P-ISSN: 2618-0723
E-ISSN: 2618-0731

NAAS Rating (2026): 5.04
www.extensionjournal.com

International Journal of Agriculture Extension and Social Development

Volume 9; Issue 1; January 2026; Page No. 159-166

Received: 15-10-2025
Accepted: 20-11-2025

Indexed Journal
Peer Reviewed Journal

Growth performance and instability analysis of area, production and productivity of onion in India using non-linear model

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DOI: https://www.doi.org/10.33545/26180723.2026.v9.i1c.2903

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Abstract

Onion (*Allium cepa* L.) is a major commercial vegetable crop in India, contributing significantly to agricultural income, food security and export earnings. Despite sustained expansion in cultivation, onion production in India exhibits considerable instability due to climatic variability, market fluctuations and regional differences in technology adoption. The present study analyses the growth performance and instability of onion area, production and productivity in India using non-linear (exponential) growth models. The study is based entirely on secondary data, covering a period of forty years (1985-86 to 2024-25) for All-India analysis and twenty years (2005-06 to 2024-25) for major onion-producing states. Growth performance was assessed using Compound Annual Growth Rates (CAGR) estimated through exponential models, while instability was measured using the Coefficient of Variation (CV) and the Cuddy-Della Valle Instability Index (CDVI), which accounts for trend effects.

The results indicate a clear structural shift in onion growth dynamics over time. During the early period (1985-86 to 2004-05), growth in production was largely driven by expansion of cultivated area, with negligible improvement in productivity. In contrast, the later period (2005-06 to 2024-25) recorded higher growth in area and production, along with modest but significant gains in productivity, reflecting improved varieties, better crop management and expansion of irrigation. State-wise analysis reveals substantial inter-state variation. Madhya Pradesh emerged as the fastest-growing state in terms of area and production, while Maharashtra maintained its dominance in overall output despite higher instability. Rajasthan recorded the highest productivity growth, largely due to rabi-season predominance and assured irrigation. Overall, the study highlights persistent instability in onion production and underscores the need for region-specific policies focusing on productivity enhancement, post-harvest infrastructure and market stabilization to ensure sustainable growth of the onion sector in India.

Keywords: Onion, Growth performance, Instability analysis, Exponential model, CDVI

1. Introduction

Onion (*Allium cepa* L.) is one of the most extensively cultivated and economically significant vegetable crops in the world. Belonging to the genus *Allium*, the crop has been an integral part of human diets since ancient times. Archaeological and botanical evidence suggests that onion domestication originated in Central Asia, with alternative views tracing its origins to Iran and the north-western Indian subcontinent, including present-day Pakistan. The consumption of wild onions likely predates organized agriculture, positioning the crop among the earliest domesticated plants. Its adaptability to diverse agro-climatic conditions, tolerance to different soil types, ease of storage, and transportability facilitated its rapid diffusion across early civilizations. Historically, onions held cultural and medicinal importance, being used not only as food but also in traditional medicine, art, and religious practices, including mummification in ancient societies.

In the present era, onions continue to hold immense nutritional and economic importance. They are consumed globally in raw, cooked, and processed forms, making them indispensable in a wide range of cuisines. Nutritionally, onions are rich in bioactive compounds that contribute to several health benefits. Scientific studies have highlighted their role in lowering cholesterol levels, reducing hypertension, exhibiting antithrombotic and hypoglycaemic effects, suppressing cancer cell growth, improving bone metabolism, and enhancing gut health by promoting beneficial bacteria such as *Bifidobacteria* and *Lactobacilli*. These attributes elevate onions beyond a basic dietary component to a functional food with therapeutic value.

