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Price dynamics of pigeonpea in India: An econometric analysis

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Abstract
Pigeonpea (*Cajanus cajan*), a vital pulse crop in India's agrarian and nutritional landscape, plays a crucial role in food security and rural livelihoods. This study was conducted to analyze the seasonality and market integration of pigeonpea prices in major markets of India, including Kalburgi (Karnataka), Amarawati (Maharashtra), Kanpur (Uttar Pradesh), Junagadh (Gujarat), and Katni (Madhya Pradesh), using monthly data from January 2015 to December 2024. Secondary data on prices and arrivals were sourced from APMCs and the AGMARKNET portal. Seasonal indices were computed using the twelve-month ratio-to-moving-average method to explore price and arrival behavior, while stationarity of the time series was examined using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Market integration was assessed through Johansen's cointegration test and Granger causality analysis to determine long-run relationships and price leadership among markets. The findings revealed that pigeonpea arrivals peaked between January and March, while price spikes occurred during June to October, confirming an inverse supply-price relationship. All price series were found to be non-stationary at levels but stationary at first differences, indicating I(1) behavior. Johansen's cointegration results indicated strong long-run market integration, particularly among Kalburgi-Kanpur, Katni-Junagadh, and Amarawati-Kalburgi pairs. Granger causality tests identified both bidirectional and unidirectional price relationships, with Kanpur, Katni, and Kalburgi emerging as influential price-leading markets. Additionally, the study highlighted significant regional variation in arrival trends and volatility: Katni showed strong growth but high volatility, while Kalburgi experienced a sharp decline in arrivals. Kanpur exhibited stable supply patterns with steady growth, making it a key anchor market. The study emphasizes the importance of understanding seasonal trends and market linkages to enhance marketing strategies, support timely policy decisions, and ensure better price realization for pigeonpea farmers. Strengthening inter-market coordination, improving procurement and storage infrastructure, and addressing region-specific challenges will be essential to stabilize prices and promote sustainable growth in the pigeonpea sector.

Keywords: Pigeonpea, seasonality, ADF and PP test, co-integration, Johansen test, granger causality test

Introduction

Pigeonpea (*Cajanus cajan* L.), commonly known as tur, arhar, or red gram, is a vital pulse crop with significant nutritional, economic, and agronomic importance in India and other tropical and subtropical regions. Recognized for its high protein content, drought tolerance, and nitrogen-fixing ability, pigeonpea plays a key role in ensuring nutritional security, improving soil fertility, and supporting sustainable agricultural systems. India, as both the largest producer and consumer of pigeonpea, contributes approximately 80% of global production, with Karnataka, Maharashtra, Uttar Pradesh, Gujarat, and Jharkhand leading in area and output. In the agricultural year 2023-24, pigeonpea was cultivated over 41.30 lakh hectares in India, yielding 34.16 lakh tonnes, with Karnataka alone accounting for nearly 30% of national production. Despite its multipurpose utility and resilience in marginal farming systems, pigeonpea cultivation and marketing face several challenges. Price volatility is a persistent issue, driven by factors such as erratic monsoons, regional yield disparities, pest infestations, policy interventions, and shifts in domestic and international demand. Although India dominates global production, it still relies on imports to meet growing demand, highlighting the imbalance between production and consumption.

Prices tend to decline during peak arrival months (January-March) and rise during lean periods (June-October), illustrating a clear seasonal price pattern linked to supply fluctuations. Pigeonpea markets across India are increasingly interconnected, with price movements in one region influencing others. This market integration makes it imperative to understand the temporal dynamics, spatial linkages, and volatility patterns of pigeonpea prices. Such insights are crucial not only for farmers aiming to time their sales for maximum returns, but also for policymakers, traders, and market participants seeking to stabilize prices, ensure efficient procurement, and plan buffer stock operations. Analyzing historical trends helps in improving marketing strategies, informing infrastructure investments, and implementing timely government interventions, thereby fostering a more resilient and equitable pulse marketing system. Therefore, the present study has undertaken with following specific objective:

1. To know the seasonality in Pigeonpea prices in major markets of India.
2. To know the market integration among the major Pigeonpea markets of India.

