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From area expansion to sustainable intensification: yield gaps, structural constraints and vision-2047 roadmap for India's vegetable sector

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Abstract

Vegetable cultivation plays a pivotal role in India's agricultural growth, nutritional security, and rural employment generation. During 2024–25, vegetables were grown over 11.71 million ha with a production exceeding 215.68 million tonnes, contributing nearly 58% of total horticultural output. Despite this impressive expansion, productivity has increased at slower rate, with national average yields (18.42 tonnes/ha), remaining substantially below the 25–30 tonnes/ha levels achieved in technologically-advanced systems. The widening gap between projected demand and current production trajectories underscores the urgency of yield acceleration through resource-efficient intensification. Persistent constraints, including fragmented landholdings, imbalanced nutrient application, declining soil health, climate variability, suboptimal irrigation practices, limited hybrid adoption, and significant post-harvest losses, have restricted productivity gains. Regional disparities further reflect agro-ecological limitations, infrastructural gaps, and differential technology uptake. Recent production growth has been driven more by area expansion than productivity enhancement, indicating structural inefficiencies within the system. The ICAR–Indian Institute of Vegetable Research, Varanasi, has addressed these challenges through a systems-based approach encompassing the development of climate-resilient and high-yielding varieties, precision nutrient and water management strategies, protected cultivation technologies, integrated pest management modules, and post-harvest innovations. Emphasis on balanced fertilization, resource-use efficiency, and region-specific technology packages aim to bridge productivity gaps while enhancing sustainability. Looking ahead to Vision-2047, the roadmap prioritizes seed system strengthening, soil health restoration, climate-smart production technologies, digital advisory platforms, and resilient supply chains. A shift from area-led growth to productivity-driven, low-input, and climate-resilient intensification will be critical to ensuring nutritional security, farmer profitability, and long-term sustainability of India's vegetable sector.

Key words: Climate-resilient production systems, Resource-use efficiency, Vegetable productivity, Vision-2047, Yield gap

Vegetables are central to Indian agriculture and nutritional security owing to their high productivity, short duration, economic viability, and rich micronutrient content. With improved varieties and technologies, the area under vegetables expanded to 11.71 million ha, producing 215.68 million tonnes in 2024–25 (Third Advance Estimates, Department of Agriculture & Farmers Welfare), contributing nearly 58% of total horticultural output. The sector generates substantial on- and off-farm employment and is particularly well suited to smallholders and rural women. Crop diversification toward high-value vegetables has been widely recognized as a pathway for enhancing farm profitability, employment, and sustainability in cereal-dominated systems (Choudhary *et al.*, 2025). Their labour-intensive nature strengthens rural livelihoods (Olowo *et al.*, 2022; Kandpal and Shukla, 2025), while global evidence confirms their role in poverty reduction (Thornton *et al.*, 2019). Rising incomes and dietary shifts toward micronutrient-rich foods have further accelerated vegetable demand (Avnee *et al.*, 2023; Nyamete *et al.*, 2024). Despite these strengths, productivity has increased at slower rate. The national average yield (18.42 t/ha) remains well below the 25–30 t/ha achieved in advanced systems. Even leading states such as Uttar Pradesh face crop-specific yield gaps due to fragmented holdings, nutrient imbalances, limited hybrid adoption, irrigation constraints, pest and disease pressures, and post-harvest losses.

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Addressing these gaps is vital for sustaining nutritional security and farmer incomes. The Vision-2047 roadmap of ICAR–IIVR prioritizes climate-resilient varieties, region-specific technologies, balanced nutrient and water management, and resource-efficient production systems to drive sustainable productivity gains under shrinking land resources, rising input costs, and climate variability.