India occupies a dominant position in global onion production. In 2023, the country produced about 31.7 million metric tonnes, accounting for nearly 30 percent of the world's total onion output (FAO, 2024). Indian onions are particularly valued in international markets for their pungency, extended shelf life, and year-round availability, making onion one of the fastest-growing horticultural

commodities in the country. Onion cultivation in India follows two major cropping seasons: the rabi crop, sown during October-December and harvested between March and May, contributes nearly 60 percent of total production and is characterized by superior storability; and the kharif crop, sown during June-August and harvested from October to January, which accounts for around 40 percent of annual output. A wide range of varieties are cultivated across the country, including Agrifound Dark Red, Agrifound Light Red, NHRDF Red, Pusa Red, Pusa Ratnar, and Pusa White Round, while yellow hybrids such as Granex 55 and Suprex are primarily grown for export markets (NHRDF, 2024) [10].

Despite steady growth in area and production over the past decade, onion production in India exhibits considerable volatility. Production peaked at over 30 million tonnes in 2022-23 but declined sharply in 2023-24 due to erratic weather conditions, unseasonal rainfall, and yield fluctuations (PIB, 2024). Such instability directly affects domestic prices and export commitments. Post-harvest losses further exacerbate the problem. While earlier estimates suggested losses of 5-12 percent, recent studies indicate that 20-35 percent of onion production is lost annually due to inadequate storage and handling practices (Suravi *et al* 2024) [17]. Curing and scientific storage are therefore critical in reducing losses and stabilizing market supply.

Maharashtra plays a pivotal role in India's onion economy, contributing nearly 40 percent of national production. The state also leads in onion storage, marketing, and export facilitation. Institutional interventions such as improved storage structures, market reforms under the APMC framework, buffer stocking by NAFED, and price stabilization through schemes like the Price Stabilization Fund and Operation Greens have been instrumental in managing supply volatility. However, persistent challenges related to production instability, post-harvest losses, and market fluctuations underscore the need for focused regional studies. In this context, the present study, confined to Maharashtra, aims to generate insights that can support farmers, policymakers, and stakeholders in improving production efficiency, post-harvest management, and marketing strategies in India's onion sector.

2. Methodology

The secondary data required for the study were collected from various institutions and published sources. The data on area, production, and productivity for All India covered the period from 1985-86 to 2024-25, representing 40 years. The state-wise APY (Area, Production, and Yield) data were compiled for the period 2005-06 to 2024-25, constituting 20 years of observations.

The study relied entirely on secondary data. The required information such year-wise, and state-wise data on area, production, productivity of onion was obtained from various reliable sources. The major sources of data included India stat Agri, Directorate of Economics and Statistics, Government of Maharashtra, NHRDF and relevant annual reports. These sources provided comprehensive and authenticated datasets.

2.1 Analytical tools and techniques employed

To study the growth performance and instability in area, production, productivity of onion in Maharashtra

This study intends to measure the growth and instability in area, production and productivity of onion in Maharashtra were examined in the present study using appropriate growth and instability measures.

Compounded Annual Growth Rate (CAGR)

The compound annual growth rate of area, production, and productivity of onion was estimated to assess the annual growth pattern over the study period. The growth rates were estimated using the best fitted functional form namely exponential models.

Exponential model

Exponential trend equation

The compound growth rate was worked out to examine the tendency of area, production, and productivity of onion to increase, decrease, or remain stagnant over time. The exponential (log-linear) model was employed to estimate the compound annual growth rate. The mathematical form of log-linear function also known as exponential function. The following exponential function was used:

$$Y_t = ab^t$$

Where,

Y_t = Area/production/productivity of onion crop in year 't'

a = Intercept

t = Time period (year 1,2,3 ..... t)

b = Regression coefficient

Coefficient of Variation (CV)

The coefficient of variation was used as a measure of relative dispersion in area, production, and productivity of onion. This measure, proposed by Karl Pearson, expressed variability relative to the arithmetic mean and facilitated comparison across variables. The coefficient of variation was computed by using the following formula:

$$CV = \frac{SD}{Mean} \times 100$$

Where,

CV = Coefficient of Variation

SD = Standard deviation

Mean = Arithmetic mean

Cuddy- Della Valle index (Cuddy and Della Valle, 1978)

The instability in area, production, and productivity of onion was measured using the Cuddy-Della Valle Instability Index (CDVI). Although several measures such as coefficient of variation, dispersion, and Coppock's instability index were available, the Cuddy-Della Valle index is preferred as it adjusted the coefficient of variation for trend effects and provided a clearer measure of instability.

