***Evaluating Growth Patterns in Indian Vegetable Farming: A Trend Analysis of Area, Production, and Productivity***

**Abstract**

This paper attempts to explore the trends and variability of total and major vegetable crops cultivation with regard to area, production and productivity across the country. The secondary data pertaining to area, production and productivity of vegetable crops grown in India were collected from the Indiastat for the period from 2009-10 to 2023-24, divided into Period I (2009-10 to 2013-14), Period II (2014-15 to 2018-19) and Period III (2019-20 to 2023-24). Statistical tools like mean, percentage Absolute Growth Rate (AGR) and Compound Annual Growth Rate (CAGR), were worked out to study total growth over a period and average annual growth rate respectively, whereas Cuddy Della Valle Instability Index was used to study variability. The study reveals a positive and consistent growth trajectory in terms of area under cultivation, production, and productivity. Period I saw the highest expansion, with absolute area growing by 17.67% (CAGR 3.31%), production increasing by 21.80% (CAGR 4.02%), while productivity remained stagnant. Onion and peas witnessed the highest growth in area and production, with low instability among the selected vegetables. Tapioca exhibited a declining trend in area and production, with moderate instability. In the context of climate change and the crucial role of leafy vegetables, root, and tuber crops in ensuring food and nutritional security, expansion of the area under vegetable cultivation and improvement in productivity would be a strategic step towards achieving ‘self-reliance’ and advancement of the ‘Make in India Mission’.

**Keywords:** GrowthTrends, Variability, Productivity, Vegetables, Tapioca, CAGR

1. **INTRODUCTION**

Vegetable is the term given to edible plant parts, a group of horticultural plants grown for human consumption for their nutritional value. These include leaves (spinach, lettuce), roots (carrots, radish), tubers (potatoes, sweet potatoes), flowers (cauliflower, broccoli), seeds (peas, beans), fruits (tomatoes, cucumbers, eggplant), and stems (celery, asparagus) (Singh B, 2017). Vegetables are considered protective foods and also play an important role in providing a balanced diet to the human beings. A balanced diet contains adequate energy source(carbohydrates), vitamins, minerals, fat, fibre and protein rich in essential amino acids (Singh B, 2017). Most of the protein (60.2 %) consumed in India is derived from cereals, which is deficient in some amino acids such as methionine and cysteine thus causing an imbalance in amino acids (Singh B, 2017). Approximately two billion individuals globally experience a lack of essential vitamins and minerals. Vegetables, as affordable sources of protein, vitamins, and minerals, contribute greatly to reducing nutrient deficiencies. In addition to the contribution of valuable nutrients, vegetables add variety, taste, colour, and texture to meals which provide fibre for digestion and prevents constipation. They neutralize the acids produced during digestion of proteinaceous and fatty foods and also provide valuable roughages which help in movement of food in intestine (Singh B, 2017).

**Table 1: Top five vegetables growing country in the world**

|  |  |  |
| --- | --- | --- |
| **Country** | **Total Production (in percent)** | **Productivity (t/ha)** |
| **China** | 52.26 | 26.10 |
| **India** | 12.20 | 15.81 |
| **USA** | 2.65 | 36.64 |
| **Turkiye** | 2.29 | 41.67 |
| **Vietnam** | 1.54 | 17.35 |

**Source:** Food and Agricultural Organization Database Statistics 2023

From the Table 1, It’s evident China leads the world in vegetable production, contributing 52.26 per cent of total output. Its expansive cultivable land, favourable climate, cheap labour and strong vegetable farming practices facilitate this dominance but the productivity of 26.10 t/ha is moderate. India follows as the second-largest producer at 12.20 per cent of the global share, yet it faces challenges reflected in its lower productivity of 15.81 t/ha. Factors such as fragmented landholdings, limited access to quality inputs, and inefficient farming practices need addressing to enhance yield. The USA, while only accounting for 2.65 percent of total vegetable production achieves impressive productivity of 36.64 t/ha that underscores the benefits of mechanization, technology integration, and effective resource use. Turkiye stands out with the highest productivity among these counterparts at 41.67 t/ha, despite its modest production share of 2.29 per cent indicating a strong focus on yield maximization, possibly through advanced farming techniques and resource efficiency.