Methodology

Data Sources

This study utilizes authoritative secondary data sources to ensure analytical validity. Monthly time-series data on Pigeonpea prices and arrivals were extracted from major Agricultural Produce Market Committees (APMCs) and the AGMARKNET portal. Pigeonpea was selected as the focal crop due to its status as India's largest oilseed in terms of cultivated area, production volume, and contribution to agricultural gross value added. The research is confined to five major producing states Karnataka, Madhya Pradesh, Maharashtra, Gujarat, and Uttar Pradesh, and from each, one representative market was chosen based on the triennium average of arrivals: Kalburgi, Katni, Amarawati, Junagadh, and Kanpur, respectively. The study period spans January 2015 to December 2024.

Analytical Tools

Seasonality Analysis

Monthly data on wholesale prices and market arrivals were utilized to analyze the seasonal patterns in the selected markets. To quantify the seasonal fluctuations in both prices and arrivals, seasonal indices were derived using the twelve-month ratio-to-moving-average technique.

Step I, involved calculating the 12-month moving totals, which were then divided by 12 to obtain the corresponding moving averages. These moving averages were further refined into a series of centred moving averages. A time span of 10 years of data was used for the computation of seasonal indices.

Step II converted the original monthly values into percentages relative to their respective centred moving averages. This step also involved eliminating the irregular components from the time series. The resulting percentages were then grouped by month, and average values for each month were computed.

Step III included adjusting the monthly average indices so that their total equalled 1200. This can be done by working out a correction factor and multiplying the average for each month by this correction factor.

The correction factor (K) is worked out as follows,

$$K = 1200/S$$

Where,
K is a correction factor
S is the sum of average indices for 12 months
Multiply K with the percentage of moving average for each month to obtain the seasonal indices.

Market co-integration

Testing of stationarity in price series.

To address the issue of spurious regression that could result from non-stationarity, this study initially tested the stationarity of the time series data using the Augmented Dickey-Fuller (ADF) test. Before investigating any long-term equilibrium relationships among price series through co-integration techniques, it was necessary to confirm that the data were stationary. This step served as the foundation for all subsequent time series analyses. The ADF unit root test, developed by Dickey and Fuller (1979), was employed to identify whether a unit root existed in the data. The presence of a unit root at level form indicated non-stationarity. In such cases, the series was differenced once, and the ADF test was reapplied to assess whether the differenced series had achieved stationarity. The ADF test is estimated using the following regression equation:

$$\Delta P = \alpha_0 + \delta_{1\,t} + \beta_1 P_{t-1} + \sum_{j=0}^{q} \beta_1\, \Delta P_{t-j} + \varepsilon_t$$

$$\Delta P_t = P_t - P_{t-1},\ \Delta P_{t-1} = P_{t-1} - P_{t-2} \ldots\ldots\ldots.\ \Delta P_{n-1} = P_{n-1} - P_{n-2}$$

Where,
P = Prices in each market
α_0 = Constant term or drift
q = The value of lags
ε_t = White noise error term

The values for this test statistic are compared with the dickey fuller values.
The null and alternate hypothesis tested in ADF are
(H0): β1 (Coefficient of Pt-1) is zero.
(H1): β1 < 0.

The null hypothesis in this context stated that the time series contained a unit root, indicating non-stationarity. In contrast, the alternative hypothesis asserted that no unit root was present, implying that the series was stationary.

Similar to the ADF test, PP test indicated the presence of a unit root at the level form, it suggested that the time series was non-stationary. In such cases, the series was transformed through first differencing, and the test was re-applied to the differenced series to determine stationarity.

Co-integration analysis using Johanson procedure

The Johansen cointegration test is a widely used statistical method for evaluating the existence and strength of long-term equilibrium relationships among non-stationary time series variables. This approach is applicable only when the time series are integrated of the same order, typically stationary at first difference. The Johansen framework includes two key techniques for determining cointegration: the Trace test and the Maximum Eigen value test. (Johansen, 1988; Johansen and Juselius, 1990) [4, 5]

The model with n variable vectors was given as,

$x_t = A_1 x_{t-1} + \varepsilon_1$

So that,
$\Delta x_t = A_1 x_{t-1} - x_{t-1} + \varepsilon_1$
$= \prod x_{t-1} + \varepsilon_1$

Where,
x_t, ε_t are (n×1) vectors,
A_I is (n×n) matrix of parameter,
I is (n×n) identity matrix

We test the rank of A_1-I matrix i.e., $\prod = A_1 - I$. If the rank is $\Pi = k$, then the series is stationary in nature. If the rank is $\Pi < k$, also known as reduced rank, then there exists cointegration among the series

