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Growth and instability analysis of rice, wheat and maize of India: A comprehensive Study

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Abstract

Cereals are the most significant staple crops in the Indian diet, with Rice, wheat, and Maize playing a pivotal role in meeting the nation's nutritional needs. India is the second-largest producer of Rice and wheat, accounting for 25.00% and 13.33% of world output, respectively. Additionally, India is the fifth-largest maize producer, accounting for 2.9% of global maize production. In this context, the present study examined the growth and instability in the area, production, and productivity of Rice, wheat, and maize during the three periods i.e., Period I (2000-2011), Period II (2011-2022) and Period III (2011-2022). Growth was measured using the compound annual growth rate (CAGR), and instability was examined using the Cuddy-Della Valle Instability Index (CDVI). The findings show crop-specific variability in growth and instability across. The results reveal that all three crops experienced positive growth in production during 2000-23. Maize exhibited the highest growth rate (4.51%) during the period 2000-23 and of 5.70% during period 2000-11. Rice recorded a negative growth rate in area (-0.046%). Instability analysis of rice showed lower variability in production and area. The instability in production of wheat was higher than that of area and productivity.

Keywords: Compound annual growth rate, instability index, CDVI, time series data, major cereals

1. Introduction

Agriculture sector contributes to 18.20% of the country's Gross Domestic Product (GDP) and serves as a vital source of livelihood and sustenance to 46.10% of the Indian population who are directly or indirectly dependent on agriculture (Economic Survey, 2024-25). The beginning of the Green Revolution in the 1960s marked a significant turning point in India's agrarian history. The introduction and rapid spread of high-yielding rice and wheat varieties in the late 1960s and early 1970s led to a steady growth in food production. Food production, which stood at 72 million tonnes in 1965-66 has now reached up to 332.29 million tonnes in 2023-24. Indian agriculture is predominantly focused on food grain cultivation, which accounts for 76% of the total cropped area and 80% of the total agricultural production (Anjum & Madhulika, 2018) [2]. Among these, cereals such as rice, wheat, and maize hold significant importance as staple foods.

The Indian agriculture remains highly dependent on monsoon rainfall, making it more vulnerable to fluctuations. As of 2021, only 51.35% of the total cropped area was covered under irrigation. In recent years, climate change has emerged as a significant contributor to production instability, with erratic rainfall, rising temperatures, and extreme weather events increasingly disrupting crop cycles and yield patterns. These climate-induced variations, combined with structural issues such as monocropping and input cost volatility, have made it essential to study both the growth potential and vulnerability of staple food crops. In this context, measuring growth and instability in agriculture becomes crucial. These metrics help reveal the underlying pattern in crop performance, such as fluctuations in area, yield, and output over time. Hence, the present study focuses on measuring the growth and instability of rice, wheat, and maize in India - three of the country's most important cereal crops. The findings aim to offer informative perspectives on the performance trends of these major crops. The research study taken up with the specific objective of estimating the growth and instability in area, production and productivity of rice, wheat, and maize in India.

2. Data and Methodology

Secondary data on the area, production, and productivity of rice, wheat, and maize was collected from various governmental and nongovernmental sources spanning the period 2000 to 2022.

2.1 Compound Annual Growth Rate

This study employed time series data of area, production, and productivity of the three major cereals - Rice, Wheat, and Maize for the period 2000-01 to 2021-22. The growth (Compound annual growth rate (%)) was estimated for three periods i.e., Period I (2000-01 to 2010-11), Period II (2011-12 to 2021-22) and Period III (2000-2022). To evaluate the trend in area, production, and Productivity of Rice, Wheat, and Maize during these periods, a semi-log transformation function was applied, with a focus on estimating the Compound Annual Growth Rate-

$$Y_t = ab^t$$

$$logY_t = \log a + t\ log\ b$$

Where, Y_t= Area or Production or Productivity of rice, wheat or maize crops
a = constant
b = regression coefficient
t = time in years

The compound annual growth rate (r) was computed by using the relationship:

CAGR (r) = [antilog (b)- 1] × 100

2.2 Instability Analysis- Cuddy Della Vella Index

The coefficient of variation (CV) was used to study the variability in the area, production and productivity. The CV or instability index was computed by using the following formula:

CV = (Standard Deviation / Mean) *100

The Cuddy Della Valle Index corrects the coefficient of variation in the long-term trend. The Cuddy-Della index is a commonly used measure of the instability of time series data John Cuddy and Della Valle created the index to assess the instability of time series data (Cuddy and Della Valle, 1978). Therefore, it is a more effective measure to capture instability. Cuddy- Della Valle Index is estimated as:

$$Cuddy\ Della\ Valle\ Instability\ Index\ (\%) = Coeficient\ of\ Variation \times \sqrt{(1-\bar{R}^2)}$$

Where,
$\bar{R}^2$ = coefficient of determination from a time trend regression adjusted for its degree of freedom

3. Results and Discussion

Growth and instability of major cereal crops

In this subsection, the compound annual growth rates of area, production, and Productivity of the three major principal crops (Rice, Wheat, and Maize) in India over three periods i.e., Period I (2000-01 to 2011-12), Period-II (2011-12 to 2022-23) and Period III (2000-01 to 2022-23).

