**Growth, Instability and Decomposition Analysis of Chilli Cultivation in India**

**ABSTRACT:**

This study analyzes the growth, instability, and decomposition of chilli cultivation in India over a 30-year period using secondary data.The study is divided into three sub-periods: 1993–2002, 2003–2012, and 2013–2022, examining variations in area, production, and yield . Growth trends are measured using the Compound Annual Growth Rate (CAGR), and variability is assessed through the Cuddy-Della Valle Instability Index (CDVI). Despite a decline in cultivated area, the results show that chili production and yield have generally increased, especially in the period 2013–2022. The decomposition analysis reveals that improvements in yield have been the primary driver of production growth, although fluctuations in area and the interaction between yield and area have impacted overall production. The study emphasizes the importance of stabilizing production and enhancing farming practices to maintain growth in chili cultivation.

**Keywords:** Chili cultivation, Yield growth, CAGR, Instability index and Decomposition analysis

1. **INTRODUCTION**

India, known as the "Spice Bowl of the World," capitalizes on its diverse agroclimatic conditions to remain a global leader in spice production (Spices Board of India, 2025; Angles et al., 2011). As the world's largest producer, consumer, and exporter of chilies, it surpasses countries like China, Thailand, Ethiopia, and Indonesia (Crop Outlook Reports, PJTSAU). In 2023-24, chili cultivation in India covered approximately 8.09 lakh hectares, yielding an estimated 29.13 lakh tonnes with an average yield of 3,273 kg/ha (ANGRAU Chilli Outlook Report.). India cultivates several well-known chili varieties, such as Jwala, Teja, Bhoot Jolokia, Dhani, and Bhavnagri, valued for their intense pungency, deep red hue, and industrial significance (Crop Outlook Reports, ANGRAU). The primary chili-producing states—Andhra Pradesh, Telangana, Madhya Pradesh, Karnataka, and Odisha—collectively contribute nearly 93% of the nation's total chili production (Spices Board of India, 2024).

Indian chilies are in high demand in domestic and international markets due to their unique characteristics, rich capsaicin content, and vibrant color (Meena et al., 2006; Kiruthika, 2024). These attributes make them essential in culinary, medicinal, and industrial sectors (Geetha & Selvarani, 2017). The growing preference for spicy foods, natural colorants, and capsaicinoids with health benefits has further driven their popularity (Baenas et al., 2019). Additionally, India plays a crucial role in supplying chilies for food processing, pharmaceuticals, and natural pigment extraction, with key export destinations including China, Bangladesh, Thailand, Sri Lanka, Malaysia, and the UAE (Commodity Board of India, 2024; Gade et al., 2020).

Despite its global dominance, India's chili sector faces challenges such as climate change, price volatility, pest infestations, and market fluctuations, which impact cultivation area, production, and yield. Figure 1 highlights significant fluctuations in these factors, influencing chili growth and efficiency. Several studies (Ashoka et al., 2013; Rajanbabu et al., 2022; Sharma et al., 2022) have examined trends in chili farming and production efficiency. Addressing these challenges requires a comprehensive analysis of production trends and instability. This study evaluates variations in area, production, and yield, incorporating decomposition analysis to identify key drivers of chili production. To sustain its leadership in the global spice trade, India must enhance efficiency and sustainability, ensuring farmer livelihoods and maintaining its competitive edge.

**Fig 1: Trends in area, production and yield of chilli in India**

**2. METHODOLOGY**

**2.1. Data Collection**

This study analyzes secondary data from FAOSTAT over a 30-year period (1993–2022), divided into three sub-periods: Period I (1993–2002), Period II (2003–2012), and Period III (2013–2022), representing the overall study period (1993–2022). It examines trends in the area, production, and yield of chilies in India to assess growth patterns and variability. The Compound Growth Rate (CGR) is employed to evaluate long-term trends, while the Cuddy-Della Valle Instability Index (CDVI) measures fluctuations in these factors. Furthermore, Decomposition Analysis is used to identify key drivers influencing changes in chili production in India.

