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RESEARCH ARTICLE

Production dynamics, price transmission and market integration analysis of onion (*Allium cepa* L.) in India

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Abstract

This study examines the production dynamics, price behaviour and market integration of onion using national-level production statistics (1984-85 to 2024-25) and state-level monthly wholesale price data (2005-06 to 2025-26) for major onion-producing and consuming states. The findings reveal that growth in onion production in India has been largely led by area expansion with limited yield improvement over time. Price analysis further indicates an upward trend across states with high volatility and pronounced seasonal patterns where prices peak during the lean supply period. Market integration analysis confirms the existence of long run relationship among states, whereas vector error correction model and Granger causality results highlight leader follower structure with Maharashtra emerging as a dominant price discovery centre. Divergent adjustment observed in Delhi and Punjab further suggests that price shocks tend to persist in consumption states due to demand pressure and supply rigidities. Impulse response and variance decomposition analysis confirm strong influence of Maharashtra in shaping price movements across the states. The findings highlight the need to shift from area-led to productivity-driven growth through investment in region-specific high-yielding varieties and strengthening of seed systems along with establishment of regional market hubs to reduce price volatility. The study also indicates strong potential for expansion of Kharif onion production in Punjab to support diversification and enhance farm incomes.

Keywords: Onion, market integration, price transmission, price volatility, cointegration.

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Introduction

Onion (*Allium cepa l.*) is globally one of the most widely grown as well as economically significant vegetable crop. It plays an important role in dietary patterns, food systems, and agricultural markets. Among hundreds of species, comprised under genus *Allium*, onions constitute the dominant share of production (Ochar & Kim, 2023). In addition to its culinary importance, onion is nutritionally rich and consumed globally; therefore, it plays an important role in stabilising food price inflation in developing countries (Czech et al., 2022; Vani et al., 2024).

India is the largest producer and consumer of onion, cultivated across diverse agro-climatic zones of the country (Gulati et al., 2022). But major production is concentrated in few states such as Maharashtra, Madhya Pradesh, Karnataka and Gujarat, which collectively contribute more than 70% of national production (Government of India, 2024). Also, the production in India suffered from significant key issues such as low productivity, high susceptibility to climate variability, post-harvest losses due to inadequate storage and supply chain infrastructure, and the seasonal nature of production, along with high vulnerability to pest and disease infestation (Ahmed & Singla, 2023; Srinivas, 2022).

Additionally, with its highly inelastic nature of demand, even minor supply shocks can lead to significant price hikes, having far-reaching implications that affect not only producers' income but also consumers' welfare (Beniwal et al., 2022). Thus, onion price volatility in India often necessitates government interventions like export restrictions, buffers stocking, and market intervention highlighting its macro-economic significance. Given the concentrated production and widespread consumption across the country, market integration plays an important role in ensuring efficient allocation of resources and reducing the regional price disparities (Singh et al., 2025).

Although few studies (Pavana et al., 2025; Kumar et al., 2022; Ahmed & Singla, 2023) has examined market integration and price transmission in onion markets in India, however, several important research gaps remain to be filled. Firstly, most of the existing work is based on relatively older data sets which may not capture the recent changes in market structure and policy framework. Secondly, these studies rely on selected market-level price data, which may not fully capture the spatial price dynamics at regional or State level. In contrast, state-level wholesale price data can provide more aggregated picture of market behaviour specially for policy analysis and interstate comparison. Thirdly, in these studies, limited focus has been given on linking production dynamics with price behaviour and market integration. Also, seasonal price movements and their interaction with market integration remain less explored. Regionally, Punjab is one of the most productive agricultural states trapped in an unsustainable cropping pattern of paddy-wheat monoculture (Paroda, 2022; Gulati & Juneja, 2022). Diversification into high-value crops like onion has become an economic and ecological necessity for Punjab. Therefore, well-integrated markets can provide necessary price incentives and reduce farmers' risk to diversify towards such crops as onion. Against this backdrop, the present study integrates production dynamics, price transmission and market integration analysis of onion in India with particular relevance for states like Punjab. By employing national-level statistics for production dynamics along with state-level data for price transmission, the study offers more comprehensive and policy-relevant insights into the onion economy in India.

Material and Methods

Selection of sample and sources of data

The present study has used a time-series analytical framework to examine the production dynamics, price behaviour, and market integration of onion in India.

Study area

For analysing price behaviour and market integration, five major onion-producing and consuming states were selected. Maharashtra and Madhya Pradesh represent key producing regions, while Delhi and West Bengal serve as major consumption and distribution centres. Punjab was included because of its relevance in the context of crop diversification and inter-regional trade linkages.