Growth and instability of Rice

Rice is considered the most important staple crop of India. It's mainly grown under both irrigated and rainfed conditions in the Eastern, North Eastern, and Southern states of the country. The average area under Rice was 44.39 million hectares during 2000-01 and has increased to 46.38 million hectares in 2023-24, showing a marginal increase. During Period I, the area under rice cultivation exhibited minimal growth of 0.09% per annum. However, in Period II, the growth rate increased to 0.38% per annum. Despite these trends, the overall growth rate during the pooled Period reflected a negative growth of -0.05 per cent per annum.
From Table 1, we can observe that production nearly doubled from 2000-01 to 2022-24, with an overall growth rate of 1.93% per annum. In Period II, the growth rate is higher (2.08**) than in Period I (1.06**). The productivity has increased at a stable rate and has increased at a CAGR of 1.76 per cent and 1.65 per cent during Period I & Period II, respectively.
The instability in rice is observed to be low for area (0.44 per cent), production (1.12per cent) and productivity (0.77 per cent). This reveals lower risk associated with rice cultivation. The greater stability in Rice can be attributed to expanded irrigation coverage, reduced reliance on monsoon rainfall, and the widespread adoption of high-yielding varieties and advanced farming technologies. Government policies, such as the National Food Security Mission (NFSM), increased minimum support prices (MSPs), and efficient procurement systems, also ensured market stability. Additionally, climate-resilient practices, reduced climatic shocks, and sustainable farming methods, such as improving soil health and implementing integrated nutrient management, can contribute to consistent yields and reduced fluctuations in production, area, and Productivity.

Table 1: Growth and Instability of Area, Production, and Productivity of Rice

Parameter	Area (Million Hectares)	Production (Million Tonnes)	Productivity (Kg/hectares)
2000 TE	44.84	86.91	1936
2011 TE	42.93	96.79	2252.33
2022 TE	45.24	124.24	2745.67
Period I			
CAGR (%)	0.09**	1.06**	1.76**
CDVI (%)	0.70	1.60	1.39
Period II			
CAGR (%)	0.38**	2.08**	1.65**
CDVI (%)	0.35	0.73	0.58
Period III			
CAGR (%)	-0.05**	1.93**	1.77**
CDVI (%)	0.44	1.12	0.77

Source: Author’s Compilation
Note: ** denotes at 5% level of significance

Growth and instability of Wheat

Wheat is the second most important staple crop in India, mainly grown in the northern, central, and Western States. The area under wheat has been showing a continuous increment over the year. During 2000 TE, the area under wheat was 26.92 million hectares, increasing to approximately 31.02 million hectares by 2022TE. The growth in area under wheat was 1.09 per cent per annum during period I, and 2.10 per cent per annum in period II.

The production has increased from 72.78 million tonnes in 2000TE to 108.4 million tonnes in 2022 TE. The wheat output recorded CAGR of 2.10 in Period I (2000-11), 1.85 in Period II and by 2.30 per cent per annum during the period III (2000-23).

The productivity of wheat has increased from 26.9 q/ha IN 2000 TE to 34.9 q/ha during 2022TE recording a growth of 1.4 per cent per annum.

The instability of wheat area was 2.48 per cent and for production (1.47 per cent) and productivity (1.09 per cent) revealing lower risk in wheat cultivation. The increased stability in wheat production can be attributed to the widespread adoption of high-yielding and climate-resilient wheat varieties, covering nearly 60% of the wheat-growing area. These varieties are designed to withstand climatic extremes, providing stability in crop yield and overall agricultural production. Additionally, favourable weather conditions, supportive government policies, and timely advisories issued to farmers have contributed to improved stability in wheat production.

