly volatile, affecting both farmers and consumers, while trade benefits from cheaper imports. A new PSF scheme was introduced in May 2015 to mitigate consumer hardship. The intervention is expected to regulate price volatility through procurement by the State/UT Government and Central agencies, maintenance of buffer stocks, and regulated market release of selected produce. Initially, interventions are limited to onions and potatoes, but other commodities may be added later.

6.5 Enhancing Technological Advancement

To make horticulture sustainable in the long run, the focus must be on introducing innovative technologies using IoT, drones, and AI for optimizing irrigation and other critical growth inputs, leading to enhanced, remunerative, and sustainable production.

6.6 Focus on Export-Oriented Production

Despite continued efforts by various organizations to increase the export share of horticulture-based products, India still lags behind several other countries.

VII

WAY FORWARD

The horticulture sector in India has demonstrated a phenomenal growth pattern and has genuinely been a sunrise sector for over five decades. This growth has been made possible through constant and increasing budgetary and policy support from the government and research endeavours. India has successfully utilized its agro-climatic advantages.

However, despite the favourable scenario so far, the fast-changing climate is already impacting horticultural production. The sustainability of productivity growth needs to be a top priority. Here are some points that need attention going forward:

7.1 Accelerating Climate-Resilient Technologies

Given the growing threat posed by climate change, it is essential to develop and promote technologies that can help horticulture adapt and mitigate its effects through a multi-faceted approach:

- Developing Climate-Resilient Varieties: Invest in research to develop crop varieties that can withstand extreme weather conditions, ensuring stable yields and food security.
- Precision Agriculture: Utilize advanced technologies like sensors, drones, and satellite imaging to monitor crop health, soil conditions, and weather patterns, allowing for precise application of water, fertilizers, and pesticides.
- Smart Irrigation Systems: Implement innovative irrigation techniques such as drip irrigation and automated systems that conserve water and respond to real-time data, reducing waste and improving crop resilience.
- Integrated Pest Management (IPM): Promote IPM practices that combine biological, cultural, physical, and chemical methods to control pests and diseases, reducing reliance on harmful chemical pesticides and enhancing crop resilience.
- Soil Health Management: Focus on practices that improve soil health, such as crop rotation, cover cropping, and organic amendments, making soils more resilient to climate impacts.
- Use of Renewable Energy: Encourage the adoption of renewable energy sources like solar and wind power for agricultural operations, reducing the carbon footprint and ensuring a sustainable energy supply.
- Climate-Smart Infrastructure: Develop infrastructure that can withstand extreme weather events, such as protected cultivation structures and resilient storage facilities, to protect crops and reduce post-harvest losses.
- Research and Development: Support ongoing research and development efforts to innovate and improve climate-resilient technologies through collaborative efforts between government agencies, research institutions, and the private sector.
- Knowledge Dissemination: Ensure farmers can access the latest information and technologies through extension services, training programs, and digital platforms, empowering them to adopt and implement climate-resilient practices effectively.

7.2 Climate-Smart Horticulture

Focusing on climate-smart horticulture practices is essential for ensuring sustainable production, particularly in the face of climate change. Climate-smart horticulture involves adopting practices and technologies that increase productivity, enhance resilience to climate impacts, and reduce greenhouse gas emissions. Here are some key components and strategies for climate-smart horticulture:

- Sustainable Soil Management: Practices like conservation tillage, crop rotation, and the use of cover crops help improve soil health and structure, increase organic matter content, and enhance water retention. Healthy soils are better able to support plant growth and withstand climate-related stresses.
- Efficient Water Use: Implementing advanced irrigation techniques such as drip irrigation, sprinkler systems, and rainwater harvesting can significantly reduce water wastage. Using soil moisture sensors and automated irrigation systems ensures that crops receive the right amount of water at the right time, optimizing water use and improving crop yields.
- Diversified Cropping Systems: Encouraging crop diversity through intercropping, agroforestry, and polycultures can increase system resilience to pests, diseases, and extreme weather events. Diversified cropping systems also enhance biodiversity and ecosystem services.
- Integrated Pest and Disease Management (IPDM): Combining biological, cultural, mechanical, and chemical control methods to manage pests and diseases reduces reliance on synthetic pesticides. IPDM practices help maintain a balanced ecosystem and minimize environmental and health risks.
- Use of Climate-Resilient Crop Varieties: Developing and adopting crop varieties tolerant to drought, heat, salinity, and other climate-related stresses is crucial for maintaining productivity. These resilient varieties can help farmers cope with changing climatic conditions and reduce yield losses.
- Agroforestry and Buffer Planting: Integrating trees and shrubs into horticultural systems can provide multiple benefits, including soil stabilization, improved microclimates, and enhanced carbon sequestration. Buffer planting around fields can protect crops from wind damage and reduce the spread of pests and diseases.
- Reduced Greenhouse Gas Emissions: Implementing practices that reduce greenhouse gas emissions, such as optimizing fertilizer use, minimizing tillage, and adopting organic farming practices, contributes to climate mitigation. Using renewable energy sources like solar and wind power in horticultural operations can further reduce the sector's carbon footprint.
- Post-Harvest Management: Improving post-harvest handling, storage, and processing of horticultural produce can reduce losses and increase the availability of fresh produce. Climate-controlled storage facilities and efficient supply chains ensure that produce reaches consumers in optimal condition.
- Community-Based Adaptation: Engaging local communities in the planning and implementing climate-smart horticulture practices ensures that solutions

are context-specific and socially acceptable. Community-based adaptation approaches foster knowledge sharing, capacity building, and collective action.

- Policy Support and Incentives: Governments can play a crucial role by providing policy support and financial incentives for adopting climate-smart horticulture practices. Subsidies for sustainable inputs, funding for research and development, and support for extension services can accelerate the transition to climate-smart agriculture.

7.3 Assessing the Impact of Technology - Scale Up

Technological advances in horticulture have shown promising results when adopted in specific regions and by certain stakeholders. However, to maximize benefits and achieve sustainable growth, these technologies must be consolidated and scaled up to benefit a larger population. Key steps to accomplish this include:

- Comprehensive Impact Assessment: Conduct thorough assessments of current technologies to understand their effectiveness, benefits, and limitations, guiding future strategies for scaling up.
- Knowledge Sharing and Capacity Building: Facilitate knowledge sharing and training among farmers, extension workers, and other stakeholders to ensure they can effectively adopt and utilize advanced technologies.
- Strengthening Extension Services: Enhance the reach and effectiveness of agricultural extension services to support the widespread adoption of advanced technologies, equipping extension workers with the latest tools and information.
- Public-Private Partnerships: Foster collaborations between government agencies, research institutions, private companies, and NGOs to leverage resources and expertise, facilitating large-scale technology dissemination and commercialization.
- Policy Support and Incentives: Implement supportive policies and provide financial incentives, such as subsidies, grants, and tax incentives, to encourage the adoption of advanced technologies.
- Access to Finance: Improve access to finance for farmers and agribusinesses through microfinance schemes, low-interest loans, and credit facilities tailored to the horticulture sector's needs.
- Infrastructure Development: Invest in infrastructure to support advanced technology adoption, including robust supply chains, cold storage facilities, and improved transportation networks.

- Digital Platforms and Tools: Promote digital platforms and tools to connect farmers with information, resources, and markets, helping them make informed decisions and sell their produce at fair prices.
- Monitoring and Evaluation: Establish a robust monitoring and evaluation framework to track the progress of technology adoption and its impact on the horticulture sector, allowing for adjustments to scaling-up strategies.
- Scaling Successful Models: Identify and replicate successful models of technology adoption across different regions and crops, tailoring them to specific agro-climatic conditions and socio-economic contexts to ensure effectiveness and sustainability.

7.4 Addressing Market Vulnerability

Market vulnerabilities and frequent price fluctuations pose significant challenges for horticultural crops, affecting both farmers' income and consumers' prices. A multi-pronged approach is needed to address these challenges, involving price support, prediction, communication, and stabilization methods. Key strategies include:

- Price Support Mechanisms: Establish minimum support prices (MSP) for key horticultural crops to provide a safety net for farmers and reduce distress sales. Implement procurement schemes where the government buys produce at MSP to stabilize market prices.
- Price Prediction and Communication: Develop and disseminate reliable price prediction models using advanced data analytics, machine learning, and AI to help farmers make informed decisions. Use effective communication channels like mobile apps, SMS alerts, and online platforms to relay this information on time.
- Price Stabilization Fund (PSF): Create a PSF specifically for horticultural crops to mitigate price volatility. Utilize the fund for procurement during low prices, maintaining buffer stocks, and regulated market release to prevent price spikes.
- Market Infrastructure Development: Invest in cold storage facilities, warehouses, and transportation networks to reduce post-harvest losses and ensure produce reaches markets in optimal condition, extending shelf life and reducing pressure to sell immediately.
- Value Chain Integration: Strengthen the value chain by promoting processing, packaging, and branding to add value and reduce market vulnerabilities. Encourage the establishment of processing units, farmer producer organizations (FPOs), and cooperatives to enhance farmers' bargaining power and market access.

- Market Intelligence Systems: Develop robust systems to monitor and analyze market trends, demand-supply dynamics, and price movements, providing valuable insights and enabling proactive measures to stabilize prices.
- Promoting Contract Farming: Encourage contract farming arrangements between farmers and buyers to provide price assurance and a steady supply of produce, facilitating the adoption of best practices and technologies.
- Insurance Schemes: Implement crop insurance schemes tailored to horticultural crops to protect farmers against losses due to price volatility, adverse weather, and other risks, providing financial stability and encouraging investment in improved practices and technologies.
- Supporting Startups and Innovations: Support startups providing market linkage, price prediction, and supply chain management services through funding, mentorship, and regulatory facilitation to enhance their impact and ensure effective implementation.

7.5 Scaling Up Technology Adoption and Commercialization

Encouraging and popularizing technological advancements such as IoT, drones, and sensor-based technologies across crops and regions is crucial for achieving sustainable and remunerative production in the horticulture sector. Here's how this can be effectively scaled up:

- Awareness and Education: Conducting widespread awareness campaigns and educational programs to inform farmers about the benefits and potential of advanced technologies. Demonstrations, workshops, and training sessions can help farmers understand how to use these technologies effectively.
- Government Support and Incentives: Providing financial incentives, subsidies, and grants to encourage farmers and agribusinesses to invest in advanced technologies. Government policies should support research and development and the commercialization of new technologies, making them more accessible and affordable for farmers.
- Public-Private Partnerships: Collaborating with private companies, research institutions, and NGOs to leverage their expertise, resources, and infrastructure. Public-private partnerships can facilitate the development, dissemination, and commercialization of innovative technologies on a larger scale.
- Infrastructure Development: Investing in the necessary infrastructure, such as high-speed internet connectivity in rural areas, to support IoT and other digital technologies. Ensuring farmers have access to reliable power sources is also critical for successfully adopting these technologies.

- Customized Solutions: Developing and promoting technology solutions tailored to the specific needs and conditions of different regions and crops. This ensures that the technologies are relevant and practical for farmers in various contexts.
- Access to Finance: Improving access to finance for farmers and agribusinesses to invest in new technologies. This can be achieved through microfinance schemes, low-interest loans, and credit facilities tailored to the horticulture sector's specific needs.
- Research and Development: Supporting ongoing research and development efforts to continuously innovate and improve technologies. Collaborative efforts between government agencies, research institutions, and the private sector are crucial for driving progress in this area.
- Extension Services: Strengthening agricultural extension services to support the widespread adoption of advanced technologies. Extension workers should be well-trained and equipped with the latest information and tools to provide timely and relevant guidance to farmers.
- Digital Platforms and Tools: Promoting digital platforms and tools to connect farmers with information, resources, and markets. Mobile apps, online marketplaces, and data analytics can help farmers make informed decisions, access inputs, and sell their produce at fair prices.
- Monitoring and Evaluation: Establishing a robust monitoring and evaluation framework to track the progress of technology adoption and its impact on the horticulture sector. Regular assessments and feedback mechanisms can help identify challenges, measure success, and adjust scaling-up strategies.
- Scaling Successful Models: Identifying and replicating successful models of technology adoption across different regions and crops. Tailoring these models to the specific agro-climatic conditions, socio-economic contexts, and needs of the target areas ensures their effectiveness and sustainability.

By focusing on these strategies, the horticulture sector can scale up the adoption and commercialization of advanced technologies, leading to increased productivity, resilience, and sustainability.

Addressing these points will be key to ensuring the continued growth and sustainability of the horticulture sector in India.

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