Study period

The study covers the period 1984–85 to 2024–25 for production analysis, with secondary data on area, production, and productivity (APY) of onion collected at the national level from official sources such as the Directorate of Economics and Statistics and Indiastat. The study period was divided into two phases: Period I (1984–85 to 2004–05) and Period II (2005–06 to 2024–25) to capture structural changes after the landmark introduction of the National Horticulture Mission (NHM) in 2005–06.

For analysing price behaviour and market integration, monthly wholesale price data from January 2005 to October 2025 were sourced from Agmarknet, National Horticulture Board (NHB) and National Horticultural Research and Development Foundation (NHRDF). State-level average wholesale prices were used instead of individual mandi-level prices to obtain a more representative picture and reduce the influence of short-term local fluctuations arising from supply disruptions, transportation constraints, or temporary market conditions.

All data series were checked for consistency and completeness. The analysis was carried out using nominal price data to ensure uniformity across the study period.

Analytical framework

The analysis was carried out in three components: (i) production dynamics, (ii) price behaviour, and (iii) market integration, using appropriate statistical and econometric techniques.

Production dynamics

Growth in area, production, and productivity was estimated using the exponential function:

$$y_t = ab^t \text{ ; } \ln y_t = \ln a + t (\ln b)$$

Where:

y_t = Area/Production/Yield at time 't'
t = Time variable (1, 2, …, n) for each period
a = Constant
b = Growth coefficient

The compound annual growth rate (CAGR) was computed as:

CAGR (r) in percentage = [antilog (ln b) -1] x 100
Instability was measured using the Cuddy–Della Valle Index (Cuddy & Della Valle, 1978):

$$CDVI = CV \times \sqrt{1 - r^2}$$

where CV is the coefficient of variation and R^2 is the coefficient of determination obtained from the trend regression. The ranges of CDVI: Low instability: 0 to 15, Medium instability: 15 to 30 and High instability: >30 (Sihmar, 2014).

To examine the sources of production growth, decomposition analysis was applied as (Minhas & Vaidyanathan, 1965):

$$\Delta P = (\Delta A \times Y_0) + (\Delta Y \times A_0) + (\Delta A \times \Delta Y)$$

Where:

- Area Effect: ($\Delta A \times Y_0$) - Contribution of area expansion
- Yield Effect: ($\Delta Y \times A_0$) - Contribution of yield improvement
- Interaction Effect: ($\Delta A \times \Delta Y$) - Joint impact of area and yield changes

Price behaviour

Price behaviour was analysed by using trend analysis, instability measures, and seasonal indices.

The long-term trend in wholesale prices was estimated using:

$$P_t = \alpha + \beta t + \epsilon_t$$

where P_t is the wholesale price, α is the intercept, β is the rate of change in prices over time, and t is the time period.

Price instability was measured using the Cuddy–Della Valle Index (CDVI). Seasonal variation was analysed using the ratio-to-moving average method, wherein a 12-month moving average was computed and centred to remove the trend component. Seasonal indices were obtained as:

Seasonal index = (Actual Price/Moving Average) x 100

Monthly indices were averaged and normalised to ensure that their sum equals 1200, thereby capturing intra-year price fluctuations.

Market integration Analysis

Market integration and price transmission were analysed using time-series econometric techniques. Stationarity of the price series was tested using Augmented Dickey–Fuller (ADF), Phillips–Perron (PP), and KPSS tests (Dickey & Fuller, 1979; Phillips & Perron, 1988; Kwiatkowski et al., 1992). Based on these results, the Johansen cointegration approach was applied to examine long-run relationships among markets (Johansen & Juselius,1990). The trace and maximum eigenvalue statistics were used to determine the number of cointegrating vectors:

$$\lambda_{trace} = -T \sum_{i=r+1}^{n} \ln(1 - \lambda_i)$$

$$\lambda_{max} = -T\,(1 - \lambda_{r+1})$$

where λ_i are the estimated eigenvalues and T is the number of observations. The presence of cointegration indicates long-run equilibrium among price series.

Short-run dynamics and adjustment towards equilibrium were analysed using the vector error correction model (VECM):

$$\Delta lnP_{it} = \alpha_i + \sum \beta_{ij} \Delta lnYP_{jt-i} + \sum \beta_{2i} \Delta lnX_{t-i} + \gamma_i ECT_{t-1} + \epsilon_{it}$$

where P_{it} represents the price in market i at time t, and ECT_{t-1} captures deviations from long-run equilibrium. A significant error correction term indicates adjustment towards equilibrium.