Table 2: Growth and Instability of Area, Production, and Productivity of Wheat

Parameter	Area (Million Hectares)	Production (Million Tonnes)	Productivity (Kg/hectares)
2000 TE	26.91	72.78	2692
2011 TE	29.13	87.51	3001
2022 TE	31.02	108.40	3499
Period I			
CAGR (%)	1.09**	2.10**	1.03**
CDVI (%)	0.67**	0.44**	0.45**
Period II			
CAGR (%)	2.10**	1.85**	2.30**
CDVI (%)	1.78**	1.20**	1.13**
Period III			
CAGR (%)	1.03**	1.68**	1.40**
CDVI (%)	2.48**	1.47**	1.09**

Source: Author's Compilation

Note: ** denotes at 5% level of significance

Growth and instability of Maize

Maize has demonstrated the highest growth in area, production and Productivity. The area under maize increased from 6.41 mha in 2002 TE to 9.81 mha IN 2022 TE and recorded a growth of 1.97 per cent per annum. The production of maize has increased from 11.56 mt in 2002 TE to 31.38 mt in 2022 TE and has recorded a high CAGR of 4.51 per cent per annum. The productivity of maize was 18.0 q/ha in 2002 TE and increased to 31.97 q/ha in 2022 TE with a CAGR of 2.54 per cent per annum.

Over the past decade, India's Maize cultivation has increased significantly due to several key factors, one of which is the rising demand in the livestock industry. The increasing demand for poultry feed accounts for nearly 60% of maize production. The use of high-yielding hybrid seeds has increased production, while expansion into non-traditional maize-growing areas has expanded the cultivable land. Additionally, the increasing industrial use of Maize for starch and ethanol production has led to increased planting. These combined factors have led to the rapid expansion of maize farming in India over the last decade. Joshi *et al.* (2005) [8] found in their study that the rapid expansion of maize cultivation, mainly driven by livestock feed, industrial demand, and adoption of hybrid seeds, also reveals its high climate sensitivity, which increases the volatility

Maize also displayed lower instability with area instability being 0.65 per cent, production (1.68 per cent) and productivity (1.22 per cent. The low instability was due to factors such as the adoption of heat-tolerant maize hybrids, which have enhanced resilience to temperature fluctuations. Joshi *et al*., (2005) [8] found in their study that the rapid expansion of maize cultivation, mainly driven by livestock feed, industrial demand, and adoption of hybrid seeds, also reveals its high climate sensitivity, which increases volatility. Additionally, the implementation of conservation agriculture practices has improved soil health and water retention, further stabilizing yields. Ravi Kumar & Savadatti (2024) [13] revealed in their study that maize showed higher volatility over the period, but it has been decreasing over time due to hybrid seed adoption.

Table 3: Growth and Instability of Area, Production, and Productivity of Maize

Parameter	Area (Million Hectares)	Production (Million Tonnes)	Productivity (Kg/hectares)
2002 TE	6.41	11.56	1803.67
2011 TE	8.53	20.07	2348
2022 TE	9.81	31.38	3197.33
Period I			
CAGR (%)	2.77**	5.70**	2.85**
CDVI (%)	0.62**	2.62**	2.48**
Period II			
CAGR (%)	1.33**	3.81**	2.28**
CDVI (%)	0.42**	1.28**	1.51**
Period III			
CAGR (%)	1.97**	4.51**	2.54**
CDVI (%)	0.65**	1.68**	1.22**

Source: Author's Compilation
Note: ** denotes at 5% level of significance

Thus, it is observed that the area under maize and wheat has increased while that of rice has remained almost the same during the period 2002TE to 2022TE. The production of all three crops, i.e., maize, wheat, and rice has increased significantly during the study period, which is primarily due to an increase in productivity. The growth in production, productivity is coupled with low instability, revealing lower risk in the cultivation of these three major food crops. The lower risk observed in the present study is due to the problem of aggregation. It is very well known that rice is grown in both upland and lowland (GoI,2022). However, across major rice growing states, the area under irrigation is as low as 33.69 per cent in Odisha and for Chhattisgarh (38.29 per cent), West Bengal (51.07 per cent), and Madhya Pradesh (59.86 per cent). Apart from the area under irrigation rice, being a kharif crop, is subjected to greater risk due to the uncertainty of the monsoon. The area under irrigation in the maize crop is only 28.56 per cent, which is much lower in many of the major maize growing states, i.e., Madhya Pradesh (6.48 per cent), Rajasthan (1.78 per cent), and Maharashtra (12.71 per cent). The maize crop is grown in both the kharif and rabi seasons. The kharif maize crop is more subject to risk as compared to the rabi season maize crop. The studies have shown that even a rise of 1 °C in the mean temperature in months of March-April leads to a reduction in the duration of the wheat crop by seven days and yield by about 400 kg per hectare (Singh *et al*., 2011) [15]. The study carried out for IGP indicates that with each 1 °C temperature rise, there is a risk that we may lose around 4-5 Mt. of wheat production (Aggarwal, 2008) [1]. Thus, there is a prevalence of high risk in cereal production and needs continuous efforts to mitigate and manage the same and continue striving for enhancing the productivity and production.

