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GROWTH AND INSTABILITY ANALYSIS OF MAJOR CROPS IN INDIA

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Abstract: This study examines the growth performance and instability of major crops in India, namely wheat, rice, maize, tur (arhar), lentil, sugarcane, and cotton, using long-term time series data from 1980–81 to 2024–25. The analysis was conducted by dividing the study period into three sub-periods to evaluate structural changes in agricultural performance over time. Compound Annual Growth Rate (CAGR), Coefficient of Variation (CV), and the Cuddy–Della Valle Instability Index were employed to assess trends and fluctuations in area, production, and productivity of the selected crops. The results indicate that wheat and rice exhibited relatively stable growth with lower instability due to improved irrigation facilities, technological advancements, and supportive government policies. Maize emerged as the most dynamic cereal crop, recording significant growth in area, production, and yield. In contrast, pulses such as tur and lentil showed comparatively lower growth and higher instability, primarily due to their dependence on rain-fed agriculture and vulnerability to climatic variability. Sugarcane demonstrated moderate growth with manageable fluctuations, whereas cotton exhibited high growth accompanied by substantial instability caused by pest incidence, climatic stress, and market uncertainties. The findings further reveal that productivity enhancement contributed more significantly to production growth than expansion in cultivated area. The study emphasizes the importance of climate-resilient technologies, efficient irrigation systems, improved pest management practices, and stable agricultural policies to ensure sustainable agricultural development and reduce production instability in India.

Keywords: Compound growth rate, Instability index, Time series data, Production performance

1. INTRODUCTION

Agriculture has historically been the backbone of India's economy, supporting nearly half of the nation's workforce and contributing significantly to food security, rural livelihoods and agro-industrial development. Over the last several decades, India has undergone a remarkable transformation in agricultural production, driven by technological advancements, policy interventions and expanding market linkages. Understanding the long-term growth patterns and instability in crop production is therefore essential for designing effective agricultural policies, stabilizing farmer's incomes and ensuring sustainable food and nutritional security.

India's crop production landscape is dominated by cereals, pulses, sugar crops and cash crops, among which Wheat, Rice, Maize, Tur (Arhar), Lentil, Sugarcane and Cotton form a crucial segment. These crops together account for a substantial share of the country's total cultivated area, domestic food supply, industrial raw materials and export earnings. Wheat and rice are fundamental to India's food grain basket, supported by procurement policies and technological innovations introduced during and after the Green Revolution. Maize has emerged as a versatile crop with rising demand in the feed, food and biofuel industries. Tur and lentil, as major pulses, play a vital role in ensuring protein security for a large vegetarian population. Sugarcane supports one of the largest agro-based industries in India, while cotton remains indispensable for the textile and apparel sectors.

Evaluating both growth and instability in the production of these key crops provides deeper insights into the sustainability and resilience of India's agricultural sector. Instability analysis highlights production risks, volatility and the degree of vulnerability experienced by different crops and regions. Against this background, the present study aims to analyse the growth performance and production instability of seven major crops wheat, rice, maize, tur, lentil, sugarcane and cotton in India using robust statistical tools. By examining trends in area, production and productivity over time and measuring fluctuations across different periods, the study seeks to identify crops exhibiting high instability, diagnose underlying causes and offer relevant policy suggestions. Understanding these dynamics will contribute to better planning, targeted interventions, risk mitigation strategies and sustainable agricultural development in India.

The analysis of growth and instability in agricultural production has been a major area of research in India, particularly due to its implications for food security, farmer's income stability and rural economic development. Numerous studies have examined long-term trends in area, production and productivity of major crops, highlighting the impact of technological progress, policy interventions and climatic variability on agricultural performance.

Early research in this domain began with investigations into the effects of the Green Revolution. Cuddy and Della Valle et al. [7] provided the widely used Cuddy-Della Valle Index for measuring instability, which later became a standard tool in agricultural variability studies. Subsequently, Minhas and Vaidyanathan et al. [16] and Hazell et al. [10] emphasized that while technological advances significantly improved crop yields, they also introduced new dimensions of regional disparities and crop-specific fluctuations. These foundational studies set the stage for later analyses that assessed how growth and instability evolved across different agricultural periods.