The time series data were first de-trended, and instability was computed using the following formula:

$$I_x = CV\sqrt{(1-R^2)}$$

Where,

CV = Coefficient of Variation

R^2 = ESS/TSS i.e. ratio of explained variation to total variation

Categorization: Based on the values of the Cuddy-Della

Valle Index, the instability levels were categorized into three groups as follows:

The ranges of instability are as follows:

a) Low instability - (between 0 to 15)
b) Medium instability - (between 15 to 30)
c) High instability - if - (greater than 30)

3. Result and Discussion

Table 01. along with Figures jointly explain the growth dynamics and instability in onion area, production and productivity in India over Period-I (1985-86 to 2004-05), Period-II (2005-06 to 2024-25) and the overall period (1985-86 to 2024-25) using the exponential growth model. The combined evidence from the table and figures clearly indicates a structural shift in onion production growth, from an area-driven phase in the early period to a more balanced growth pattern involving both area expansion and productivity improvement in the later period.

During Period-I, onion area and production recorded moderate but positive growth rates, with CAGR values of 3.95 per cent and 4.06 per cent, respectively, as shown in Table 01 and fig 01 & 02 However, productivity growth remained almost stagnant at 0.10 per cent (Figure 03), indicating that the increase in production during this period was primarily due to expansion of cultivated area rather than yield improvement. Similar area-led production growth in onion during earlier decades was reported by Nalegaonkar *et al.* (2020) [9], who observed that limited technological adoption and dependence on traditional practices constrained productivity growth. Comparable findings were also reported in earlier growth instability studies on onion in India (Agricultural Update, 2016) [16].

The instability indicators further strengthen this interpretation. As shown in Table 01, the coefficient of variation and CDVI values for production were higher than those for area and productivity during Period-I, reflecting greater year-to-year fluctuations in output. This pattern of higher production instability compared to area has also been documented by Nalegaonkar *et al.* (2020) [9], who attributed such variability to climatic shocks, pest incidence and price-induced supply responses in onion cultivation.

A notable improvement is observed during Period-II. Table 01 shows that onion area expanded at a faster rate, with a CAGR of 5.82 per cent, while production growth accelerated to 6.81 per cent. These trends are clearly visible in Figure 01 and Figure 02, which show a sharp rise in growth rates compared to Period-I. Importantly, productivity growth improved to 1.00 per cent (Figure 03), indicating that yield enhancement began contributing meaningfully to output growth. Similar acceleration in onion production and productivity during the post-2005 period has been reported by ICAR-DOGR (2020), which attributes the improvement to the release of improved varieties, better crop management practices and expansion of irrigation facilities. National Horticulture Board statistics also report substantial increases in onion area and production during this period (NHB, 2019-20).

Although production variability were remained relatively high in Period-II, the CDVI values declined compared to Period-I, suggesting some improvement in production stability. A reduction in instability in the later period has also been reported in empirical studies on onion growth dynamics in India (Nalegaonkar *et al.*, 2020) [9], indicating the stabilizing role of improved technology and management practices.

For the overall period (1985-86 to 2024-25), Table 01 shows that onion production recorded a higher CAGR 7.25 per cent than area 5.53 per cent, while productivity increased at 1.65 per cent per annum. This long-term pattern, also reflected in Figures, confirms that productivity gains increasingly complemented area expansion in driving onion production growth. Similar long-run trends, where production growth exceeds area growth due to gradual yield improvement, have been reported in earlier studies on onion in India (Nalegaonkar *et al.*, 2020; Agricultural Update, 2016) [9, 1].