Granger Causality Test

The presence and causality direction of long-run market price relationship can be assessed by using the Granger causality test directed within vector auto regressive (VAR) model. To perform the Granger causality analysis, an Autoregressive Distributed Lag (ADL) model was specified as follows:

$$X_0 = \sum_{i=1}^{n} \alpha_i Y_{0-i} + \sum_{i=1}^{n} \beta_i X_{0-j} + u_1$$
$$Y_0 = \sum_{i=1}^{n} \lambda_i Y_{0-i} + \sum_{i=1}^{n} \delta_i X_{0-j} + u_2$$

Where,
$\mu 1$ & $\mu 2$ are error terms
t = time period
X_0 & Y_0 are the price series of two different markets

To test the pattern of causality between two markets, 'F' test was used.
The null hypothesis H_0: The lagged X_0 does not granger cause Y_0
The Alternative hypothesis H_1: The lagged X_0 granger cause Y_0
Here 'F' statistic must be used in combination with the p value when deciding about the significance of the results.
If 'p' value is less than the alpha level, individual p values are studied to find out which of the individual variables are statistically significant.

Results and Discussion

Seasonal indices of market arrivals of Pigeonpea in major markets of India.

Seasonal indices for arrivals have been estimated using the 12-month moving average method to analyze long-term seasonal variations in pigeonpea arrivals across major markets in India. These indices provide valuable insights into cyclical patterns driven by the crop's harvesting timeline, regional climatic factors, and market behavior. The seasonal indices of monthly market arrivals of pigeonpea in the selected markets are presented in Table 1. In Kalburgi (Karnataka), the highest arrivals were recorded in January (212.80), followed closely by February, while the lowest arrivals occurred in October (26.00), indicating minimal inflow during the early Rabi season. A similar trend was observed in Amarawati (Maharashtra), where arrivals peaked in February (256.50) and were lowest in October (34.50). This pattern suggests that post-harvest marketing of pigeonpea is concentrated in late winter months. The Junagadh (Gujarat) market showed a sharp seasonal peak in February (318.20), with significantly reduced arrivals in November (14.50), reflecting a delayed post-harvest inflow possibly influenced by agro-climatic conditions. In Kanpur (Uttar Pradesh), arrivals peaked slightly later, with the highest index in May (119.50), and the lowest in October (86.50), indicating a more prolonged marketing season. The Katni (Madhya Pradesh) market presented a distinct trend, with February (269.40) as the peak month and October (19.70) showing the lowest arrivals. These results consistently reveal that pigeonpea arrivals across markets are concentrated between January and March, with February emerging as the dominant arrival month in most markets, whereas the lean period is typically observed between August and November. The seasonal indices for all markets, as depicted in Figure 1, clearly illustrate the strong seasonality in pigeonpea arrivals. Most markets exhibited a steep rise in arrivals beginning in January, peaking in February and March, and declining thereafter. The lean season from August to November is consistent across regions, highlighting the impact of the crop's agronomic cycle, harvesting period, and associated market logistics. These findings are consistent with those of Singh and Sikka (2017) [12], who also reported high seasonality in pigeonpea arrivals across APMCs in Maharashtra and Madhya Pradesh, with peak inflows occurring from January to March and minimal arrivals during August to November. Similarly, Balai *et al*. (2021), in their study on lentil arrivals in KUMS Bundi, observed a comparable seasonal trend, with peak arrivals between February and June. Overall, the analysis confirms a distinct seasonal pattern in pigeonpea marketing across India, driven by regional harvesting schedules and supply chain dynamics. These insights are crucial for developing effective procurement strategies, improving warehousing and distribution systems, and enabling farmers to make informed decisions about the timing of market participation to maximize price realization.

Table 1: Seasonality in Pigeonpea Arrivals in major markets of India.

Market/Month	Kalburgi (KA)	Amarawati (MH)	Kanpur (UP)	Junagadh (GJ)	Katni (MP)
JAN	212.80	79.80	95.10	168.90	105.70
FEB	202.50	256.50	101.20	318.20	269.40
MAR	129.90	163.40	87.70	183.90	261.00
APR	120.20	153.00	109.60	148.50	127.70
MAY	116.20	174.50	119.50	115.20	111.50
JUN	98.10	135.40	109.60	64.50	81.80
JUL	86.20	51.80	103.50	43.90	81.10
AUG	60.60	57.00	91.50	35.10	61.90
SEP	33.10	44.20	105.10	46.00	26.50
OCT	26.00	34.50	86.50	22.90	19.70
NOV	36.00	28.60	98.10	14.50	18.70
DEC	78.20	21.40	92.70	38.40	34.90