A substantial body of work has focused on cereal crops, especially wheat and rice, due to their dominance in India's food grain economy. Sidhu et al. [21] and Fan et al. [9] documented that yield growth for wheat and rice accelerated significantly during the Green Revolution but slowed in the post-reform period due to stagnation in input use efficiency and deteriorating soil health. Chand et al. [4] observed that while rice productivity exhibited moderate growth, instability in production increased in several states owing to climatic variability and water-related constraints. For wheat, Kumar et al. [12] reported that although area under cultivation stabilized, productivity gains largely drove output growth, with relatively lower fluctuations due to widespread irrigation coverage.

Studies on maize, a crop gaining prominence due to its rising industrial demand, show mixed trends. Singh et al. [22] found that maize experienced moderate growth driven by hybrid seed adoption, yet production instability remained high in rain-fed regions. Kumar et al. [13] further highlighted that climate sensitivity and erratic rainfall patterns contribute significantly to maize yield volatility, particularly in central and eastern India.

Research on pulses, including tur (arhar) and lentil, underscores their consistent vulnerability to climatic and market-related risks. Joshi et al. [11] reported that pulses suffered from low growth and high instability due to limited technological breakthroughs, inadequate irrigation, and dependence on marginal lands. Similarly, Ali et al. [1] emphasized that despite policy efforts like the National Food Security Mission (NFSM), pulses continued to exhibit high production variability. Chand et al. [6] noted marginal improvements in productivity during the 2000s; however, instability remained relatively high due to frequent droughts and susceptibility to pest attacks. Lentil, in particular, demonstrated comparatively stable growth, but Kumar et al. [15] observed regional disparities due to differences in adoption of improved varieties.

The importance of sugarcane in India's agro-industrial sector has attracted considerable academic attention. Sharma et al. [20] found significant growth in sugarcane production driven by expansion in irrigated areas and technological improvements. However, Mishra [17] documented increasing instability in recent decades due to water scarcity, fluctuating sugar prices and the cyclic nature of sugarcane cultivation. The strong linkage between sugarcane pricing policies and area allocation decisions has been highlighted by Chand et al. [3] indicating that policy-induced incentives often lead to unstable production cycles.

Studies on cotton, a key cash crop, reveal significant variability linked to technological change, especially the adoption of Bt cotton. Qaim et al. [19] found substantial yield improvements and moderate reductions in risk following Bt technology adoption. However, Narayanamoorthy et al. [18] cautioned that yield instability persists due to factors such as pest resistance, input-intensive practices and climatic shocks. In more recent studies, Birthal et al. [2] observed improved productivity but increasing variability in rain-fed cotton-growing regions.

Several comparative studies have examined growth and instability across multiple crops. Chand et al. [5] noted a general deceleration in agricultural growth after the mid-1990s, accompanied by rising instability due to climatic uncertainty. Kumar et al. [14] emphasized the growing impact of climate change on cereals

and pulses, identifying heat stress and droughts as major contributors to production variability. Tripathi et al. [23], in their analysis of major food grains, concluded that yield instability remains a major concern in rain-fed crops compared to irrigated crops such as wheat and rice. Furthermore, Das et al. [8] highlighted regional heterogeneity, with some states showing improvement in stability due to irrigation expansion, while others continue to face severe variability.

Despite the availability of rich literature, gaps remain in comparative analysis across cereals, pulses, sugar crops and cash crops in a single framework. Additionally, recent patterns influenced by climate variability, shifting cropping patterns and evolving market dynamics require updated empirical assessments. The present study contributes to the existing body of knowledge by systematically analysing growth and instability in seven major crops wheat, rice, maize, tur, lentil, sugarcane and cotton using long-term time series data. By understanding their production behaviour, the study aims to generate insights for policy, planning and sustainable agricultural development.