India is known as fruit and vegetable basket of the world. India being a home to wide variety of vegetables owing to its diverse climatic conditions holds a unique position in production figures among other countries. India’s diverse climatic conditions, ranging from tropical in the south to temperate in the north, offer the potential to grow a wide variety of vegetables year-round. However, this diversity also brings challenges such as uneven rainfall, temperature extremes, and regional variability in soil quality, which can affect crop yields. India is the second largest producer of overall vegetables production in the world (Table 1), after China and one of the centres of origin of many vegetables with the total production of 207.2 million tonnes of vegetables in the year end 2023-24 (NHB, 2023) contributing around 12 percent of the world’s vegetable production. Cultivation of vegetable is very appealing to small and marginal farmers as it offers higher economic returns compared to traditional crops. Research has shown that cultivating vegetables on small landholdings is more profitable, as it utilizes family labour effectively and ensures employment, income, and nutrition security throughout the year. (Ryan and Spencer 2001, Singh et al., 2002). In a densely populated country like India, where most farmers have small landholdings, vegetable production plays a crucial role in socio-economic development. Furthermore, the demand for fresh vegetables has increased due to the rise in health consciousness among both urban and rural populations, which implies a promising future for vegetable growers.

According to the guidelines from the National Institute of Nutrition (NIN), individuals should consume 400 g of vegetables per day, comprising 100 g of leafy greens, 250 g of other vegetables, and 50 g of roots and tubers. According to this recommendation, per capita vegetable requirement works out to be 146 kg per year and total annual requirement of the country to be around 209.74 million tonne (with 143.81 crore current population). And, there is approximately 20% post-harvest losses in vegetables, so the effective production amounting to 165.77 million tonnes indicating a significant gap in the production and demand.

Uttar Pradesh leads among the states in terms of vegetable output (Table 2) with a production of 34.43 million tonnes (Mt), followed by West Bengal. These two states combined account for a 30.71 % share of the country's vegetable production, highlights their significance in the agricultural landscape. Also, the 10 states in Table 2 contributes for 80.23 % of the country’s total vegetable production, demonstrates a concentrated production capability.

**Table 2: Top Ten Vegetable Growing State in India**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Rank** | **States** | **Area (Mha)** | **Production (Mt)** | **Productivity (t/ha)** |
| 1 | Uttar Pradesh | 1.43 | 34.43 | 24.11 |
| 2 | West Bengal | 1.58 | 29.20 | 18.45 |
| 3 | Madhya Pradesh | 1.27 | 24.35 | 19.10 |
| 4 | Bihar | 0.92 | 17.15 | 18.64 |
| 5 | Gujarat | 0.75 | 15.26 | 20.34 |
| 6 | Maharashtra | 0.92 | 12.33 | 13.43 |
| 7 | Odisha | 0.76 | 10.62 | 13.93 |
| 8 | Tamil Nadu | 0.36 | 9.26 | 25.50 |
| 9 | Punjab | 0.33 | 6.88 | 20.58 |
| 10 | Chhattisgarh | 0.49 | 6.75 | 13.75 |

**Source:** Dept. of Agriculture & Farmer’s Welfare 2023

**2. METHODOLOGY**

This chapter presents general description of the study area, data collection and the methods being used for analysis of data to fulfill the objectives of the study. The study focusses on the vegetable production landscape across India, with particular attention to key crops and states known for their significant contributions to vegetable cultivation. We carried out this research to analyze the trends in the area, production, and productivity of major vegetables in India as vegetables are essential for nutritional security, particularly for smallholder farmers and low-income consumers. The short crop cycles of vegetables offer quick returns, which is ideal for government initiatives to double farmers' income. Crops like potatoes, tomatoes and onions dominate consumption, particularly among socio-economically disadvantaged people, as their cultivation are supported by price stabilization measures. The demand for leafy greens and other vegetables driven by health-conscious consumers, leads to a rise in vegetable imports that shows gaps in domestic production due to limited government support for these crops. The import value of edible vegetables and certain roots and tubers increased from $1189.1 million in 2018-19 to $3832.14 million in 2023-24, with notable fluctuations in between. This study helps to assess how government policies, market dynamics, and consumer preferences influences vegetable cultivation. It will also identify opportunities for increasing domestic production, reducing import dependency, and supporting smallholder farmers.