Growth trends and structural shifts in Indian vegetable production

Over the past three decades (1991–92 to 2024–25), India's vegetable sector has expanded substantially (Fig. 1). The cultivated area increased from 5.59 million ha to 11.71 million ha (109.48% increase), while production rose from 58.53 million tonnes to 215.68 million tonnes (268.50% increase). Productivity improved from 10.47 t/ha to 18.42 t/ha (75.93% increase). These gains were supported by improved varieties and hybrids, advancements in production and protection technologies, infrastructure development, policy support, and farmers' adoption of modern practices. India has consequently achieved near self-sufficiency in vegetables, with a surplus available for export. India's vegetable exports have shown a consistent positive growth trend over the past two decades, with a compound annual growth rate (CAGR) of 6.66% in export quantity and 14.40% in export value, reflecting the expanding role of the vegetable sector in international trade (Pal *et al.*, 2023a). However, a closer examination of growth patterns reveals structural imbalances. The compound annual growth rate (CAGR) during 1991–2021 was 4.45% for production compared to only 1.45% for productivity, indicating that output expansion has been driven more by area increase than by yield enhancement. Decadal analysis further shows that while the period 2001–2011 recorded strong gains in both areas and production, productivity growth slowed sharply after 2011, declining to below 1% per annum at the national level.

This trend suggests that earlier productivity gains achieved through varietal improvement and input intensification are now increasing at slower rate under existing management systems. The emerging productivity plateau reflects a complex interaction of agronomic, ecological, institutional, and market-related constraints, which points to the importance of a transition from area-led expansion to productivity-driven, resource-efficient intensification.

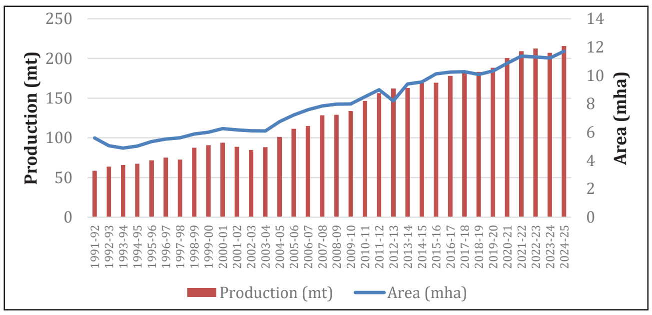

Fig. 1: Trends in area and production of vegetables in India

Decadal growth analysis (1991–2021) indicates that the highest expansion in area (4.12% p.a.) and production (6.48% p.a.) occurred during 2001–2011, while productivity growth peaked earlier (3.03% p.a.) during 1991–2001 (Table 1). Overall CAGR during 1991–2021 was 2.92% (area), 4.45% (production), and 1.45% (productivity), indicating production growth has been more area-driven than yield-led.

Recent trends (2011–12 to 2024–25) show only modest productivity gains at the national level, from 17.39 to 18.42 t/ha (5.92% increase) (Fig. 2). These improvements reflect the adoption of improved hybrids,

Table 1: Compound annual growth rate of area, production and productivity of vegetables in India (1991–2021) (%)

Year	Area	Production	Productivity
1991–2001	2.14***	5.24***	3.03***
2001–2011	4.12***	6.48***	2.27***
2011–2021	2.38***	2.56***	0.67**
1991–2021	2.92***	4.45***	1.45***

better crop management, and supportive policy measures, though overall yield growth remains moderate.

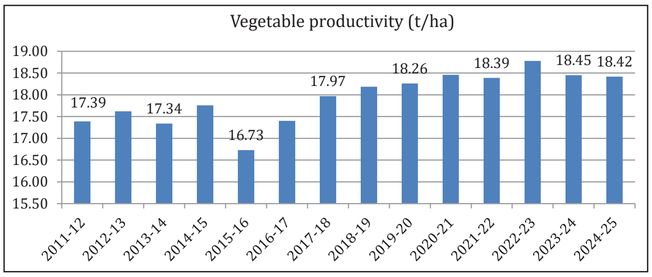

Fig. 2: National vegetable productivity trend

Vegetable availability and demand projection

India's vegetable availability has steadily improved alongside population growth (Table 2). In 2024–25, with a population of 1,450.94 million and production of 215.68 million tonnes, per capita gross and net vegetable availability reached 407.26 g/day and 285.08 g/day, respectively.

Projections indicate further increases by 2030–31, with population expected at 1,504 million and production at 258.33 million tonnes, raising gross and net availability to 470.58 g/day and 329.41 g/day. By 2040–41, production is projected to reach 316.79 million tonnes for a population of 1,593 million, translating into 544.83 g/day gross and 381.38 g/day net availability.