Policies and measures taken up for managing risk and uncertainty

1. The government launched Pradhan Mantri Fasal Bima Yojana (2016)- which provides support to farmers in case of crop failure due to natural calamities, pests, or diseases. It provides income assurance to the farmer under climate variability.
2. The National Food Security Mission (NFSM) launched by the government in 2007 encourages intercropping (e.g., Pulses in rice-wheat cropping system) and diversification of pulses to improve soil fertility and reduce input dependency. NFSM also promotes sustainable cropping to address monocropping risks and improve climate resilience.
3. Scheme like NICRA (National Innovations in Climate Resilient Agriculture, 2011) by ICAR promotes drought, flood and heat-tolerant crop varieties to help farmers adapt to climate-induced yield risks.
4. Adoption of input-efficient technology can enhance sustainability in agriculture and reduce production costs. Govt policies such as PM-KUSUM (2019) promote solar irrigation to reduce fossil fuel use; and Schemes like Per Drop More Crop encourage micro-irrigation, which ultimately improves the water use efficiency. These interventions can help farmers achieve sustainability and also support climate-smart agriculture.
5. The Biofortification Programme under ICAR and Harvest Plus partnership promotes the cultivation of nutrient-enriched rice, wheat and maize. These improved varieties enhance nutritional security and offer higher market value, thereby improving farm income

Table 4: Measures to manage risk in agriculture

	Features	Disadvantages
Crop Insurance	The crop insurance scheme is made good with inclusion of technology like drones, AI, etc. The use of weather-based crop insurance scheme enhances efficiency in loss assessment.	All the farmers are not insuring crops. The insured farmers are not aware of nature of insurance policy and hence feel cheated
Cost reduction	The promotion of nano-urea, solar irrigation, and micro-irrigation schemes are leading to reduction of cost of production	The effectiveness of nano-urea technology is being evaluated The solar irrigation and micro-irrigation technology is capital intensive and needs to be promoted with subsidy schemes
Natural farming/ organic farming	The government is promoting natural farming / organic farming as it reduces cost of production. The government	The inputs needed for organic farming needs to be produced at large scale

	scheme like Paramparagat Krishi Vikas Yojana (PKVY) and Mission Organic Value Chain Development for North Eastern Region (MOVCDNER)	The differential price for organic / natural farming produce is difficult to realize The productivity is low in initial years The varieties suitable for organic/ natural farming needs to be developed and promoted
Crop management technologies	Direct seeded rice, system of rice intensification, system of wheat intensification, etc	The DSR technology results in water saving (15-20%) and cost saving but also invites the problem of weed management. It takes 17-18 irrigation as compared to 25-27 irrigations in traditional rice cultivation. The SRI and WRI techniques lead to reduction in cost of seeds but is labour intensive
Changing cropping pattern	Incorporation of pulse crop between rice and wheat crop rotation, shifting away from rice crop to less water requiring crops	The farmers are not willing to shift to crops other than rice in regions like Punjab.
Addressing stubble burning	Efforts are on for scaling up CBG production, framing Biofuel policy, Industrial Boiler Policy, CRM rationalisation, analysis of satellite data, investments in biomass power.	The efforts to manage paddy straw by spraying microbial consortia take more than the critical 20 days time
Crop diversification	The Punjab government announced on Wednesday its plan to diversify 12,000 hectares of paddy cultivation to kharif maize during the year 2025	Crop diversification will not only help improve soil fertility and reduce water usage, but also build a more sustainable and robust agricultural system

The programmes and policies implemented to overcome the risk in agriculture have paved the way for enhanced income to the farmers by stabilising the income and enhancing the quality of produce. However, looking into the weaknesses inherent in all such efforts it is desirable that concerted effort be made to improve the effectiveness of such programmes and schemes.

4. Conclusion

The study reveals moderate to high growth in production and productivity, accompanied by varying degrees of instability particularly in maize during the early period—highlighting the need for region- and crop-specific interventions. In light of these findings, integrating climate-smart agricultural practices and adopting targeted policy measures becomes essential for ensuring long-term sustainability and resilience. Strengthening crop insurance schemes like PMFBY can protect farmers from climate-induced risks, while promoting sustainable cropping patterns such as pulse integration in the rice-wheat system, can enhance soil health and reduce vulnerability. Moreover, the adoption of climate-resilient and biofortified crop varieties, especially stress-tolerant hybrids for wheat and maize, can help mitigate yield fluctuations and address nutritional needs. Encouraging the use of cost-effective technologies such as nano-fertilizers, solar irrigation, and micro-irrigation will further reduce input costs and stabilize farm incomes. The insights from this study can aid policymakers in formulating strategic, climate-resilient, and region-specific policies to enhance productivity, reduce volatility, and strengthen food security in a changing climate scenario.

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