However, the overall CV and CDVI values indicate persistent instability in onion production over the entire study period. FAO (2024) also highlights that onion is a climate-sensitive crop, and fluctuations in productivity and output are common in major producing countries due to weather variability and market shocks. From a methodological standpoint, the use of the Cuddy-Della Valle Instability Index is appropriate, as it measures instability after adjusting for trend effects, and similar applications of CDVI have been widely used in agricultural growth studies (Dalal *et al.*, 2024) [3].

Table 1: Growth performance & instability index in area, production & productivity of onion in India using (exponential) model. (1985-86 to 2024-25)

Summary Statistics/States	Area ('000' Ha)	Production ('000' MT)	Productivity (MT/Ha)
(Period-I) 1985-86 to 2004-05			
MEAN	390.70	4278.23	10.88
SD	96.52	1309.98	1.49
CV	24.71	30.62	13.69
CDVI	8.60	18.96	13.68
CAGR (%)	3.95	4.06	0.10
R^2	0.87	0.61	0.0024
(Period-II) 2005-06 to 2024-25			
MEAN	1229.57	20127.67	16.18
SD	401.95	7129.14	1.59
CV	32.69	35.42	9.80
CDVI	12.26	15.40	8.14
CAGR (%)	5.82	6.81	1.00*
R^2	0.85	0.81	0.30

(overall) 1985-86 to 2024-25			
MEAN	810.13	12202.95	13.53
SD	513.50	9487.27	3.08
CV	63.38	77.74	22.79
CDVI	12.82	21.09	22.60
CAGR (%)	5.53	7.25	1.65
R^2	0.95	0.92	0.67

(Note. P< 0.05 '*' for 5% l.o.s & P<0.01 '**' for 1% l.o.s)