Rising incomes, urbanization, and dietary diversification are accelerating vegetable demand. Household demand (including food away from home) is projected to increase to 190 million tonnes by 2030–31 and 236 million tonnes by 2040–41. Total demand (household + other uses) is expected to reach 270 million tonnes in 2030–31 and 330 million tonnes in 2040–41 (Table 4). Production slightly lagged demand in 2019–20, and, under current growth trajectories, the supply gap is likely to persist unless productivity growth accelerates.

Regional productivity disparities

Vegetable productivity across Indian states shows wide disparities (Table 4), ranging from below 10 t/ha to over 30 t/ha. Andhra Pradesh records the highest average productivity (>30 t/ha). States such as Kerala, Tamil Nadu, Gujarat, Himachal Pradesh, Jammu & Kashmir, Punjab, Telangana, Tripura, and Uttar Pradesh fall within

Table 2. Population, vegetable production, and gross and net vegetable availability in India

Year	Population (million)	Vegetable production (mt)	Gross vegetable availability in gm (per capita per day)	Net vegetable availability in gm (per capita per day)
2010-11	1243.48	146.55	322.89	226.02
2015-16	1328.03	169.48	349.64	244.75
2020-21	1402.62	200.45	391.54	274.08
2021-22	1414.20	209.14	405.17	283.62
2022-23	1425.42	212.55	408.53	285.97
2023-24	1438.07	207.21	394.76	276.33
2024-25	1450.94	215.68#	407.26	285.08
Projection				
2030-31	1504.00@	258.33	470.58	329.41
2040-41	1593.00@	316.79	544.83	381.38

Note: The population estimates are converted from calendar to financial year.
3rd Advance estimates, Department of Agriculture & Farmers Welfare; @ UN projection estimates

Table 3:. Projected Vegetable Production and Demand in India

Year	Vegetable Production (mt)	Household vegetable demand (home + FAFH) (mt)	Total vegetable demand (household + other demand) (mt)
2019-20 (Actual)	188	138	199
2025-26	224	166	238
2030-31	254	190	270
2035-36	285	213	301
2040-41	318	236	330
2047-48	367	263	365

Source: Working Group report on Crop Husbandry, Agriculture Inputs, Demand and Supply (2024), NITI Aayog, New Delhi; FAFH: Food away from home

Table 4. Regional productivity patterns of vegetables across different states (TE 2023-24)

Vegetable productivity	States
>30 t/ha	Andhra Pradesh
25-30 t/ha	Kerala and Tamil Nadu
20-25 t/ha	Gujarat, Himachal Pradesh, Jammu & Kashmir, Punjab, Telangana, Tripura and Uttar Pradesh
15-20 t/ha	Bihar, Haryana, Karnataka, Madhya Pradesh and West Bengal
10-15 t/ha	Assam, Jharkhand, Maharashtra, Chhattisgarh, Meghalaya, Nagaland, Odisha and Rajasthan
<10 t/ha	Manipur, Uttarakhand, Arunachal Pradesh, Mizoram and Sikkim

the 20–30 t/ha range. Bihar, Haryana, Karnataka, Madhya Pradesh, and West Bengal have moderate productivity levels of 15–20 t/ha, while several other states fall below 15 t/ha, which is lower than the national average.

Productivity is particularly low in hilly and North-Eastern states due to a combination of agro-ecological and socio-economic constraints, including sloping terrain, soil erosion, low soil fertility, erratic rainfall, limited irrigation coverage, restricted mechanization, poor access to quality seeds and inputs, fragmented landholdings, weak infrastructure, and market isolation (Pal and Pal, 2025). These structural constraints contribute to persistent regional yield gaps, which demonstrate the importance of location-specific technological and institutional interventions.

Crop-wise yield gap analysis

Crop-wise productivity comparisons for 2023–24 (Table 5) reveal substantial inter-state variation. The overall average productivity of vegetables in Uttar Pradesh was 24.11 t/ha, which is 30.68% higher than the national average of 18.45 t/ha. Among states, Andhra Pradesh recorded the highest overall productivity (34.34 t/ha), while Mizoram registered the lowest (5.48 t/ha). Uttar Pradesh outperformed the national average in all major vegetables except green chillies.