The time series data of the area, production, and productivity of vegetables from 2009 to 2023 were collected for this study. The primary sources of data were government publications and the Indiastat website. The widely used methodology Absolute Growth Rate(AGR), Compound Annual Growth Rate and Cuddy Della Valle Instability Index (CDVI) was selected for this study.

The Absolute growth rate of study variables (Area, Production and Productivity) was analyzed using the following formula:

AGR = (EV-BV/BV) \*100

The Compounded annual growth rate of study variables (Area, Production and Productivity) was analyzed using the following formula:

𝐶𝐴𝐺𝑅 = (E𝑉 /𝐵𝑉) 1/ 𝑛 − 1 × 100,

Here, EV stands for Ending Value, BV stands for Beginning Value, and n stands for the number of years considered for analysis.

Cuddy Della Valle Instability Index was used to measure the variability of area under cultivation, production and productivity of vegetables across India over the last 15 years. The instability index is derived from the coefficient of variation which is multiplied by the square root of the differences between the coefficient of determinations (R2) and unity.

Della Valle Instability Index = CV x (1 – R2 )1/2

Where, CV = Coefficient of Variation and R2 = Coefficient of determinations. The level of instability can be categorized into low instability (between 0-15), medium instability (between 15-30), and high instability (more than 30).

The selection of major crops for this study was based on their significant average contributions to the nation’s total vegetable area and production over the previous five years, from 2019 to 2023. The selected vegetables—potato, onion, tomato, brinjal, peas, okra, cauliflower, tapioca and cabbage represent a significant share of the total area (69.44%) under cultivation and production volume (76.57%). These crops collectively offer a thorough picture of production trends and patterns in India’s vegetable sector which makes them ideal for in-depth examination in this paper.

**Table 3: List of Vegetables Selected for Study**

|  |  |  |
| --- | --- | --- |
| **Vegetables** | **Area (in percent)** | **Production (in percent)** |
| Potato | 20.24 | 27.33 |
| Onion | 15.05 | 13.65 |
| Tomato | 7.64 | 10.30 |
| Brinjal | 6.42 | 6.32 |
| Cabbage | 3.84 | 4.83 |
| Cauliflower | 4.40 | 4.63 |
| Okra | 4.92 | 3.36 |
| Tapioca | 1.58 | 3.09 |
| Peas | 5.35 | 3.06 |
| **Total** | **69.44** | **76.57** |

**Source:** Author’s Construction from Dept. of Agriculture & Farmer’s Welfare

**3. RESULTS & DISCUSSIONS**

**Table 4: Area, Production and Productivity of Total Vegetables**

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Area** | **Production** | **Productivity** |
| **(mln ha)** | **(mln MT)** | **(MT/ha)** |
| 2009-10 | 7.99 | 133.74 | 17 |
| 2010-11 | 8.50 | 146.56 | 17 |
| 2011-12 | 8.99 | 156.33 | 17 |
| 2012-13 | 9.21 | 162.19 | 18 |
| 2013-14 | 9.40 | 162.90 | 17 |
| 2014-15 | 9.54 | 169.48 | 18 |
| 2015-16 | 10.11 | 169.06 | 17 |
| 2016-17 | 10.24 | 178.17 | 17 |
| 2017-18 | 10.06 | 184.04 | 18.3 |
| 2018-19 | 10.07 | 183.17 | 18 |
| 2019-20 | 10.24 | 188.13 | 18.4 |
| 2020-21 | 10.86 | 200.45 | 18.5 |
| 2021-22 | 11.37 | 209.14 | 18.4 |
| 2022-23 | 11.31 | 212.55 | 18.8 |
| 2023-24 | 11.23 | 207.21 | 18.4 |
| **CAGR (%)** | **2.30** | **2.96** | **0.55** |
| **Mean** | **9.94** | **177.54** | **17.79** |
| **CDVI (%)** | **2.64** | **2.57** | **2.39** |

**Source:** Author’s Construction from Dept. of Agriculture & Farmer’s Welfare

*Trend in the area under vegetables:* The area under vegetable crops in India has grown at the rate of 2.30 % per year during 2009–10 to 2023–24, to reach an overall value of 11.23 million hectare as on 2023–24. The mean area under vegetables was observed to be 9.94 million hectares. The Cuddy Della Vella Instability Index shows 2.64 % of instability in areas under cultivation of vegetables in India.