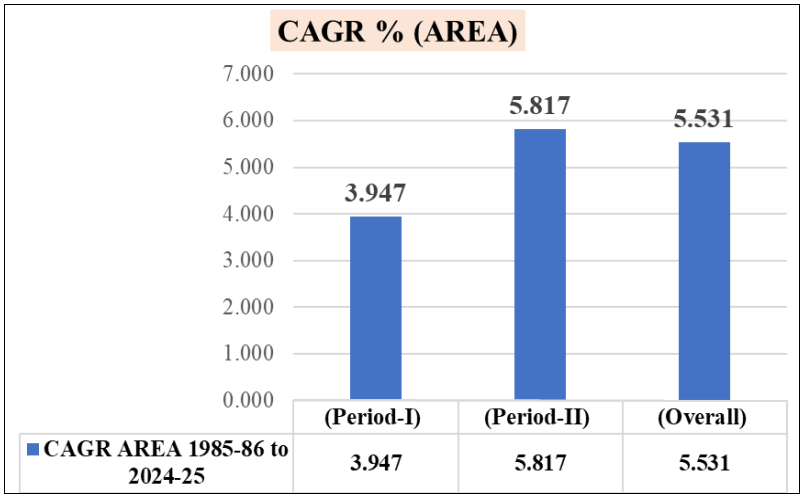

Fig 1: Growth Performance of Onion Area in India

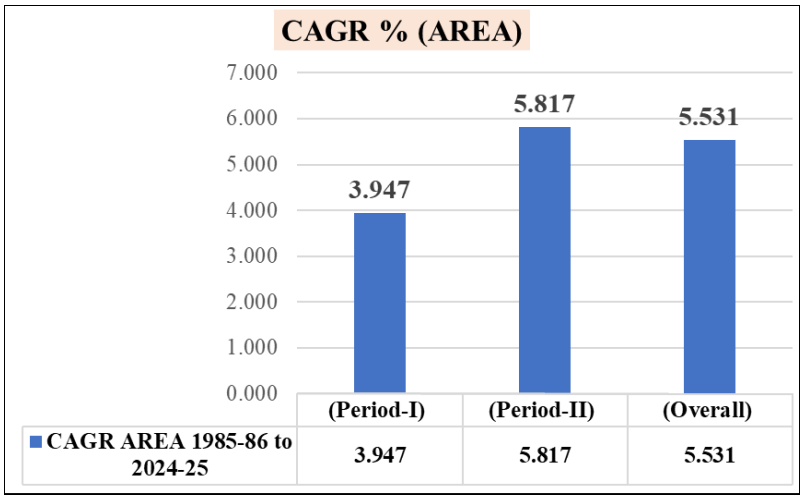

Fig 2: Growth Performance of Onion Production in India

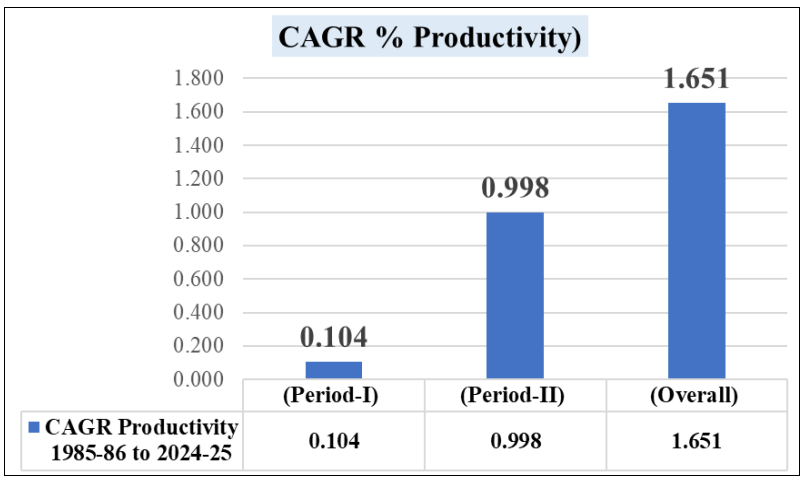

Fig 3: Growth performance of onion Productivity in India.

3.1 State-wise growth performance and instability in onion area using the exponential model (2005-06 to 2024-25)

Table 2.1. together with the corresponding CAGR (%) area graph in fig. no. 04 presents the state-wise growth performance and instability in onion area across major producing states during 2005-06 to 2024-25 using the exponential growth model. The combined interpretation of the table and figure indicates substantial inter-state variation in both the magnitude and consistency of area expansion under onion cultivation.

Madhya Pradesh recorded the highest compound growth rate in onion area at 11.11 per cent, as clearly reflected in both the table and bar chart. The high R^2 value (0.91) suggests a strong and systematic expansion of onion area over time, supported by moderate instability (CDVI of 15.00). This rapid growth reflects the emergence of Madhya Pradesh as a major onion-growing state in the post-2005 period, driven by diversification towards horticultural crops and expansion of irrigated area. Similar rapid expansion of onion area in Madhya Pradesh has been reported in national horticultural statistics and empirical studies (NHB, 2020; Nalegaonkar *et al.*, 2020) [9].

Maharashtra, traditionally the leading onion-growing state, recorded a high CAGR of 9.49 per cent in area, supported by a strong R^2 value (0.80). However, higher CV and CDVI values indicate notable fluctuations in acreage over time. This suggests that while onion cultivation expanded significantly in Maharashtra, area allocation was highly responsive to price movements and climatic variability. Comparable patterns of high growth accompanied by higher instability in Maharashtra's onion area have also been reported by Nalegaonkar *et al.* (2020) [9].

Rajasthan exhibited moderate area growth with a CAGR of 5.09 per cent, indicating gradual expansion of onion cultivation. The relatively lower variability compared to Maharashtra suggests a more stable expansion, possibly supported by rabi-season dominance and assured irrigation. Similar moderate expansion of onion area in Rajasthan has been observed in earlier studies (Shende & Meshram, 2016) [16].

Karnataka, Gujarat and Bihar recorded relatively low compound growth rates, ranging between 1.78 and 3.22 per cent, with weak trend significance and varying instability levels. These results indicate limited and inconsistent expansion of onion area in these states, likely due to agro-climatic constraints and competition from other crops. Such inter-state differences in onion area expansion have also been highlighted in earlier empirical studies (Nalegaonkar *et al.*, 2020) [9].