For tomatoes, the national average was 24.97 t/ha, with Andhra Pradesh highest (45.00 t/ha) and Arunachal Pradesh lowest (6.02 t/ha). Uttar Pradesh recorded 40.01 t/ha, which is 60.23% above the national average. In brinjal, the national yield was 19.03 t/ha; Andhra Pradesh led with 50.00 t/ha, while Arunachal Pradesh recorded 3.37 t/ha. Uttar Pradesh achieved 36.04 t/ha, exceeding the national average by 89.39%.

Cabbage productivity averaged 23.58 t/ha nationally, with Tamil Nadu highest (68.74 t/ha) and Sikkim lowest (5.88 t/ha); Uttar Pradesh recorded 34.69 t/ha (+47.12%). In cauliflower, the national average was 19.31 t/ha; Tamil Nadu led (27.92 t/ha), and Kerala lagged (4.62 t/ha). Uttar Pradesh achieved 23.53 t/ha (+21.85%). For okra, the national yield was 13.12 t/ha; Andhra Pradesh recorded the highest productivity (35.00 t/ha) and Rajasthan the lowest (5.02 t/ha), while Uttar Pradesh registered 13.94 t/ha (+6.25%).

Overall, the highest productivities across crops were concentrated in Andhra Pradesh, Jammu & Kashmir, Tamil Nadu, Uttar Pradesh, and Telangana, whereas lower productivity levels were predominantly observed in NEH states, Kerala (in selected crops), and Rajasthan. These variations highlight significant yield gaps and the scope for region-specific productivity enhancement strategies.

Table 5. Vegetable productivity and gap analysis in important crops during 2023-24

Crop	National productivity (t/ha)	Productivity in Uttar Pradesh (t/ha)	% Difference in productivity (National vs. U.P.)	State with highest productivity*	State with lowest productivity *
Potato	24.57	27.55	+12.13	Andhra Pradesh (30.00)	Sikkim (7.24)
Onion	15.75	16.91	+7.37	Jammu & Kashmir (27.95)	Sikkim (6.16)
Tomato	24.97	40.01	+60.23	Andhra Pradesh (45.00)	Arunachal Pradesh (6.02)
Brinjal	19.03	36.04	+89.39	Andhra Pradesh (50.00)	Arunachal Pradesh (3.37)
Cabbage	23.58	34.69	+47.12	Tamil Nadu (68.74)	Sikkim (5.88)
Cauliflower	19.31	23.53	+21.85	Tamil Nadu (27.92)	Kerala (4.62)
Okra	13.12	13.94	+6.25	Andhra Pradesh (35.00)	Rajasthan (5.02)
Peas	10.91	13.23	+21.26	Jammu & Kashmir (21.63)	Assam (0.92)
Chillies (Green)	10.65	2.91	-72.68	Tamil Nadu (27.68)	Kerala (0.94)
Bottle gourd	16.99	31.23	+83.81	Andhra Pradesh (49.97)	Kerala (6.79)
Radish	15.87	26.83	+69.06	Tamil Nadu (35.28)	Arunachal Pradesh (1.18)
Beans	9.32	15.58	+67.17	Jammu & Kashmir (22.54)	Rajasthan (2.37)
Carrot	22.21	63.52	+186.00	Uttar Pradesh (63.52)	Sikkim (5.57)
Pumpkin	22.30	39.82	+78.57	Telangana (52.76)	Arunachal Pradesh (6.87)
Cucumber	14.70	25.89	+76.12	Jammu & Kashmir (28.81)	Arunachal Pradesh (2.86)
Bitter gourd	13.02	19.80	+52.07	Andhra Pradesh (48.01)	Mizoram (3.95)
Pointed gourd	13.14	28.05	+113.47	Andhra Pradesh (50.00)	Assam (9.58)
All vegetables	18.45	24.11	+30.68	Andhra Pradesh (34.34)	Mizoram (5.48)

**Figures in parentheses are the average productivity of the state.*

Structural, agronomic and systemic constraints in vegetable production

Despite impressive expansion in area and production, vegetable productivity in India remains constrained by interlinked structural, agronomic, climatic, and market-related factors. These constraints collectively explain the persistence of yield gaps and the recent stagnation in productivity growth.