The direction of price transmission was examined using the Granger causality test (Granger, 1969):

$$lnP_{it} = \sum_{i=1}^{m} \alpha_i lnXP_{it-i} + \sum_{j=1}^{m} \beta_j lnP_{jt-j} + \varepsilon_t$$

$$lnP_{jt} = \sum_{i=1}^{m} \alpha_i lnP_{jt-i} + \sum_{j=1}^{m} \beta_j lnP_{it-j} + \varepsilon_t$$

where P_i and P_j are market price series (log-transformed), and t represents time. Rejection of the null hypothesis confirms the presence of Granger causality between markets.

Impulse response functions (IRF) were used to trace the effect of price shocks across markets over time, while forecast error variance decomposition (FEVD) was applied to assess the contribution of each market in explaining price variability (Lütkepohl, 1990).

Results and Discussion

Growth and instability in onion production in India

The growth trends indicate significant expansion in onion cultivation over the last four decades (Table 1). During 1984–85 to 2004–05, the growth in area and production was 3.82 and 3.88% respectively, while the productivity growth was negligible and insignificant. In contrast, during 2005-06 to 2024-25, both the area and production grew at a higher rate along with improvement in productivity growth (0.93%). For the overall period, production grew at the rate of 7.11% compared to the growth in area (5.45%) and productivity (1.58%), indicating area expansion as the primary driver along with the emerging contribution of productivity in recent years.

To further confirm the dominance of area effect in production growth, decomposition analysis was carried out (Table 2). The results revealed that a substantial portion of production growth in both periods can be attributed to an increase in cultivated area, while the yield and interaction effect remain insignificant. This indicates heavy reliance of onion production on area expansion with considerable scope for increase in productivity (Bhardwaj & Parashar, 2023).

The instability analysis (Table 3) indicates moderate to high variability in onion production over time, largely driven by yield fluctuations. Although the instability has declined in the second period, the variation remains significant enough to influence overall supply conditions and has the potential to create supply shocks, thereby contributing to price volatility.

Price behaviour of onion in selected states

Onion prices show a consistent and statistically significant increase across all selected states (Table 4). Higher price growth in consuming states like West Bengal and Punjab possibly reflects stronger demand-side pressure as well as supply-side constraints. In contrast, producing states like Maharashtra and Madhya Pradesh exhibit relatively moderate price increase likely reflecting increasing costs (Birthal et al., 2019).

Table 1: Growth in area, production and productivity of onion in India (% per annum)

Period	*Area*	*Production*	*Productivity*
Period I	3.82*	3.88*	0.05
Period II	5.82*	6.81*	0.93*
Overall	5.45*	7.11*	1.58*

Note: * indicate significance at 1 per cent level

Table 2: Decomposition of onion production growth in India (per cent)

Period	*Area effect*	*Yield effect*	*Interaction*
Period I	71.33	9.05	19.62
Period II	91.02	9.55	-0.57
Overall	89.33	5.85	4.83

Table 3: Instability in area, production and productivity of onion in India

Period	*Area*	*Production*	*Productivity*
Period I	9.81	20.3	13.68
Period II	10.9	10.64	8.69
Overall	22.49	29.08	13.18

Table 4: Trend in prices of onion in selected states of India

S. No.	*State*	*Equation*	*r^2*	*t-value*
1	Maharashtra	$P_{MH} = 491.85 + 5.81t$	0.226	8.49*
2	Madhya Pradesh	$P_{MP} = 348.99 + 4.39t$	0.271	9.58*
3	Delhi	$P_{DL} = 644.99 + 6.13t$	0.239	8.82*
4	West Bengal	$P_{WB} = 773.97 + 8.73t$	0.292	10.10*
5	Punjab	$P_{PB} = 598.65 + 7.11t$	0.298	10.23*

Note: * indicate significance at 1% level.

Despite this upward trend, prices remain volatile. The results of instability analysis (Table 5) show lower variability during harvest months (March–May) when market arrivals are high, whereas volatility rises from August and reaches a peak during the lean supply period (September–November) due to reduced arrivals and high dependence on stored stocks. Additionally, storage and supply disruptions further intensify this variability (Birthal et al., 2019).