Table 2: State wise Growth Performance & Instability Index in Area, Production and Productivity of onion using (Exponential) Model. (2005-6 -2024-25)

Table 2.1: Area (000Ha)

Sr. No	Summary Statistics/Stats	MH	MP	KN	GJ	BR	RJ
1	**AVERAGE**	485.49	122.96	171.80	61.03	53.11	69.52
2	**SD**	245.19	63.18	41.02	21.68	7.21	26.38
3	**CV**	50.50	51.38	23.87	35.52	13.58	37.95
4	**CDVI**	22.10	15.00	20.28	33.52	11.29	24.59
5	**CAGR (%)**	9.49	11.11	3.22*	2.16	1.78*	5.09
6	**R^2**	0.80	0.91	0.27	0.10	0.30	0.58

(Note. P< 0.05 '*' for 5% l.o.s & P<0.01 '**' for 1% l.o.s)

MH:	Maharashtra	GJ:	Gujrat
MP:	Madhya Pradesh	BR:	Bihar
KN:	Karnataka	RJ:	Rajasthan

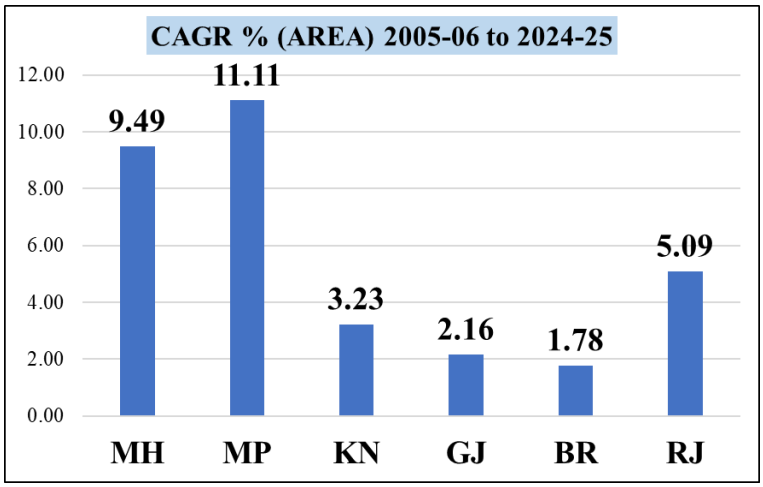

Fig 4: State wise Growth Performance of Onion Area.

3.2 State-wise growth performance and instability in onion production using the exponential model (2005-06 to 2024-25)

Table 2.2. along with the CAGR (%) production graph presents the state-wise growth performance and instability in onion production across major onion-producing states during 2005-06 to 2024-25 using the exponential growth model. The combined interpretation of the table and figure indicates pronounced inter-state differences in production growth and stability, reflecting variations in area expansion, productivity levels and cropping patterns.

Madhya Pradesh recorded the highest compound growth in onion production, with a CAGR of 13.91 per cent, as clearly reflected in both the table and bar chart. The relatively high R^2 value (0.84) indicates a strong and consistent growth trend, although variability remained high. This rapid growth highlights the increasing importance of Madhya Pradesh as a major onion-producing state, largely driven by expansion in cultivated area and gradual improvements in productivity. The state-wise production growth pattern observed in Table 2.2. and the corresponding CAGR figure reveals that higher production growth in states such as Madhya Pradesh and Maharashtra is accompanied by moderate to high instability, indicating expansion driven largely by area response and market incentives rather than uniform yield improvement. Sharma, N., & Kachhwaha, S. (2020) [15].

Maharashtra, despite being the leading state in terms of average production (7,108.61 thousand MT), recorded a slightly lower but still robust CAGR of 8.86 per cent. However, higher CV and CDVI values indicate considerable production fluctuations, reflecting the state's exposure to climatic variability and price-induced supply responses. The coexistence of positive compound growth and production instability across states, as reflected in the exponential model results

Rajasthan showed a moderately high production growth of 8.91 per cent, supported by a strong R^2 value (0.86) and relatively lower instability compared to Maharashtra and Madhya Pradesh. This suggests a more stable production expansion, largely associated with *rabi*-season dominance and assured irrigation. Similar stable growth trends in Rajasthan's onion production have been observed in earlier studies (Shende & Meshram, 2016) [16].