1.1 Objectives

The study was conducted to observe the production performance of major crops of India. The specific objectives are:

- To examine the growth rate of area, production and yield (productivity) over 3 decades
- To analyse the instability in area, production and productivity over 3 decades

2. Materials and methods

2.1 Selection of crops

Various crops have been selected based on the area, production and yield as shown in Table 1. Times series data from 1980/81 to 2024/25 (45 years) regarding area under cultivation, production and yield of major crops were used to find out the Compound Annual Growth Rate (CAGR), Coefficient of Variation (CV) and Instability Index. The analysis was done by dividing the period (1980/81 to 2024/25) into three periods:

Period I: from 1980/81 to 1994/95
Period II: from 1995/96 to 2009/10
Period III: from 2010/11 to 2024/25

Table 1: Crops selected for the study

Category	Crops
Cereals	Wheat, Rice, Maize
Pulses	Tur, Lentil
Cash crops	Sugarcane, Cotton

The data on area, production and yield of all the selected crops were collected from the various issues of Agriculture Statistics at a Glance, Reports of Ministry of Agriculture and Livestock Development, FAOSTAT.

2.2 Compound Annual Growth Rate (CAGR)

The Compound Annual Growth Rates were estimated by using log linear functions which is appropriate functional form described by Gujarati, 1988. The function was applied in many other studies for the computation of CAGR. Equation to compute CAGR is:

$$Z_t = xy^t\varepsilon \quad (1)$$

Where,

Z_t= Area/production/yield (Dependent variable) in the time period t, $x =$ intercept, $y^t =$ Regression Coefficient (1+r), $t =$ years which take value 1,2,3,……., n, $\varepsilon =$ error term for the year t

Taking logarithm to the both sides to transform the equation into log linear form for estimation:

$$Log\ Z = \log x + \log y + log\epsilon \quad (2)$$

The compound growth rate (r) of area, production and yield in percentage was computed by using the function:

$$CAGR\ (r)(\%) = \{Antilog\ of\ (\ln y - 1) \times 100\} \quad (3)$$

Regression coefficient was tested for significance by using student's t-test.

2.3 Instability Index

The agricultural instability can be measured by different methods, such as the coefficient of variation (CV), dispersion, Cuddy Della Valle Index (CDVI) etc. The present study applies the Cuddy Della Valle Index and Coppock instability index for measuring the instability. Cuddy Della Valle index first de-trends the given series and gives a clear direction about the instability. The use of coefficient of variation as a measure to show the instability in any time series data has some limitation. If the time series data exhibit any trend, the variation measured by CV can be over-estimated, i.e., the region which has growing production are at

constant rate will score high in instability of production if CV is applied for measuring instability. As against that, Cuddy Della Valle index attempts to de-trend the CV by using coefficient of determination (R^2). Thus, it is a better measure to capture instability in agricultural production. A low value of this index indicates the low instability in farm production and vice-versa. CDVI was originally developed by Cuddy and Valle (1978) for measuring the instability in time series data that is characterized by trend. The estimable form of the equation is as follows:

$$CDVI = CV \times \sqrt{1 - R^2} \quad (4)$$

Where CV is the coefficient of variation in percent, and R^2 is the coefficient of determination from time trend regression adjusted by the number of degrees of freedom.

2.4 Coefficient of Variation

Coefficient of variation was calculated by using the following formula:

$$Coefficient\ of\ variation = \frac{Standard\ deviation}{Mean} \times 100 \quad (5)$$

3. Results and discussion

This section presents the empirical findings on the growth performance and instability of the major crops in India across three sub-periods and the overall study period. The analysis is based on Compound Annual Growth Rates (CAGR) and instability indices of area, production and yield for seven major crops wheat, rice, maize, tur, lentil, sugarcane and cotton. The results highlight structural changes, technological developments, climatic variability and policy impacts that shaped the growth and stability of Indian agriculture.

3.1 Growth trend and instability in the area of main crops of India

In this section, compound annual growth rate and instability of the area under cultivation of major crops were examined in three periods and in overall period.