Seasonal indices further confirm consistent intra year pattern across all states (Table 6). Prices remain below average during April-May due to abundant supply and rise steadily from June onwards, crossing the average mark in August. They peak in November across all states before declining in December, though prices remain above average. Therefore, the similarity in seasonal patterns across states highlights that price movements are largely driven by common production cycles rather than localised factors, indicating strong interdependence among states.

Stationarity and long-run integration

The unit root tests were applied to check stationarity of price series, as a prerequisite to avoid spurious results in cointegration analysis. The price series were found to be stationary at first difference, indicating integrated series of order one (I (1)), which further allows for cointegration analysis. The results of the Johansen cointegration test (Table 7) reveal the presence of at least five cointegrating equations. This indicates that onion markets across states exhibit long run equilibrium relationship and thus allowing efficient transmission of price signals.

Speed of adjustment and direction of price relationships

As the Johansen cointegration results confirmed long-run relationships across states, the vector error correction model

Table 5: Instability in prices of onion across selected states by Cuddy-Della-Valle Index (per cent)

Month	*Maharashtra*	*Madhya Pradesh*	*Delhi*	*West Bengal*	*Punjab*
Jan	49.5	57.85	48.07	46.3	49.46
Feb	47.08	50.87	42.04	37.1	36.61
Mar	29.03	30.69	26.42	26.69	28.76
Apr	22.03	20.86	22.8	21.34	21.36
May	29.25	22.08	27.66	20.87	19.74
Jun	39.41	33.82	35.12	27.86	31.1
Jul	46.23	41.71	41.02	32.54	35.61
Aug	62.92	55.97	56.56	43.75	48.09
Sep	64.43	67.15	63.1	47.77	54.73
Oct	46.04	49.22	46.69	42.66	47.96
Nov	43.47	43.71	44.79	36.72	40.08
Dec	68.18	50.11	48.29	57.16	51.24
Average	45.63	43.67	41.88	36.73	38.73

Table 6: Seasonal indices of onion prices in selected states of India (per cent)

Month	*Maharashtra*	*Madhya Pradesh*	*Delhi*	*West Bengal*	*Punjab*
Jan	103.42	106.88	108.75	107.96	108.12
Feb	91.36	97.25	98.04	96.22	96.78
Mar	72.18	85.64	82.11	78.35	83.02
Apr	61.27	69.83	66.94	63.75	68.91
May	60.94	61.72	61.58	63.48	61.36
Jun	73.65	71.08	70.02	70.86	69.12
Jul	85.78	84.63	86.45	86.92	85.34
Aug	111.54	102.76	107.84	105.96	105.28
Sep	126.88	120.95	122.73	118.84	121.67
Oct	139.62	136.14	137.92	133.41	135.08
Nov	150.73	139.28	139.85	146.92	142.31
Dec	122.63	124.84	118.77	127.33	123.01
Average	100.00	100.00	100.00	100.00	100.00

Table 7: Johansen co-integration test of long-run market integration of onion prices

Null hypothesis	*Eigen value*	*Trace statistic*	*p-value*
None*	0.31	212.67	0.000
At most 1*	0.16	121.14	0.000
At most 2*	0.12	77.11	0.000
At most 3*	0.09	44.92	0.000
At most 4*	0.07	20.2	0.000

Trace test indicates 5 co-integrating equations at 5% level of significance

was estimated to analyse short-run dynamics and long-run adjustment. Based on Akaike information criteria, two lag structure was used for all selected states.

The estimated VECM equations are as follows:

$$\Delta MH_t = -0.118ECT_{t-1} + \mathbf{0.726\Delta MH_{t-1}} - \mathbf{0.804\Delta PB_{t-2}}$$

$$\Delta MP_t = 0.084ECT_{t-1} + \mathbf{0.644\Delta MH_{t-1}} - \mathbf{0.391\Delta MP_{t-1}} - \mathbf{0.321\Delta MP_{t-2}}$$

$$\Delta DL_t = \mathbf{0.173ECT_{t-1}} + \mathbf{0.667\Delta MH_{t-1}} + \mathbf{0.339\Delta MH_{t-2}}$$

$$\Delta WB_t = -0.061ECT_{t-1} + \mathbf{0.854\Delta MH_{t-1}}$$

$$\Delta PB_t = \mathbf{0.198ECT_{t-1}} + \mathbf{0.598\Delta MH_{t-1}}$$

The results indicate short-run transmission from Maharashtra to all other states with significant influence of its lagged prices across all equations, thus confirming its dominant role in price formation. The error correction term (ECT), which captures long-run adjustment, is statistically significant only for Punjab and Delhi. Both states having a positive sign of ECT indicate divergent adjustment, which implies that in these states, deviations from long-run equilibrium