**2.2. Compound Annual Growth Rate (CAGR)**

Compound annual growth rates was estimated to know the growth pattern on area, production and yield of major rabi pulse crops in Madhya Pradesh. The growth rate was estimated by using exponential trend model (Gade et al., 2020 and Kaur & Sharma., 2024).

Exponential trend equation: 𝑌 =𝑎bt.

It was converted into log linear function with the help of log arithmetic transformation as under:

LnY= Ln a +t b.

Where,

Y = Dependent variable (area, production and yield *etc*.)

a = Intercept

b = regression coefficient / (1 + r)

t = Year

r = Compound growth rate / (Antilog b) -1

The percent compound growth rate (r) will be as,

r = [(Anti log of b) – 1] x 100

**2.3. Cuddy and Della Instability Index**

To assess the extent of instability in crop area, production, and yield, the Cuddy-Della Valle Instability Index (Cuddy and Della Valle, 1978) was used as a measure of variability. The formula suggested by Cuddy and Della Valle (1978) is applied to calculate the degree of variation around the trend as follows:

Cuddy Della Valle Instability Index (CDVI) =CV × √1- R2

Where,

CV = Co-efficient of variation

R2= Coefficient of determination from a time-trend regression adjusted by the number of degrees of freedom.

**2.4. Decomposition Analysis**

The initial structured method of breaking down the growth trend was introduced by Minhas and Vaidyanathan (1965). The decomposition of the growth of chilli crop has been investigated to measure the relative contribution of area, yield and their combined effect to the total output change for the crops under consideration. Several scholars (Rehman and Salam, 2011; Sharma et al., 2017; Devegowda et al., 2019) have adapted and modified this model, presenting it as follows:

= × ×100+ ×100

Change in Production = Yield Effect + Area Effect + Interaction Effect

Where, ∆A = An - Ao

∆𝑃 = Pn – Po

∆Y = Yn - Yo

Ao,Yo and Po are the values of area, production and yield of the chilli crop in the base year respectively and An, Pn and Yn are values of area, production and yield of the chilli crop in the current period respectively. Thus, the total change in production can be decomposed into yield effect, area effect and their combined interaction *i.e*., change in production due to change in area and yield

**3. Results and Discussion:**

**3.1 Compound Annual Growth Rate (CAGR) of Chilli Area, Production, and Yield**

The Compound Annual Growth Rate (CAGR) analysis of chilli area, production and yield is conducted for the period from 1993 to 2022, encompassing three sub-periods: Period Ⅰ (1993–2002), Period Ⅱ (2003-2012), Period Ⅲ (2013-2022) which together constitute the overall study period (1993 to 2022). Table 1 and figure 2 highlights the CAGR of chilli area, production, and yield, showing fluctuations in cultivation. The area declined by -0.48% in Period I (insignificant), grew by 1.09% in Period II (non-significant), and significantly decreased by -1.86% in Period III (5% level). Over the entire period (1993–94 to 2021–22), the area shrank at -0.78% annually, highly significant at the 1% level. This suggests a long-term contraction in the area devoted to agriculture, possibly due to land-use changes, urbanization, or economic shifts affecting farming viability.

**Table 1. Compound annual growth rates in the area, production and yield of chilli in India**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No** | **Aspects/ Periods** | **AREA (%)** | **PRODUCTION (%)** | **YIELD (%)** |
| 1 | Period I (1993-2002) | -0.48NS | 2.59\* | 3.08\*\* |
| 2 | Period II (2003-2012) | 1.09NS | 1.12NS | 0.03NS |
| 3 | Period III (2013-2022) | -1.86\*\* | 3.31\*\* | 5.27\*\*\* |
| 4 | Overall Period (1993-2022) | -0.78\*\*\* | 3.15\*\*\* | 3.96\*\*\* |

**Note:** \*\*\* Statistically significant at 1% percent level; \*\* Statistically significant at 5% level \* Statistically significant at 10% level; NS - Statistically non-significant

Despite the decline in cultivated area, overall agricultural production has shown a positive growth trend. In Period I, production grew at an annual rate of 2.59%, though this was only marginally significant at the 10% level. Growth slowed to 1.12% in Period II, with no statistical significance, indicating weaker production gains. However, Period III saw a significant surge of 3.31% annually (significant at the 5% level), reflecting improved output despite reduced cultivated land. Over the entire period, production registered a strong and highly significant growth rate of 3.15% (at the 1% level). This suggests that despite fluctuations in cultivated area, agricultural output has steadily increased, likely due to technological advancements, improved crop varieties, and better farming practices.