Structural and farm-level limitations

Vegetable cultivation in India is dominated by small and fragmented landholdings, limiting economies of scale, mechanization, and adoption of precision technologies. Smallholders often face restricted access to quality seeds, protected cultivation systems, precision irrigation infrastructure, and mechanized tools. Quality seed alone contributes about 15–20% to total agricultural production, and this contribution can increase up to 40% with effective management of other inputs, highlighting the critical role of a strong seed system in enhancing vegetable productivity (Pal and Pal, 2025). Weak aggregation mechanisms and limited institutional linkages constrain technology adoption and market access. Strengthening structured market arrangements, including contract farming models, can reduce transaction costs, improve price realisation, and enhance risk-sharing between producers and buyers (NAAS, 2022c). Accelerated mechanization through smallholder-friendly equipment and custom hiring centres is essential to reduce labour dependency and enhance operational efficiency (NAAS, 2025b).

Soil health degradation and nutrient imbalance

Imbalanced fertilizer use, typically skewed toward nitrogen, has led to deficiencies of secondary and micronutrients in intensively cultivated regions. Continuous cropping without adequate organic matter replenishment has reduced soil organic carbon, impaired soil structure, and lowered nutrient-use efficiency (NAAS, 2021). As a result, nitrogen use efficiency in open-field vegetable systems often remains below 40%, increasing production costs without proportional yield gains. Long-term soil fatigue suppresses productivity even under high-input regimes.

Climate variability and abiotic stress

Vegetables, being shallow-rooted and short-duration crops, are highly sensitive to temperature fluctuations, moisture stress, and extreme weather events. Rising heat stress, erratic rainfall, waterlogging, and climate-induced pest and disease outbreaks have increased yield instability. Rainfed, peri-urban, and resource-poor regions are particularly vulnerable, necessitating climate-resilient production systems.

Regional Disparities and Technology Diffusion Gaps

Vegetable productivity varies widely across states, from below 10 t/ha in several North-Eastern and hilly regions to above 30 t/ha in technologically advanced states. These disparities reflect differences in agro-ecology, irrigation access, infrastructure, extension support, input availability, and market connectivity. In low-productivity regions, limited hybrid adoption, suboptimal crop management, and weak value-chain integration continue to widen yield gaps.

Pest, disease and input cost pressures

Vegetable crops are highly susceptible to pests and diseases, requiring frequent protection measures that account for 10–15% of total cultivation cost in intensive systems. Overreliance on chemical pesticides has increased resistance, environmental risks, and production expenses. Simultaneously, rising costs of fertilizers, irrigation, seeds, and labour have compressed profit margins, discouraging investment in advanced technologies.

Post-harvest losses and market constraints

Post-harvest losses in vegetables range between 15% and 30%, significantly reducing effective marketable surplus. Inadequate cold-chain infrastructure, poor handling, price volatility, and distress sales during seasonal gluts further erode farmer profitability. Smallholders face higher per-unit transaction costs and limited access to organized markets. Investment in decentralized packhouses, cold-chain infrastructure, and small-scale processing is critical to reducing post-harvest losses and enhancing farmer incomes. Secondary agriculture, including processing, value addition, and waste utilization, has been identified as a key pathway for increasing farm profitability and rural employment (NAAS, 2022b).

Demand–Supply Imbalance and Growth Transition

With rising population, urbanization, and dietary diversification toward micronutrient-rich foods (Yadava *et al.*, 2024; Krishna *et al.*, 2024), vegetable demand is projected to increase substantially. Diversification toward high-value crops has been recognized as a pathway for improving farm income and employment in cereal-dominated systems (Choudhary *et al.*, 2025). However, current productivity trends, averaging around 18–19 t/ha nationally, remain below the 25–30 t/ha achieved in advanced systems. Land resources are finite, and continued area expansion is neither sustainable nor sufficient to meet future demand.