Table 8: Granger Causality Results based on VECM Block Exogeneity Wald Test (n=246)

Dependent variable	*Excluded*	*Chi-sq*	*df*	*Prob.*
D(MH)	D(MP)	3.584	2	0.1666
	D(DL)	4.723	2	0.0943
	D(WB)	1.174	2	0.5560
	D(PB)	8.431	2	0.0148*
	All	20.336	8	0.0091*
D(MP)	D(MH)	20.681	2	0.0000*
	D(DL)	3.783	2	0.1508
	D(WB)	0.106	2	0.9485
	D(PB)	3.410	2	0.1818
	All	64.321	8	0.0000*
D(DL)	D(MH)	21.349	2	0.0000*
	D(MP)	3.150	2	0.2070
	D(WB)	0.618	2	0.7340
	D(PB)	0.567	2	0.7531
	All	24.196	8	0.0021*
D(WB)	D(MH)	45.908	2	0.0000*
	D(MP)	4.266	2	0.1185
	D(DL)	5.120	2	0.0773
	D(PB)	3.221	2	0.1998
	All	61.079	8	0.0000*
D(PB)	D(MH)	23.705	2	0.0000*
	D(MP)	4.064	2	0.1311
	D(DL)	5.295	2	0.0708
	D(WB)	4.096	2	0.1290
	All	37.823	8	0.0000*

Note: *denotes rejection of null hypothesis at 0.05 level of significance. MH: Maharashtra, MP: Madhya Pradesh, DL: Delhi, WB: West Bengal, PB: Punjab

prices tend to persist rather than correct over time. This can be attributed to high consumption demand and heavy dependence on inter-regional trade with weaker local production bases, which limit the immediate supply response in these consumption states (Tripathi & Lawande, 2019). Additionally, inefficiencies in storage, transportation and market integration can amplify the persistence of these deviations.

The Granger causality results (Table 8 and Figure 1) further confirm this hierarchical structure by illustrating the direction of causality between prices of selected states. Maharashtra emerges as the primary price discovery centre, with significant unidirectional causality flowing to Madhya Pradesh, Delhi, West Bengal and Punjab, while receiving no significant feedback from these markets except Punjab. The bidirectional causality between Maharashtra and Punjab suggests that while Maharashtra dominates price formation, Punjab's role as a major consuming state with growing

Table 9: Contribution of markets to price variability (10-month horizon)

Market	*Own shock (%)*	*Maharashtra shock (%)*
Maharashtra	97.3	–
Madhya Pradesh	5.8	93.2
Delhi	3.53	95.2
West Bengal	1.93	95.9
Punjab	0.94	98.5

Note: Values represent percentage contribution to forecast error variance

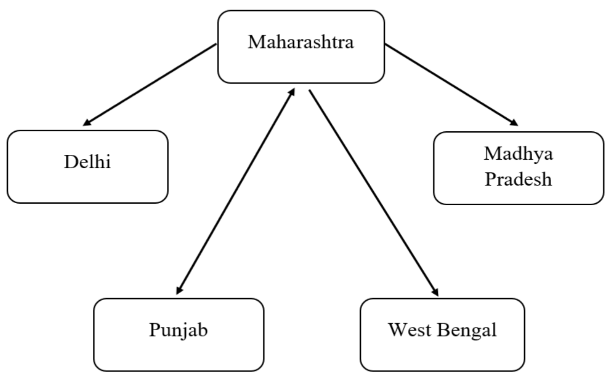

Figure 1: Granger causality direction between selected states pairs

market linkages allows it to send limited but significant price signals back to Maharashtra.

Price shock transmission and market influence

The impulse response function and variance decomposition further analysed the price reaction across states over a period of ten months for standard deviation shocks in Maharashtra prices. The IRF results (Figure 2) revealed strong and immediate responses across all states. Prices in Madhya Pradesh, Delhi, and West Bengal respond rapidly within initial periods. The responses generally peak within a few periods and gradually stabilise, indicating efficient short-run transmission. Punjab has a rapid initial increase followed by slightly more persistent adjustment, showing marginally slower dissipation of shocks. The variance decomposition results (Table 9) further justify these findings by showing that a substantial share of price variation in other selected states is explained by shocks originating in Maharashtra, whereas its own price variation is largely self-driven. This implies that any supply disruption or production shocks in Maharashtra can have widespread implications for price stability across the Indian onion market (Kumar et al., 2022).