Karnataka, Gujarat and Bihar recorded relatively lower compound growth rates, ranging between 2.74 and 3.97 per cent, with weak trend significance and varying instability levels. These results indicate limited and inconsistent production expansion, possibly due to climatic constraints, competition with other crops and lower technological penetration. Such regional disparities in onion production growth have also been highlighted in previous empirical analyses (Nalegaonkar *et al.*, 2020) [9].

Table. 2.2: Production (000MT)

Sr. No	Summary Statistics/Stats	MH	MP	KN	GJ	BR	RJ
1	AVERAGE	7108.61	2806.40	2414.62	1457.91	1163.59	952.07
2	SD	3503.54	1599.14	693.31	577.90	255.48	458.57
3	CV	49.28	56.98	28.71	39.63	21.95	48.16
4	CDVI	18.21	22.53	26.33	36.45	16.85	17.53
5	CAGR (%)	8.86	13.91	3.56	2.74	3.97**	8.91
6	R^2	0.86	0.84	0.15	0.15	0.41	0.86

(Note. P< 0.05 '*' for 5% l.o.s & P<0.01 '**' for 1% l.o.s)

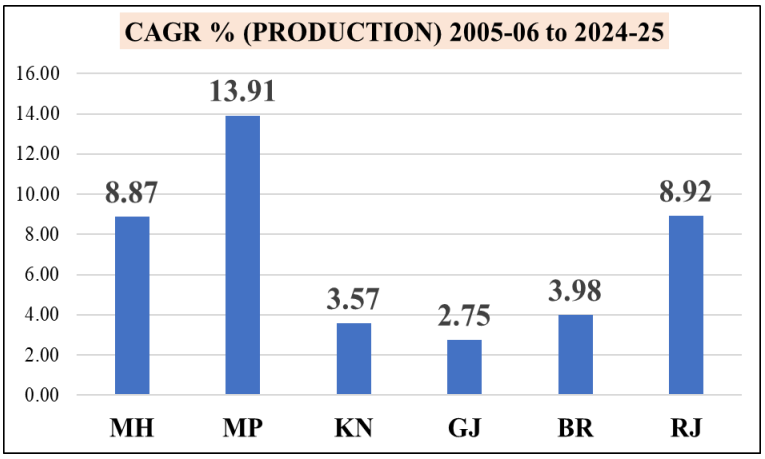

Fig 5: State wise Growth Performance of Onion Production.

3.3 State-wise growth performance and instability in onion productivity using the exponential model (2005-06 to 2024-25)

Table 2.3, together with the corresponding CAGR (%) productivity figure, presents the state-wise growth performance and instability in onion productivity across major onion-producing states during 2005-06 to 2024-25 using the exponential growth model. The combined interpretation of the table and figure reveals pronounced inter-state differences in productivity levels, growth rates and stability, reflecting variations in seasonal cropping patterns, agro-climatic conditions and production practices.

Rajasthan recorded the highest compound growth in onion productivity, with a CAGR of 4.22 per cent, as clearly reflected in both the table and figure. Although the average productivity level in Rajasthan is moderate, the statistically

significant growth rate indicates a sustained improvement over time. The relatively higher instability (CV and CDVI) suggests year-to-year fluctuations; however, the overall growth trend remains positive. The higher productivity growth in Rajasthan can largely be attributed to the predominant cultivation of onion during the rabi season, which benefits from favourable temperature, assured irrigation and lower pest and disease pressure. Earlier studies and ICAR publications have consistently reported that rabi onion yields are superior to *kharif* and late-*kharif* yields, explaining the relatively higher productivity performance of *rabi*-dominated states such as Rajasthan.