*Trends in the production of vegetables*: In terms of production, the compound growth rate during the period 2009–10 to 2023–24 was observed to be 2.96% for the country as a whole. During this period, the mean production under vegetables was found to be 177.54 million tonnes for India. The Cuddy Della Vella Instability Index shows 2.57% instability in production of vegetables in India. In India, the per cent change in production of vegetables during the study period revealed an increasing trend.

*Trends in the productivity of vegetables*: The overall compound growth rate in productivity of vegetables was seen to be 0.55 % in the country as a whole. The mean productivity of vegetables for India was found to be 17.79 Mt/ha. The Cuddy Della Vella Instability Index shows 2.39% variation in productivity of vegetables in India in terms of productivity of vegetables.

Due to advancements in production technology, rising demand and various governmental supports over this time period, the area, production, and productivity of vegetables increased consistently in India with CAGRs of 2.30 %, 2.96%, and 0.55%. The mean area, production, and productivity values indicate a consistent upward trend which is in line with the findings Kumar *et al*. (2023), while the low CDVI across area (2.64%), production (2.57%), and productivity (2.39%) signifies low instability in each metric. This stability is promising for long-term planning and forecasting, pointing to a sustainable production environment for vegetables in India, favourable for meeting both domestic demands and potential export opportunities.

**Fig 1** : Growth in area, production and productivity of vegetables over the years in India

**Table 5: Absolute Growth Rate (AGR) over the period and CAGR**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Period | Year | Area | | Production | | Productivity | |
| AGR(%) | CAGR (%) | AGR(%) | CAGR (%) | AGR(%) | CAGR (%) |
| I | 2009-10 – 2013-14 | 17.67 | 3.31 | 21.80 | 4.02 | 0.00 | 0.00 |
| II | 2014-15 – 2018-19 | 5.56 | 1.09 | 8.08 | 1.57 | 0.00 | 0.00 |
| III | 2019-20 – 2023-24 | 9.69 | 1.87 | 10.14 | 1.95 | 0.26 | 0.05 |

**Source:** Author’s Calculation

*Period I: 2009-10 to 2013-14 (High Growth Phase)*

Vegetable cultivation expanded at rapid pace during this period with the support of favourable government policies, technological advancements, and rising demand with population increase. The National Horticulture Mission (NHM) and Horticulture Mission for North East and Himalayan States (HMNEH) (2005-06) might have played an instrumental role in this expansion by providing subsidies for planting materials, irrigation, and post-harvest infrastructure, ensuring holistic sectoral growth. Furthermore, the National Mission on Micro Irrigation (NMMI) (2006-2014) might have contributed to improved water-use efficiency through drip and sprinkler irrigation, potentially leading to better crop production. These efforts might have collectively driven the significant increase in production (4.02% CAGR) and area expansion (3.31% CAGR), though productivity remained stagnant during this phase.

*Period II: 2014-15 – 2018-19 (Slowdown in Growth)*

Vegetable cultivation experienced moderate expansion during this period, though at a slower pace compared to the previous phase which might be attributed to resource constraints and shifting policy priorities. An initial slowdown might have resulted from the introduction of the Mission for Integrated Development of Horticulture (MIDH) (2014), which merged NHM and HMNEH, as administrative transitions took place. Similar to this, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) (2015) might have strengthened micro-irrigation initiatives, but its immediate impact might have been limited due to awareness gaps, trust issues, and high costs which prevented its widespread implementation. The Soil Health Card Scheme (2015) might have attempted to address soil fertility issues and improve nutrient management, but its slow implementation might have delayed visible productivity gains. These factors might have played a role in slowed growth rate in area (1.09% CAGR) and production (1.57% CAGR), with productivity remaining unchanged.