**Figure 2. Bar graph showing Compound annual growth rates (CAGR) in the area, production and yield of chilli in India**

A detailed analysis of yield further highlights this trend. In Period I, yield grew significantly by 3.08% annually (5% level), reflecting early advancements in farming efficiency. However, Period II showed stagnation, with a negligible increase of 0.03% (non-significant), indicating minimal yield gains. In contrast, Period III saw a substantial rise in yield at 5.27% annually (1% level). Over the entire period (1993–94 to 2021–22), yield maintained a strong and statistically significant growth rate of 3.96% (1% level), emphasizing the crucial role of yield improvements in enhancing agricultural output.

**3.2. Cuddy Della Valle Instability Index (CDVI):**

The analysis of the Cuddy-Della Valle Instability Index (CDVI) for chilli production in India highlights notable trends in instability over time (Table 2 and Figure 3). In Periods I and II, the CDVI for area remained relatively low and stable at 5.64 and 5.27, indicating minimal fluctuations in land use for chilli cultivation. However, in Period III, the index increased to 6.56, suggesting a slight increase in irregularity, possibly due to factors such as competition for land, urbanization, or shifting agricultural priorities. Over the entire period (1993–2022), the overall CDVI for area reached 7.30, reflecting a moderate rise in instability, although the cultivated area remained relatively stable in the long run.

**Table 2 Cuddy Della Valle Index in area, production and yield of Chilli in India**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No** | **Aspects/ Periods** | **Area** | **Production** | **Yield** |
| 1 | Period I (1993-2002) | 5.64 | 10.44 | 7.29 |
| 2 | Period II (2003-2012) | 5.27 | 6.37 | 2.25 |
| 3 | Period III (2013-2022) | 6.56 | 10.95 | 10.52 |
| 4 | Overall Period (1993-2022) | 7.30 | 10.19 | 10.32 |

**Figure 3 Bar Graph showing Cuddy Della Valle Index in area, production and Yield of Chilli in India**

In contrast, chilli production exhibited greater variability. The CDVI for production was 10.44 in Period I, indicating moderate instability, but declined to 6.37 in Period II, suggesting a phase of increased stability. However, the most notable surge occurred in Period III, where the CDVI rose sharply to 10.95, highlighting heightened unpredictability in production. This fluctuation may be linked to factors such as climate variability, market demand shifts, and other external influences. Over the entire period, the overall CDVI for production stood at 10.19, reflecting a persistent level of instability in chilli output.

The yield of chilli exhibited the highest level of instability. The CDVI for yield in Period I was 7.29, indicating moderate fluctuations, but it dropped significantly to 2.25 in Period II, suggesting a more stable phase. However, in Period III, the CDVI for yield spiked to 10.52, reflecting a sharp rise in instability, likely due to challenges such as unpredictable weather, water scarcity, and pest infestations. Over the entire period (1993–94 to 2021–22), the overall CDVI for yield stood at 10.32, highlighting persistent volatility, especially in the later years, underscoring the need for measures to enhance stability in chilli production

In summary, while the area under chili cultivation has remained relatively stable, both production and yield have become increasingly volatile, particularly from period III onwards. This trend highlights the growing challenges in managing chili production in India, driven by environmental, technological, and market uncertainties.

**Decomposition annual of area, production and yield of chilli in India**

Decomposition analysis was carried out to evaluate the influence of area, yield, and their interaction effects on production variability. The results of this analysis are presented in Table 3 and Figure 4.