ICAR-IIVR's role and interventions

The ICAR-IIVR, Varanasi, has made significant contributions in developing technologies to reduce costs and improve vegetable productivity. The institute has optimized fertigation protocols for tomato, cucumber, and okra, demonstrating yield increases of up to 70% with higher nutrient use efficiency. Integrated nutrient management models combining FYM, poultry manure, vermicompost, and biofertilizers have resulted in improved yields, enhanced soil carbon sequestration, and better pest regulation compared to chemical-only systems. The institute developed crop-specific micronutrient formulations, such as 'Kashi Sookshma Shakti/ Kashi Sookshma Shakti Plus', which boosted yields by 15–30% across crops like pea, French bean, carrot, and bottle gourd at a fraction of the cost of conventional fertilizers. IIVR has also pioneered grafting techniques in solanaceous and cucurbitaceous vegetables to combat soil-borne diseases and abiotic stresses, reducing chemical dependence and crop losses. Protected cultivation technologies, including double-stem tomato training, fertigation scheduling, and off-season hybrid production, have enhanced yield and quality while ensuring higher price realization. The institute has standardized drip irrigation and mulching packages for tomato and okra, achieving up to 56% water savings along with higher yields. Natural and organic farming modules validated by IIVR demonstrated competitive yields with reduced input costs. Additionally, innovative cropping systems like maize–pea–pumpkin and rice–vegetable–legume sequences have proven highly profitable, improving land use efficiency and farmer incomes. Varieties such as Kashi Anmol and Kashi Aman developed by ICAR–IIVR have demonstrated substantial economic benefits, including higher net returns, improved benefit–cost ratios, and significant economic surplus generation, clearly highlighting the strong impact of varietal innovations on farmer profitability and livelihood security (Pal *et al.*, 2025; Pal *et al.*, 2023b). Mechanization efforts, nutri-garden models, and bio-input formulations such as Kashi Jaiv Shakti and CRB-7 further highlight IIVR's leadership in sustainable, low-cost vegetable production.

Vegetable technology requirements in country

Given the diverse agro-climatic conditions and production constraints across states, the needs of vegetable technology must be region-specific. Broadly, priorities include improving water-use efficiency, promoting climate-resilient varieties, strengthening post-harvest systems, expanding protected cultivation, and empowering farmer collectives for improved market access.

General technology needs

- Development and dissemination of high-yielding, biofortified (NAAS, 2022a), disease-resistant and climate-resilient cultivars remain central to sustainable productivity enhancement. IIVR's contributions include non-staking bush-type legumes (Kashi Nidhi, Kashi Kanchan, Kashi Vishan, and the Kashi Bauni Sem series) that reduce labour costs, and resistant varieties such as Kashi Prakram and Kashi Sahishnu (okra, resistant to YVMV and ELCV); Kashi Arun & Kashi Krishna (carrot); and Kashi Lohit (radish) as nutritionally superior varieties; and Kashi Modak (brinjal, tolerant to shoot and fruit borer) (details in Table 7). IIVR-developed varieties have demonstrated measurable economic impact, generating ₹239.41 crore additional income and widespread adoption across 27 states (Pal *et al.*, 2023c).
- Integrated Pest and Disease Management (IPM) should be widely adopted. IIVR's validated modules, including Kashi Jaiv Shakti, CRB-7, Kashi Trichocapsule, and actinomycetes-based bioformulations, provide effective eco-friendly alternatives to chemical pesticides.
- Integrated Nutrient Management (INM), combining soil-test-based fertilizer application with organic inputs such as FYM, compost, and biofertilizers, can enhance nutrient-use efficiency. Technologies like IIVR's micronutrient formulation *Kashi Sookshma Shakti* and sensor-based fertigation protocols in tomato and capsicum demonstrate the potential to cut costs while boosting yields.
- Water-use efficiency enhancement through drip irrigation, fertigation, mulching, and sensor-based scheduling are critical for improving water productivity and reducing input costs.
- Post-harvest management through improved storage, transportation, and processing facilities is critical. IIVR has developed several value-added products (instant pumpkin halwa mix, bitter gourd encapsulation, minimally processed carrot/pumpkin) and shelf-life extension methods (wax/chitosan coating, MAP packaging). Further, integration of renewable energy solutions, including solar-powered cold storage and agro-processing units, can significantly reduce operational expenses and enhance sustainability in vegetable value chains (NAAS, 2024).
- Capacity building and collective action on farmer training, FPO strengthening, and technology dissemination are essential for scaling innovations (NAAS, 2015).
- Mechanization and cultural practices should be promoted, e.g., smallholder-friendly machinery, staking, pruning, and scientific harvesting methods can enhance fruit development, reduce losses, and improve market value. Further, grafting techniques should be promoted in stress-prone areas to enhance resistance to diseases, tolerance to abiotic stresses, and yield stability. Use of grafted Brimato/Pomato needs to be promoted for urban/terrace gardening.
- Infrastructure development, including rural roads, cold storage, decentralized packhouses, and primary processing units, will improve farmers' access to remunerative prices.