Table 2: CAGR of the area under the crops

Crops	Period I	Period II	Period III	Overall Period
Wheat	0.68	0.57	0.41	0.82
Rice	0.52	0.04	0.73	0.28
Maize	0.18	2.50	1.75	1.59
Tur	1.53	0.21	0.86	0.90
Lentil	1.92	0.54	0.41	1.07
Sugarcane	1.91	0.77	0.79	1.41
Cotton	-0.23	0.38	0.83	1.54

Table 2 represents the CAGR of area which reflects notable differences across crop categories and time periods. Wheat experienced consistent but moderate expansion in area, with the highest growth in the overall period (0.82%), supported by assured procurement and better irrigation. Rice recorded low area growth (0.28%) overall, reflecting land shift from rice to more profitable crops or non-agricultural uses. Maize exhibited the highest area expansion among cereals (1.59%), mainly due to rising demand for feed and industrial use, and increased adoption of hybrids during period II and III. Both tur and lentil registered moderate overall growth in area (0.90% and 1.07%, respectively). Higher growth in period I reflects government price support policies and traditional pulse-growing regions, while the decline in period II indicates diversion of land toward cereals and oilseeds. Sugarcane showed strong and stable area expansion (1.41%), supported by irrigation development and higher profitability in states like Uttar Pradesh and Maharashtra. Cotton recorded the highest overall area growth (1.54%), driven by the adoption of Bt varieties and expansion in cotton belts during period III.

Table 3: Instability in the area under the crops				
Crops	Period I	Period II	Period III	Overall Period
Wheat	3.31	3.48	2.55	3.2
Rice	2.51	3.06	2.25	3.1
Maize	2.02	2.80	4.00	5.74
Tur	4.81	3.16	9.68	8.22
Lentil	3.96	5.53	8.86	8.62
Sugarcane	7.43	8.87	7.22	7.88
Cotton	6.96	7.24	5.4	9.49

Table 3 represents the results of instability which indicate the degree of variability due to climatic conditions, market fluctuations, and crop-specific constraints. Wheat and rice showed low instability (3.2% and 3.1% overall), reflecting their essential role in food security and better irrigation coverage. Maize exhibited rising instability (overall 5.74%), suggesting diversification into this crop varies significantly based on rainfall and market incentives. Tur and lentil displayed high instability (above 8% overall), largely due to their rain fed nature, susceptibility to pests and limited technological advancements compared to cereals. Sugarcane showed moderate instability (7.88%), closely linked to water availability and delayed payments from mills. Cotton exhibited the highest area instability (9.49%), partly due to climatic stress, pest outbreaks (e.g., pink bollworm), and fluctuations in global prices.

3.2 Growth trend and instability in the production of main crops of India

In this section, compound annual growth rate and instability of the production under cultivation of major crops were examined in three sub periods and in overall period.

Table 4: CAGR of the production under the crops				
Crops	Period I	Period II	Period III	Overall Period
Wheat	3.72	1.26	1.95	2.44
Rice	3.50	1.18	2.54	2.00
Maize	2.49	4.67	4.61	4.23
Tur	0.70	0.57	2.72	1.25
Lentil	4.22	0.83	3.94	2.25
Sugarcane	3.43	0.53	2.46	2.15
Cotton	3.83	6.14	-0.37	4.49

The computational results of CAGR in Table 4 shows that wheat and rice recorded moderate production growth (2.44% and 2.00% overall), driven by yield improvements rather than expansion in area. Maize showed the highest production growth (4.23% overall), reflecting the combined effect of area expansion and adoption of high-yielding hybrids. Tur and lentil recorded modest growth rates (1.25% and 2.25%), limited by their rain fed characteristics. Lentil performed better in period III due to improved varieties and expanding demand. Sugarcane and cotton grew at 2.15% and 4.49% overall. Cotton's exceptional production growth in period II (6.14%) coincides with the introduction of Bt cotton, though output declined in period III (−0.37%) due to pest resurgence and climatic variability.

Table 5: Instability in the production under the crops				
Crops	Period I	Period II	Period III	Overall Period
Wheat	5.29	6.06	12.92	6.19
Rice	6.74	7.46	3.60	7.30
Maize	12.51	9.32	5.72	11.36
Tur	11.23	12.51	18.58	18.10
Lentil	8.04	11.00	14.62	13.36
Sugarcane	8.58	11.22	8.43	10.26
Cotton	14.14	24.12	7.05	20.83

Table 5 represents the instability in production of wheat and rice which shows that moderate instability (6–7%) overall, indicating relatively stable production due to better irrigation, fertilizer use, and policy support. Maize, however, showed higher instability (11.36%), influenced by dependence on monsoon and fluctuating market demand. Tur and lentil exhibited very high instability (18.10% and 13.36%), the highest among all

crop groups. Their inherent vulnerability to rainfall variability, pest incidence, and limited technological advancement largely explains these fluctuations. Sugarcane exhibited moderate instability (10.26%), while cotton displayed extremely high instability (20.83%). Cotton's instability is linked to climatic extremes, pest infestation cycles, and unstable global market trends.