*Period III: 2019-20 to 2023-24 (Recovery but Productivity Decline)*

The growth of the area cultivated (1.87% CAGR) and production levels (1.95% CAGR) have shown signs of recovery in this phase, likely aided by increased resilience in the post-pandemic environment along with a renewed policy emphasis on horticulture. Nevertheless, productivity growth (0.05% CAGR) remained negligible, that highlights persistent challenges in yield improvement. Several government initiatives might have played a significant role in this partial recovery. Operation Greens initiative introduced in 2018 have helped stabilize prices for perishable vegetables like tomato, onion, and potato —collectively referred to as TOP crops, which might have incentivized farmers to expand cultivation. Additionally, the PM Kusum Yojana, launched in 2019, might have improved irrigation access to some extent through solar-powered pumps and the supply chain of vegetables may have benefitted from PM Formalization of Micro Food Enterprises (PM-FME), initiated in 2020, which supported small-scale vegetable processing, could serve to motivate further cultivation. Moreover, the Agri Infrastructure Fund established in 2020 could have facilitated post-harvest infrastructure development, though its impact may have been relatively small due to implementation challenges. Lastly, the MIDH-Cluster Development Programme, introduced in 2022, might have further promoted organized vegetable clusters, potentially improving efficiency and market access.

On the export front, the government's focus on global market integration have strengthened during this period. The Agricultural Export Policy (2018) might aimed to double agricultural exports by 2022, with a special emphasis on perishable horticultural products. Infrastructure developments in cold storage, packhouses, and logistics under AIF may have helped improve the quality and shelf life of exported vegetables, though challenges in implementation and market access might have persisted.

**Fig 2** : Comparative average growth and compounded growth in three periods

*Area, production and productivity of selected vegetables in India:*

**Table 6:** Growth and Instability in area, production and productivity of major vegetables in India

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Vegetables** | **Mean Area** | **CAGR %** | **CDVI** | **Mean Production** | **CAGR %** | **CDVI** | **Mean Productivity** | **CAGR %** | **CDVI** |
| Potato | 2.09 | 1.58 | 2.65 | 48.46 | 3.01% | 5.08 | 23.07 | 1.41% | 4.68 |
| Onion | 1.32 | 4.86 | 10.70 | 21.88 | 4.71 | 9.78 | 16.57 | -0.15 | 6.43 |
| Tomato | 0.82 | 2.00 | 8.31 | 18.95 | 3.66 | 7.73 | 23.16 | 1.63 | 5.76 |
| Brinjal | 0.70 | 0.98 | 5.67 | 12.61 | 1.65 | 5.70 | 18.10 | 0.67 | 4.66 |
| Cabbage | 0.40 | 1.95 | 3.06 | 8.98 | 2.43 | 2.98 | 22.62 | 0.47 | 1.42 |
| Cauliflower | 0.44 | 2.74 | 2.94 | 8.42 | 2.87 | 3.76 | 19.23 | 0.12 | 1.95 |
| Okra | 0.52 | 1.40 | 3.51 | 6.24 | 2.84 | 6.18 | 11.99 | 1.41 | 3.17 |
| Tapioca | 0.20 | -1.80 | 5.81 | 6.36 | -1.65 | 22.71 | 32.22 | 0.15 | 20.16 |
| Peas | 0.50 | 3.49 | 3.02 | 5.01 | 5.40 | 3.56 | 9.86 | 1.85 | 2.85 |

**Source**: Author’s construction

*Potato*: Potato cultivation in India has experienced consistent growth in area (CAGR 1.58%) and production (CAGR 3.01%), while productivity growth is relatively moderate at a CAGR of 1.41%. The low volatility in area, production and productivity indicate a consistent expansion trend with sustainable yield variations, which might have been driven by climatic and agronomic factors. Uttar Pradesh continues to be on top in terms of production, followed by West Bengal and Bihar, all benefiting from large-scale cultivation and strong market linkages. However, regional disparities in productivity persists. States like Gujarat and Punjab register higher yields due to efficient irrigation systems, utilization of high-quality seeds and better storage infrastructure. Whereas, Bihar and West Bengal face constraints such as fragmented landholdings, traditional farming methods and inconsistent irrigation access. The impact of rising temperatures on tuber dormancy is also notable, as it affects both seed quality and yield stability. Moreover, the water-intensive nature of potato cultivation and inadequate cold storage infrastructure further increases post-harvest losses, which in turn influences price stability and determines overall area-production trend.