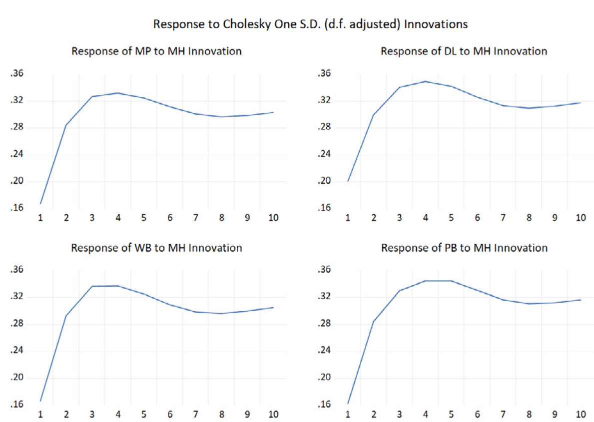

Figure 2: Response of other state markets to change in prices of Maharashtra markets

Conclusion

The study reveals that Indian onion production continues to be largely driven by area expansion, with persistent production instability making supply uncertain. Prices show high volatility along with upward trends and seasonal patterns. Moreover, market integration analysis confirms efficient price transmission across states, with Maharashtra, dominating the leader-follower structure, emerging as the centre of both price discovery and transmission. From a policy perspective, there is a need to shift focus from area-led to productivity-driven growth, which requires investment in research and development of region-specific high-yielding varieties, alongside strengthening seed systems and extension services. Given Maharashtra's dominance in price discovery, policy interventions in the state, especially related to production, stabilisation and market regulation, can have a nationwide effect on price stability. Further, to reduce dependence on a single dominant market, there is a need to establish alternative regional market hubs and strengthen inter-state market linkages. Regionally, there is strong potential for expanding kharif onion production in Punjab as indicated by the seasonal price patterns. Promoting suitable varieties, assured marketing and infrastructure support can enable farmers to benefit from higher prices while encouraging diversification away from the rice-wheat system.

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सारांश

यह अध्ययन प्रमुख प्याज उत्पादक और उपभोक्ता राज्यों के लिए राष्ट्रीय स्तर के उत्पादन आंकड़ों (1984-85 से 2024-25) और राज्य स्तरीय मासिक थोक मूल्य आंकड़ों (2005-06 से 2025-26) का उपयोग करके प्याज के उत्पादन गतिशीलता, मूल्य व्यवहार और बाजार एकीकरण की जांच करता है। निष्कर्षों से पता चलता है कि भारत में प्याज उत्पादन की वृद्धि मुख्य रूप से क्षेत्र विस्तार द्वारा संचालित रही है, जबकि उपज में सुधार सीमित रहा है। मूल्य विश्लेषण से सभी राज्यों में उच्च अस्थिरता और स्पष्ट मौसमी पैटर्न के साथ ऊर्ध्वगामी प्रवृत्ति का संकेत मिलता है, जहां आपूर्ति की कमी के दौरान कीमतें चरम पर होती हैं। बाजार एकीकरण विश्लेषण राज्यों के बीच दीर्घकालिक संबंध की पुष्टि करता है, जबकि वेक्टर एरर करेक्शन मॉडल और ग्रेंजर कार्य-कारण परिणाम महाराष्ट्र को प्रमुख मूल्य खोज केंद्र के रूप में उभरते हुए नेता-अनुयायी संरचना को उजागर करते हैं। दिल्ली और पंजाब में देखा गया विचलनशील समायोजन यह दर्शाता है कि मांग दबाव और आपूर्ति कठोरता के कारण उपभोग राज्यों में मूल्य विचलन बने रहते हैं। आवेग प्रतिक्रिया और विचरण अपघटन विश्लेषण राज्यों में मूल्य आंदोलनों को आकार देने में महाराष्ट्र के मजबूत प्रभाव की पुष्टि करते हैं। निष्कर्ष क्षेत्र-विशिष्ट उच्च उपज वाली किस्मों में निवेश और बीज प्रणालियों को मजबूत करने के साथ-साथ मूल्य अस्थिरता को कम करने के लिए क्षेत्रीय बाजार केंद्रों की स्थापना के माध्यम से क्षेत्र-नेतृत्व से उत्पादकता-संचालित विकास की ओर स्थानांतरित करने की आवश्यकता को उजागर करते हैं। अध्ययन विविधीकरण का समर्थन करने और कृषि आय बढ़ाने के लिए पंजाब में खरीफ प्याज उत्पादन के विस्तार की प्रबल संभावना भी दर्शाता है।