3.3 Growth trend and instability in the yield of main crops of India

In this section, compound annual growth rate and instability of the productivity under cultivation of major crops were examined in three sub periods and in overall period.

Table 6: CAGR of the yield under the crops

Crops	Period I	Period II	Period III	Overall Period
Wheat	3.02	0.69	1.54	1.61
Rice	2.96	1.24	1.80	1.72
Maize	2.51	2.11	2.81	2.59
Tur	-0.82	0.36	1.85	0.34
Lentil	2.31	0.29	3.50	1.17
Sugarcane	1.49	-0.23	1.66	0.72
Cotton	4.07	5.73	-1.18	2.91

Table 6 represents the growth rate of productivity of wheat and rice which shows the moderate yield growth (1.61% and 1.72% overall), indicating slow but steady technological improvement. Maize displayed the strongest yield growth among cereals (2.59%), explaining its rapid production expansion. Tur and lentil recorded relatively lower yield growth (0.34% and 1.17% overall). Yield stagnation in tur indicates lack of high-yielding varieties and continued rain fed cultivation. Lentil showed better performance in period III due to adoption of short-duration and high-yielding varieties. Sugarcane recorded low yield growth (0.72%), constrained by water stress and pest attacks. Cotton exhibited moderate growth (2.91%), with significant gains in period I and II due to Bt adoption, although yield contracted in period III (−1.18%) as pest resistance increased.

Table 7: Instability in the yield under the crops

Crops	Period I	Period II	Period III	Overall Period
Wheat	3.61	3.82	5.11	5.61
Rice	4.57	4.98	2.41	5.20
Maize	11.35	8.01	4.11	8.32
Tur	8.24	10.92	11.71	11.68
Lentil	6.49	7.70	9.94	11.55
Sugarcane	2.72	4.93	4.55	5.84
Cotton	10.62	20.21	7.51	18.47

The instability in the yield has been represented in Table 7 which directly reflects environmental, technological and agronomic challenges. Wheat and rice show moderate instability (5.61% and 5.20% overall), reflecting sensitivity to extreme weather events despite overall improvements in crop management. Tur and lentil recorded high instability (11.68% and 11.55%), consistent with their vulnerability to climatic variability, diseases and limited technological adoption. Sugarcane exhibited low instability (5.84%) due to strong varietal stability and irrigation dependence. Cotton showed very high instability (18.47%), again confirming the influence of pest cycles and climatic stress.

Cereals (wheat, rice, maize) showed stable area and yield patterns with moderate and consistent growth, driven by irrigation, improved seeds and government support. Pulses (tur, lentil) demonstrated low growth and high instability, reflecting rainfed cultivation, limited technological progress and climatic sensitivity.

Cash crops particularly cotton exhibited high growth but also high instability, indicating vulnerability to market forces and climate. Maize emerged as the most dynamic cereal with strong growth in area, production and yield, though instability remains a concern. Cotton and pulses need policy attention due to their high instability and declining yield performance in recent years.

The findings of the present study highlight important patterns in the growth and instability of major crops in India over the past four decades, reflecting the combined influence of technological advancements, policy interventions, climatic conditions and market dynamics. The variation in compound annual growth rates (CAGR) and instability indices across cereals, pulses and cash crops underscores the structural heterogeneity in Indian agriculture.