*Onion*: Onion cultivation in India has exhibited strong growth in area and production at a CAGR of 4.86% and 4.71%, respectively. However, the productivity has experienced a slight decline, recorded at -0.15% CAGR which indicates a decline in yield improvements over time. Close to moderate instability in production (CDVI 9.78%) and in area (CDVI 10.70%) suggest that fluctuations might be driven by weather conditions, market dynamics, frequent government interventions like ban on export, minimum export price setting and farmer responses to price volatility. Maharashtra remains the leading state in onion production, followed by Madhya Pradesh and Karnataka, which benefit from extensive cultivation lands, favourable agro-climatic conditions and well-established supply chains. However, productivity varies significantly across states, for instance Gujarat consistently achieves higher yields due to superior irrigation management, soil fertility, and the ability to cultivate two onion crops annually. Conversely, challenges persist as increasing temperatures and unpredictable rainfall patterns negatively impact bulb development, while storage losses further contributing to price volatility, which subsequently influences both the area under cultivation and production trends.

*Tomato:* Tomato cultivation in India has grown moderately, with area expanding at 2.00% CAGR, production at 3.66% CAGR, and productivity increasing at 1.63% CAGR. The increasing instability in area (CDVI 8.31%) and production (CDVI 7.73%) suggests fluctuations influenced by climatic factors, market dynamics, and seasonal price variations, while low instability in productivity (CDVI 5.76%) indicates relatively stable yield trends. The expansion in tomato production might be attributed to increasing cultivation area, adoption of high-yielding varieties, rising demand due to culinary uses and convenience product and government initiatives such as Operation Greens (2018), which aimed to stabilize prices and support production for perishable crops like tomato, onion, and potato (TOP crops). Additionally, schemes like PM Formalization of Micro Food Enterprises (PM-FME) (2020) have encouraged small-scale vegetable processing, indirectly promoting production growth. Madhya Pradesh, Odisha, and Karnataka lead in tomato production due to larger cultivated areas, improved market access, and favourable agro-climatic conditions. However, regional disparities in productivity persist—Andhra Pradesh achieves the highest yield (~45 t/ha,2023), whereas states like West Bengal (~21 t/ha,2023) and Chhattisgarh (~22 t/ha,2023) lag behind, likely due to differences in soil quality, irrigation access, and farming practices. Despite the growth in production, the increasing temperatures have been shown to adversely affect lycopene synthesis, leading to declines in fruit quality and overall production output.

**Fig 3:** Growth and Instability in area, production and productivity of major vegetables in India

*Brinjal*: Brinjal cultivation in India has shown moderate growth, with area expanding at 0.98% CAGR, production at 1.65% CAGR, and productivity at 0.67% CAGR, indicating stable expansion. Low instability in area (CDVI 5.67%), production (CDVI 5.70%), and productivity (CDVI 4.66%) suggest fewer external disruptions. West Bengal (23.83%), Odisha (16.91%), and Gujarat (12.23%) lead in production, benefiting from year round robust cultivation practices and established supply chains, while Andhra Pradesh (50.00 t/ha), Kerala (42.03 t/ha), and Uttar Pradesh (36.04 t/ha) achieve the highest productivity due to better irrigation and hybrid seed adoption. However, states like Jharkhand (11.27 t/ha) and Tamil Nadu (13.51 t/ha) lag due to soil degradation and rain-fed farming. Pest infestations (fruit and shoot borer), price volatility, and post-harvest losses remain key challenges, limiting productivity gains.

*Cabbage*: Cabbage cultivation in India has grown steadily, with area expanding at 1.95% CAGR, production at 2.43% CAGR, and productivity at 0.47% CAGR, indicating slow but stable yield improvements. Low instability in area (CDVI 3.06%), production (CDVI 2.98%), and productivity (CDVI 1.42%) suggest a highly stable crop. West Bengal (22.95%), Odisha (12.44%), and Madhya Pradesh (10.32%) dominate production due to extensive cultivation and favourable climatic conditions. Tamil Nadu (68.7 t/ha), Kerala (47.8 t/ha), and Uttar Pradesh (34.7 t/ha) achieve the highest productivity, benefiting from controlled irrigation and better agronomic practices. However, states like Sikkim (5.9 t/ha) and Uttarakhand (7.0 t/ha) lag due to harsh climatic conditions and rainfed farming. Pest infestations (diamondback moth), post-harvest losses, and price fluctuations remain key challenges affecting the trend to some extent.