Madhya Pradesh also exhibited significant productivity growth at 2.68 per cent, supported by a moderate R^2 value (0.55), indicating a reasonably systematic improvement in yields over time.

Bihar recorded a moderate productivity growth of 2.16 per cent, with relatively lower instability compared to Rajasthan. This suggests gradual yield improvement under comparatively stable production conditions, though the overall growth magnitude remains limited due to structural constraints such as small landholdings and lower technological penetration. Comparable moderate productivity trends in eastern India have also been documented in earlier studies (Shende & Meshram, 2016) [16].

Maharashtra, Karnataka and Gujarat recorded low productivity growth, with CAGR values below one per cent. Although Gujarat reported the highest average productivity (24.82 MT/ha) and very low instability, the growth rate remained modest, indicating near-saturation of yield levels. Maharashtra and Karnataka showed negligible productivity growth with weak trend significance, reflecting the impact of multi-season onion cultivation (*kharif*, late-*kharif* and *rabi*). In such states, higher rabi yields are offset by lower productivity during kharif and late-kharif seasons, resulting in a lower combined growth rate. Similar observations on diluted productivity growth in multi-season onion-growing states have been reported in earlier studies (Sharma & Kachhwaha, 2020) [15].

Table 2.3: Productivity (MT/Ha)

Sr. No	Summary Statistics/Stats	MH	MP	KN	GJ	BR	RJ
1	**AVERAGE**	15.17	21.50	13.85	24.82	21.54	14.14
2	**SD**	2.15	3.97	2.92	1.32	3.13	4.59
3	**CV**	14.23	18.50	21.13	5.32	14.55	32.47
4	**CDVI**	14.04	12.30	21.08	4.74	10.31	26.48
5	**CAGR (%)**	0.38	2.68**	0.27	0.43*	2.16**	4.22**
6	**R^2**	0.025	0.55	0.0045	0.20	0.49	0.33

(Note. P< 0.05 '*' for 5a% l.o.s & P<0.01 '**' for 1% l.o.s)

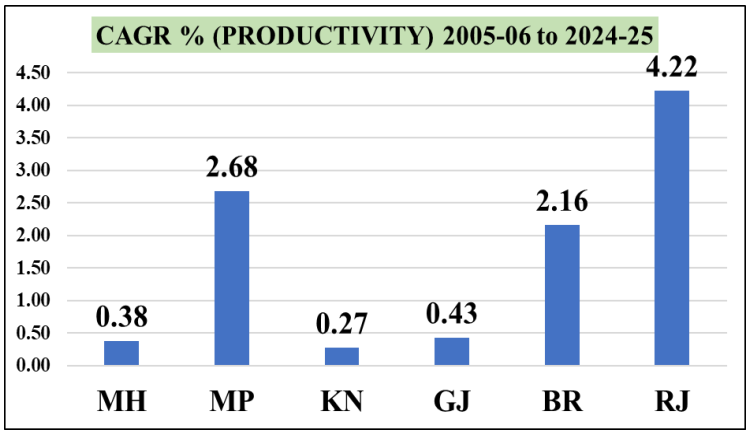

Fig 6: State wise Growth Performance of Onion Productivity.

4. Conclusion

The study reveals a clear structural transition in onion growth dynamics of India, with production shifting from an area-led expansion during the early period to a more balanced growth performance driven by both area and productivity improvements in the later period. However, persistent instability in production and productivity across states highlights the crop's sensitivity to climatic variability, seasonal effects and market-induced supply responses and Storage capacities underscoring the need for sustained technological and institutional interventions.

5. Policy Implications

Focused investment in productivity-enhancing technologies, region-specific varietal development and climate-resilient practices is essential to reduce yield instability. Strengthening post-harvest infrastructure, scientific storage and market stabilization mechanisms can further mitigate price volatility and ensure sustainable growth in India's onion sector. The current study is government agencies, research institute, NGO's, SAU & policy makers are suggested to take needful action in order to said variation in production and productivity of onion.

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