3.4 Trend and growth rates in area, production and yield of major crops in India

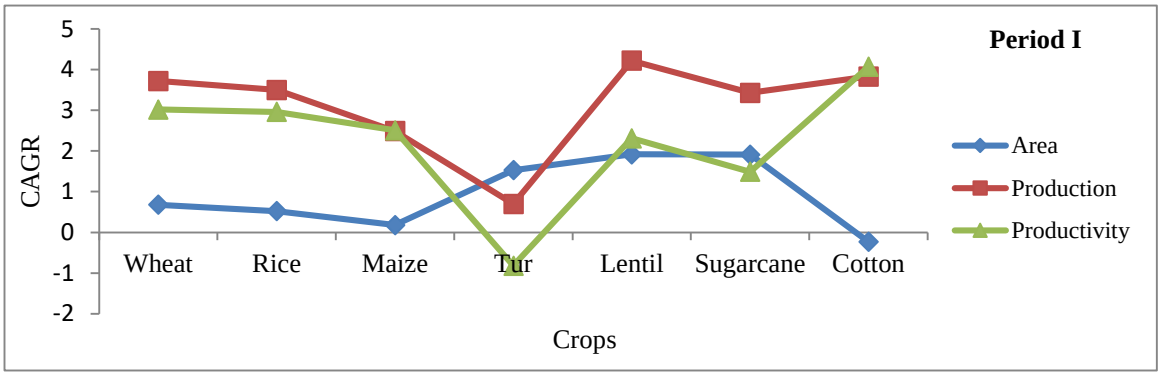

Fig. 1: CAGR of major crops of India for the period I

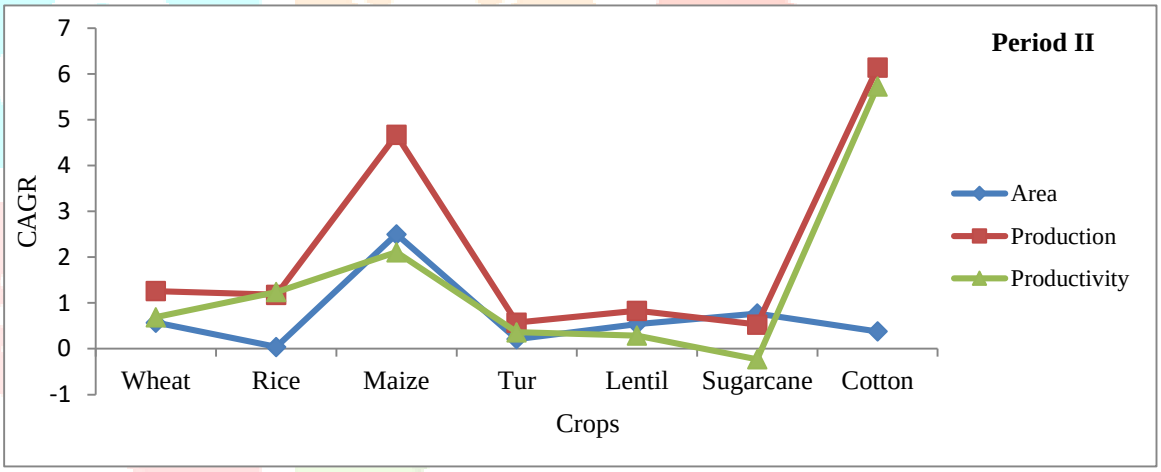

Fig. 2: CAGR of major crops of India for the period II

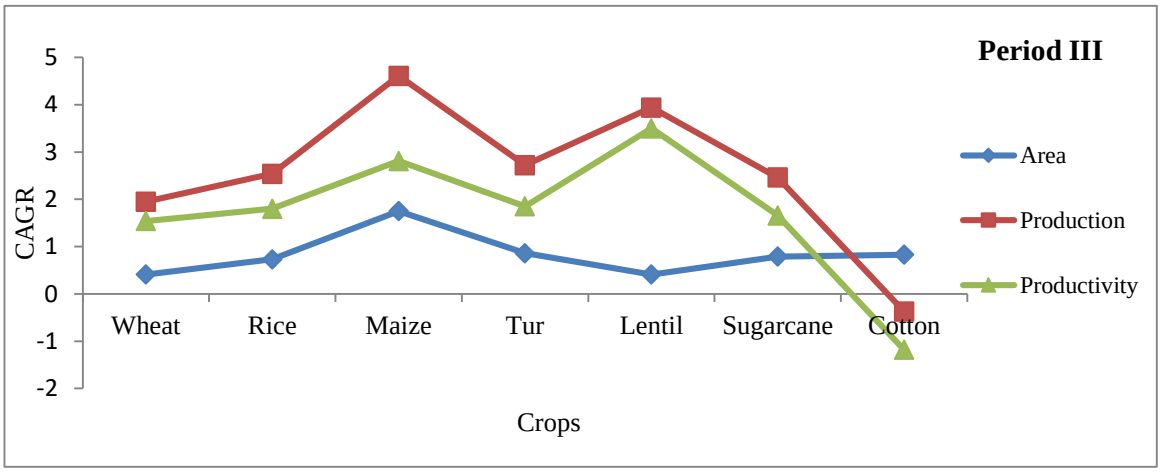

Fig. 3: CAGR of major crops of India for the period III

The graphical representation of CAGR analysis shows that production growth of major crops was mainly driven by productivity rather than area expansion. In Period I, Lentil and Cotton recorded higher production growth, while Tur showed poor productivity performance. During Period II, Maize and Cotton emerged as the best-performing crops with significant increases in production and productivity. In Period III, Maize and Lentil maintained consistent positive growth in area, production, and productivity. Cotton, however, experienced negative productivity and production growth in the later period. Overall, the study indicates a gradual shift from area-based agricultural growth toward productivity-led growth due to technological improvement and better farming practices.