*Cauliflower*: Cauliflower cultivation in India has demonstrated steady growth in area (CAGR 2.74%) and production (CAGR 2.87%), but productivity growth remains stagnant (CAGR 0.12%), highlighting limited adoption of yield-enhancing practices. Area (CDVI 2.94%) and production (CDVI 3.76%) exhibit low instability, indicating stable expansion, while productivity instability (CDVI 1.95%) reflects minor yield fluctuations. West Bengal leads production, followed by Bihar and Madhya Pradesh, benefiting from favourable climates and large cultivation areas. However, productivity varies significantly, with Tamil Nadu, Uttar Pradesh, and West Bengal achieving higher yields due to improved seed varieties, efficient nutrient management, and irrigation. Challenges such as rising temperatures, pest infestations, water stress, and post-harvest losses persist also play a significant role in driving the trend.

*Okra*: Okra cultivation in India exhibits low instability in area (CDVI 3.51%), production (CDVI 6.18%), and productivity (CDVI 3.17%), reflecting a stable expansion trend. The sector has achieved moderate growth in area (CAGR 1.40%) and production (CAGR 2.84%), with a slight increase in productivity (CAGR 1.41%), indicating gradual yield improvements. West Bengal, Odisha, and Gujarat dominate production, leveraging large cultivation areas and favourable agro-climatic conditions. However, Telangana, Himachal Pradesh, and Jammu & Kashmir report higher productivity, attributed to balanced temperature and improved farm management practices. It’s susceptibility to yellow vein mosaic virus (YVMV), climate variability, erratic rainfall, and price volatility, also play a role in driving the production trend.

*Tapioca*: Tapioca cultivation in India has exhibited a declining trend in area (CAGR -1.80%) and production (CAGR -1.65%) that is in line with the findings of Prakash *et al*. (2020), indicating a gradual contraction of tapioca farming which may be due to replacement with other commercial crops coupled with other socio-economic constraints. However, productivity has remained relatively stable with a slight increase (CAGR 0.15%). The crop shows low instability in area (CDVI 5.81%) but faces moderate instability in production (CDVI 22.71%) and productivity (CDVI 20.16%), suggesting that external factors like climate variability and disease outbreaks significantly impact yields. Tamil Nadu and Kerala dominate tapioca production cultivating more than 92% of total country’s production as it grows well in tropical, warm humid climates with well-distributed rainfall, with Tamil Nadu contributing the largest. However, unlike other staple crops, tapioca has limited demand in the retail market, as it is primarily cultivated for starch extraction and sago production. Most of the production is marketed to private sago manufacturers, resulting in low price realization for farmers. The lack of government intervention in price regulation further exposes farmers to market fluctuations and exploitation by private buyers. Additionally, Cassava Mosaic Virus (CMV) remains a major factor, affecting crop health and yield stability.

*Peas*: Pea cultivation in India has shown a strong growth trend in area (CAGR 3.49%) and production (CAGR 5.40%), indicating increasing farmer interest and expanding cultivation. Productivity has also improved at a moderate rate (CAGR 1.85%), suggesting gradual enhancements in farming practices and input efficiency. The crop exhibits low instability in area (CDVI 3.02%) and production (CDVI 3.56%), reflecting a relatively stable cultivation pattern, while productivity instability remains low (CDVI 2.85%), indicating consistent yield levels across seasons. Uttar Pradesh is the largest producer of peas, contributing a significant share of national output, followed by Madhya Pradesh and Punjab. These states benefit from favourable climatic conditions and well-established supply chains. However, productivity varies across regions, with states like Jammu & Kashmir and Jharkhand achieving higher yields (21.63 t/ha and 19.99 t/ha, respectively), attributed to better agronomic practices and soil conditions. Despite its steady growth, peas face challenges related to price fluctuations and limited processing infrastructure, which could have impacted the trend. The increasing demand for fresh and frozen peas presents opportunities for value addition and export potential which may further drive the trend.