**Table 3. Decomposition analysis in area, production and yield of chilli in India**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Yield effect (%)** | **Area effect (%)** | **Interaction effect (%)** |
| Period I (1993-2002) | 515.24 | -343.75 | -71.49 |
| Period II (2003-2012) | 53.59 | 45.07 | 1.34 |
| Period III (2013-2022) | 170.19 | -48.88 | -21.30 |
| Overall Period (1993-2022) | 164.86 | -20.19 | -44.67 |

**Fig.4 . Decomposition effect of Chilli in India**

**Period I (1993–2002)**

The improvement in yield (*i.e*., the output per unit area) was extremely significant during this period. A 515.24% contribution indicates that enhanced crop performance per unit area was the primary driver of production changes. In contrast, the change in the area under chilli cultivation contributed negatively by -343.75%. This means that, despite expectations that more land would boost production, the actual expansion in area worked against production gains during this period. The combined effect of changes in yield and area further reduced production by -71.49%. The negative interaction implies that the simultaneous changes in yield and area compounded the negative impact, rather than supporting each other. Production was primarily driven by a dramatic improvement in yield (515.24%), which was largely negated by a substantial negative impact from changes in the area (-343.75%) and further compounded by a negative interaction (-71.49%).

**Period II (2003–2012)**

During this period, improvements in yield contributed positively to production, although the effect was more modest than in Sub-Period I. The change in the area under cultivation also had a positive impact, contributing 45.07% to production. This suggests that an expansion in cultivated land helped boost production during this period. The interaction between yield and area was nearly neutral, with a slight positive effect of 1.34%. This indicates that the changes in yield and area operated largely independently, with little additional combined effect on production. Both yield (53.59%) and area (45.07%) contributed positively, with an almost neutral interaction (1.34%), resulting in a more balanced influence on production.

**Period III (2013–2022)**

In this later period, further improvements in yield contributed significantly (170.19%) to production changes, emphasizing that enhancing crop performance per unit area remained important. However, the change in the area under cultivation had a negative impact during this period, with a contribution of -48.88%. This suggests that alterations in the extent of cultivation detracted from overall production gains. The negative interaction effect of -21.30% indicates that the simultaneous changes in yield and area further reduced the net production gains. A significant yield improvement (170.19%) was offset by a negative area effect (-48.88%) and a further negative interaction (-21.30%), reducing the net production gain.

**Overall Period (1993–2022):**

Over the entire period, improvements in yield have been a positive force, contributing 164.86% to the overall production change. This underscores the long-term importance of enhancing output per unit area. The overall change in the area under cultivation contributed negatively by -20.19%, indicating that variations in cultivated land have, on balance, detracted slightly from production gains. The combined effect of simultaneous changes in yield and area further reduced production by -44.67% over the full period, suggesting that the interplay between these factors often compounded negative effects on production. Improvements in yield (164.86%) have been crucial for increasing production, but these gains have been partially offset by a slight overall negative effect from changes in the area (-20.19%) and a negative combined interaction (-44.67%).

Yield improvements have been the strongest driver of production, with significant effects in Sub-Period 1 (515.24%) and Sub-Period 3 (170.19%). Over 1993–2022, the yield effect remained crucial at 164.86%. The impact of cultivated area was inconsistent—negative in Sub-Periods 1 (-343.75%) and 3 (-48.88%), but slightly positive in Sub-Period 2 (45.07%), leading to an overall negative effect (-20.19%). Negative interaction effects in Sub-Periods 1 (-71.49%) and 3 (-21.30%) suggest that simultaneous changes in yield and area often reduced net production gains, with an overall interaction effect of -44.67%.

**Conclusion**

This study examines chili cultivation in India from 1993 to 2022, highlighting key trends in area, production, and yield. Despite a decline in cultivated area, chili production saw positive growth, particularly from 2013–2022, with significant improvements in yield. The Compound Annual Growth Rate (CAGR) and Cuddy-Della Valle Instability Index (CDVI) reveal that while area instability remained low, production and yield experienced notable fluctuations, especially due to factors like climate change and pest outbreaks. Decomposition analysis shows that yield improvements were the primary driver of production growth, though changes in cultivated area negatively impacted overall production in the later years. The study underscores the importance of stabilizing yield and managing fluctuations to ensure sustainable growth in chili cultivation.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

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

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