3.5 Instability in area, production and yield of major crops in India

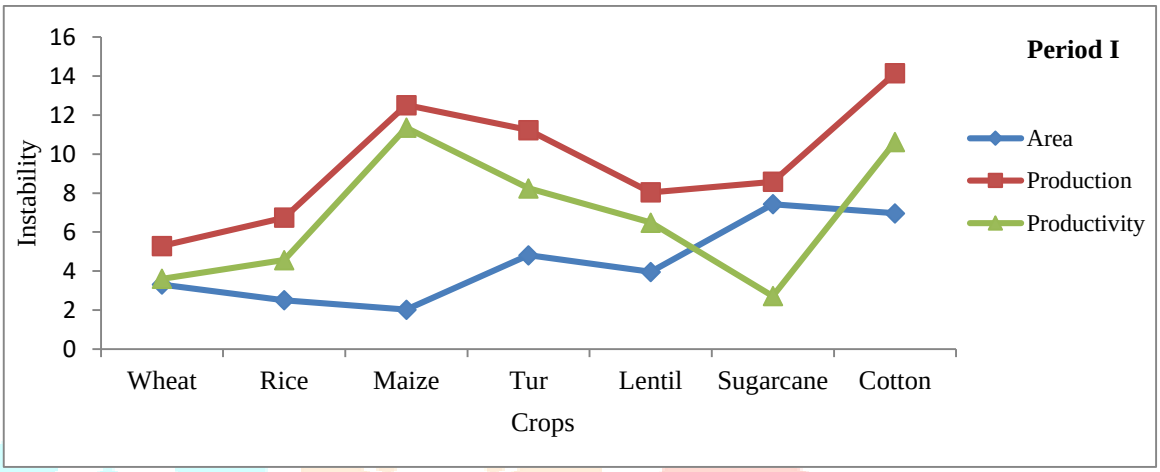

Fig. 4: Instability of major crops of India for the period I

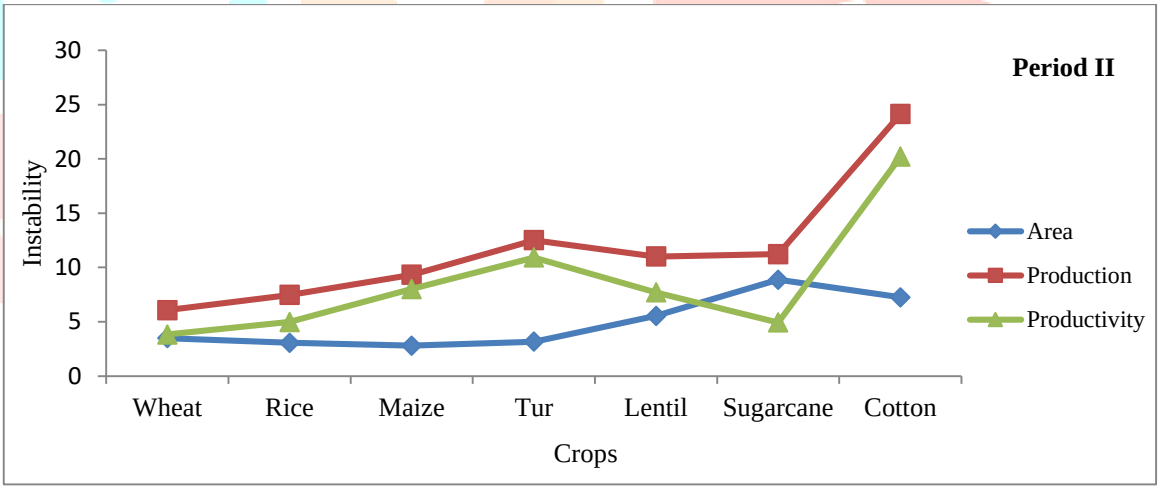

Fig. 5: Instability of major crops of India for the period II

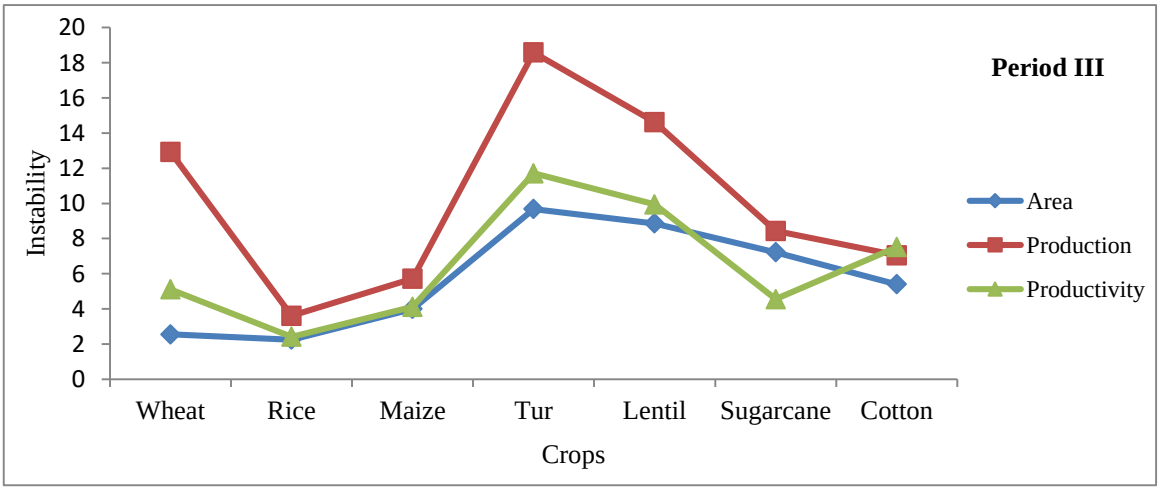

Fig. 6: Instability of major crops of India for the period III

The graphical representation of instability analysis of major crops across the three periods reveals considerable fluctuations in area, production, and productivity. In Period I, Maize and Cotton showed higher instability in production and productivity, while Wheat and Rice remained comparatively stable. During Period II, Cotton recorded the highest instability in production and productivity, indicating greater variability in output performance. In Period III, Tur and Lentil exhibited maximum instability, particularly in production and productivity, whereas Rice remained relatively stable. Overall, the results indicate that fluctuations in yield and external factors such as climate and market conditions played a major role in agricultural instability across the study periods.

4. Conclusion

This study examined long-term growth and instability in the area, production and yield of major crops in India and found significant differences across cereals, pulses and cash crops. Wheat and rice showed moderate but stable growth due to strong irrigation support and technological adoption, while maize emerged as the most dynamic cereal with high growth despite moderate instability in rain fed regions. Pulses such as tur and lentil recorded low growth and high instability, reflecting their dependence on marginal lands and climatic vulnerability. Sugarcane displayed steady growth with moderate fluctuations, whereas cotton showed high instability despite initial gains from Bt adoption. Overall, the results highlight that climate variability, pest pressures and market fluctuations continue to affect crop performance, especially in rain fed areas. Strengthening irrigation, promoting climate-resilient technologies, improving pest management and stabilizing markets are essential to enhance productivity and reduce instability in Indian agriculture.

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