**4. CONCLUSION**

The analysis of vegetable cultivation trends in India from 2009-10 to 2023-24 reveals a positive and consistent growth trajectory in terms of area under cultivation (**2.30%**), production (**2.96%**), and productivity (**0.55%**). The low CDVI across area, production, and productivity indicates a stable and resilient sector suggesting that vegetable cultivation in India is less susceptible to fluctuations. However, despite this growth, India's vegetable production still struggles to meet actual domestic requirements due to rising consumption needs, significant post-harvest losses of approximately 20%, and lower productivity compared to global leaders. Also, the vegetable farming are concentrated to particular geographical condition as only 10 states contributes for 80.23 % of the total production so there is a need to increase the geographical diversification to enhance the productivity, nutrition and food security. Moreover, challenges such as degrading soil health, declining water availability, and the increasing unpredictability of climate conditions further constrain productivity improvements in many regions. Addressing these requires localized solutions tailored to agro-climatic zones.

Vegetable cultivation in India experienced varying growth trends across three distinct periods. Period I (2009-10 to 2013-14) saw the highest expansion, with area growing by 17.67% (CAGR 3.31%), production increasing by 21.80% (CAGR 4.02%), while productivity remained stagnant. Period II (2014-15 to 2018-19) witnessed a slowdown, with area expanding by only 5.56% (CAGR 1.09%) and production by 8.08% (CAGR 1.57%), while productivity remained unchanged. Period III (2019-20 to 2023-24) indicated a partial recovery in area (9.69%, CAGR 1.87%) and production (10.14%, CAGR 1.95%), but productivity growth remained minimal at 0.26% (CAGR 0.05%).

Among the selected vegetables, onion and peas showed the highest growth in area and production (CAGR 4.86% & 5.40%), with low instability. Potato and tomato also exhibited steady growth in area and production, with low instability. Brinjal, cabbage, cauliflower, and okra maintained stable trends with moderate productivity growth and low instability. Tapioca showed a declining trend in area and production, with moderate instability in productivity (CDVI 20.16). Overall, while most crops experienced stable expansion, productivity gains remained modest, requiring further improvements in cultivation practices and inputs. In this context, adopting advanced technologies such as precision farming, protected cultivation, and improved irrigation methods becomes crucial. Promoting climate-smart agriculture and nutrient-rich varieties can also address regional disparities and enhance resilience.

Despite significant growth in the area and production but modest growth in productivity of vegetables, inadequate post-harvest handling and marketing facilities, along with the absence of a systematic marketing system, discourage vegetable growers. There is a pressing need to diversify the traditional ‘cereal- cereal’ production system for the agricultural sustainability as well as to diversify the diet table of the country. To feed a minimum of 400 gms/person/day by 2030, India must grow production at an average annual rate of 11.18% and expand the area under cultivation at 5.61% (assuming projected population to be 151.8 crore in 2030), if the country fails to work on the productivity rate and there is persistent 20% post-harvest losses. It is also evident from the Table 1 that India has the lowest productivity among top 5 vegetable producing country in the world. The growth of vegetable production by increasing the area only under vegetable crops cannot be a healthy solution for long time because agriculture lands are limited, not expanding rather decreasing day by day. The country's marketing system remains largely unregulated with poor infrastructure, exacerbating challenges for vegetable growers. Policy-level interventions can play a transformative role. Government support in the form of crop-specific incentives, extension services, and public-private partnerships can help in mainstreaming innovations and improving farmers’ access to markets. Strengthening market intelligence systems can also play a pivotal role in addressing price volatility, ensuring sustainable production, and enhancing farmers' profitability. In addition there is need to promote contract farming of vegetables which generally bridges the gap by provision of quality inputs, management skills, technical guidance and even financial assistance to the resource poor farmers who can’t afford the cost of modern inputs and invest more in cultivation of vegetables. The post-harvest loss of vegetables can be minimised by establishing efficient cold storage, fast and efficient transportation facility and developing a good network of well regulated market channels. Through these combined efforts, India can enhance vegetable production, ensure market stability, and support smallholder farmers.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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