Region-specific technology needs

Coastal states

- Adoption of saline- and drought-tolerant varieties along with improved drainage systems to tackle waterlogging, salinity, and extreme weather. IIVR's work on tolerant legumes can be adapted here.

- There has been a wider use of protected cultivation structures (polyhouses, shade nets) to safeguard crops and enable off-season production (NAAS, 2010; 2019).

Hilly and NEH states

- Adoption of low-cost protected structures (naturally ventilated polyhouses, tunnels) to extend growing seasons and facilitate off-season production.
- Promotion of biofertilizers and organic farming, leveraging the region's high soil organic matter and low chemical intensification.
- We need to implement water harvesting and efficient irrigation systems to mitigate scarcity.

Arid and semi-arid states

- Emphasizes mainstreaming climate-resilient varieties and location-specific adaptation strategies.
- Innovative land-use models such as agrivoltaics, which combine crop production with solar energy generation, offer opportunities for climate buffering, income diversification, and improved resource-use efficiency (NAAS, 2025a).
- The adoption of efficient irrigation systems (drip, sprinkler) and water conservation practices (mulching, bunding, terracing, and conservation tillage) is crucial.
- Promotion of precision agriculture tools (sensor-based irrigation and fertigation) to optimize input use.
- Development and adoption of drought- and heat-tolerant varieties such as IIVR's Kashi Rituraj (radish, tolerant at 38–43°C), Kashi Tapas & Kashi Adbhut (high-set tomato varieties), Kashi Manu (climate-resilient water spinach variety) and cauliflower VRCR75-1 (curd formation at >42°C).
- Protected cultivation structures, such as greenhouses and shade nets, provide protection against extreme heat and erratic rainfall.
- Aligning crop selection and planting schedules with rainfall patterns to maximize productivity.

States with large urban populations

- Promotion of peri-urban vegetable cultivation to supply fresh produce to cities while creating local employment.
- Encouragement of urban farming initiatives (terrace, rooftop, balcony gardens). IIVR's short-duration leafy vegetable varieties and hydroponics models can be promoted for urban spaces.
- In high rainfall areas, raised-bed cultivation to ensure better drainage, warmer soil conditions, and healthier plant growth.
- In densely populated zones, technologies for container/rooftop/terrace gardening, vertical farming, hydroponics and modular protected structures are needed (NAAS, 2013). Quality seedling supply, safe inputs (water, soil), and wastewater treatment are critical (NAAS, 2022d). IIVR's short-duration leafy varieties and protocols for small-scale protected cultivation could be promoted in these settings to meet local fresh supply needs and reduce transportation/post-harvest costs.

Vision-2047 strategic framework for transforming India's vegetable sector

National cross-cutting strategic priorities

Achieving sustainable transformation of the vegetable sector requires coordinated national-level interventions that address productivity, resource efficiency, and resilience simultaneously. Central to this strategy is the development and large-scale dissemination of high-yielding, biofortified, climate-resilient, and pest- and disease-resistant varieties. Genetic improvement, including stress-tolerant cultivars and non-staking or input-efficient varieties, can reduce production risks while enhancing yield stability.

Precision resource management forms the second pillar of national strategy. Soil-test-based nutrient application, customized micronutrient formulations, nano-fertilizers, and integrated nutrient management approaches are essential for improving nutrient-use efficiency and restoring soil health. Similarly, micro-irrigation, sensor-based fertigation, mulching, and water-saving technologies are critical to enhancing water-use efficiency under conditions of declining groundwater availability.

Integrated pest and disease management (IPDM), based on resistant varieties, biological control agents, ecological engineering, and advanced diagnostics, must progressively replace excessive reliance on chemical pesticides. This transition will not only reduce production costs but also ensure safer, residue-free produce aligned with consumer demand.

Post-harvest strengthening constitutes another national priority. Investments in decentralized pack-houses, grading and sorting units, cold-chain infrastructure, and small-scale processing can significantly reduce post-harvest losses while improving farmer realization. Integration of renewable energy solutions, including solar-powered irrigation and cold storage systems (NAAS, 2024a), can further enhance sustainability and reduce operational costs.

Mechanization and digital agriculture will play a transformative role in reducing labour dependency and improving operational efficiency. Promotion of smallholder-friendly machinery, Custom Hiring Centres, drone-based applications, and AI-enabled advisory systems is essential for timely and precise farm operations (NAAS, 2024b; NAAS, 2025b).

Region-specific strategic interventions

Given India's agro-climatic diversity, regionally tailored interventions are indispensable. In coastal regions, emphasis must be placed on salinity- and waterlogging-tolerant varieties, improved drainage systems, and protected cultivation structures to buffer extreme weather events. Likewise, in hilly and North-Eastern states, low-cost protected structures such as naturally ventilated polyhouses and tunnels can extend growing seasons and enable off-season production. Promotion of biofertilizers and organic production systems can leverage the relatively low chemical intensity of these regions, while water harvesting and micro-irrigation systems can mitigate moisture variability.

Arid and semi-arid regions require climate-resilient, heat- and drought-tolerant varieties alongside efficient irrigation systems such as drip and sprinkler methods. Mulching, conservation tillage, and sensor-based fertigation are essential to optimize limited water resources. Innovative land-use models such as agrivoltaics, integrating crop production with solar energy generation, offer opportunities for climate buffering, resource-use efficiency, and income diversification (NAAS, 2025a).

States with large urban populations require expansion of peri-urban vegetable clusters and promotion of rooftop, terrace, hydroponic, and modular protected cultivation systems to address land scarcity and reduce transportation losses (NAAS, 2013). Quality seedling production systems and safe input management are critical in these intensive production zones.

Institutional and energy integration

Technological interventions must be complemented by institutional strengthening. Farmer Producer Organizations (FPOs), cooperatives, and structured market arrangements can enhance aggregation, reduce transaction costs, and improve farmer bargaining power. Contract farming models may further support market integration and risk-sharing mechanisms (NAAS, 2022c). Secondary agriculture, through processing, value addition, and waste utilization, offers substantial scope for enhancing farm incomes and generating rural employment (NAAS, 2022b). Development of decentralized processing units and cluster-based value chains can reduce post-harvest losses while stabilizing prices.

Integration of renewable energy technologies, particularly solar-powered irrigation, cold storage, and agro-processing units, will be crucial for reducing energy costs and improving environmental sustainability (NAAS, 2024a). Such convergence of agricultural and energy systems aligns with long-term climate adaptation goals.

Strategic outcomes under Vision-2047

If implemented in a phased and coordinated manner, the proposed technology framework has the potential to significantly transform India's vegetable sector by 2047. The central objective is to raise national average productivity beyond 30 t/ha through the combined adoption of climate-resilient varieties, precision nutrient management, protected cultivation, and improved agronomic practices. Enhanced micro-irrigation, sensor-based fertigation, mulching, and other water-saving technologies are expected to improve water-use efficiency by nearly 50%, strengthening sustainability under growing water scarcity. Integrated pest and disease management, through biocontrol agents, resistant cultivars, and ecological engineering, can reduce pesticide expenditure by 30–40% while ensuring safer, residue-free produce. Strengthened post-harvest systems, including decentralized packhouses, cold chain infrastructure, improved storage, and value-addition technologies, aim to reduce losses to below 10%, thereby increasing marketable surplus and farmer profitability. Renewable energy-based infrastructure, particularly solar-powered irrigation and post-harvest systems, will be critical for reducing energy costs and carbon footprint in vegetable production systems (NAAS, 2024a). Institutional innovations such as FPO-led aggregation and structured contract farming arrangements can improve market integration and farmer bargaining power (NAAS, 2015). Integrated agrivoltaic systems may further enhance sustainability by combining renewable energy generation with climate-resilient crop production (NAAS, 2025a).

Overall, Vision-2047 calls for a transition from area-led growth to productivity-driven, resource-efficient intensification supported by technological innovation and institutional reform. Scaling sustainable intensification, mechanization, and smart farming solutions will be critical to bridging yield gaps and ensuring long-term nutritional and livelihood security.

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