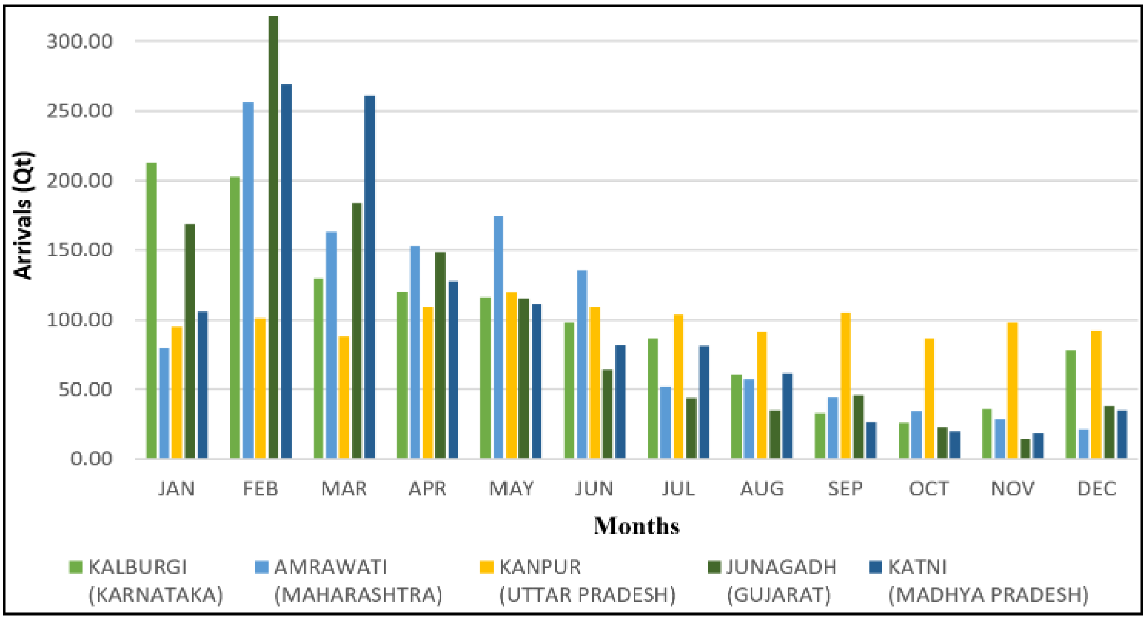

Fig 1: Seasonal indices of market arrivals of Pigeonpea in major markets of India.

Seasonal indices of market prices of Pigeonpea in major markets of India

Seasonal indices of monthly market prices for pigeonpea were estimated using the 12-month moving average method to understand the long-term price behavior and seasonal fluctuations in key producing markets. These indices provide insight into cyclical price movements influenced by supply cycles, consumer demand, and broader market dynamics. The seasonal indices of pigeonpea prices across the selected markets are presented in Table 2. In the Kalburgi (Karnataka) market, the highest price index was recorded in October (106.80), while the lowest was observed in January (95.20), indicating a significant price rise during the lean post-monsoon period. Similarly, in Amarawati (Maharashtra), the maximum price index was also seen in October (103.30), while the lowest was in January (94.60), reflecting a consistent pattern of higher prices during the second half of the year. In the Junagadh (Gujarat) market, prices peaked in November with an index of 106.00, and were lowest in February (97.90), aligning with reduced availability post-harvest. The Kanpur (Uttar Pradesh) market showed a distinct trend, with the highest price index in July (103.50) and the lowest in March (97.00), likely influenced by regional supply timing and demand fluctuations. The Katni (Madhya Pradesh) market registered the highest seasonal index in July (106.40), while the lowest was recorded in November (93.80), suggesting price pressure during post-harvest influx and a spike in mid-year due to declining stock levels. All markets exhibited relatively higher pigeonpea prices from July to October, while lower prices were typically observed from November to February, coinciding with peak arrival periods. This seasonal price movement reflects typical market behavior where prices rise during the lean supply period due to reduced availability and increased demand, particularly during the monsoon and festive seasons. Conversely, prices tend to drop during post-harvest months when supply increases. The seasonal indices, illustrated in Figure 2, further reinforce this trend, showing that prices generally rise from May to October, peaking in September to November depending on the market, and decline thereafter. For example, Kalburgi and Amarawati showed peaks in October, Junagadh in November, and Kanpur and Katni peaked during July, before declining in the subsequent months. These findings are supported by earlier studies. Kumawat and Meena (2021) reported that pigeonpea prices in major APMCs of Rajasthan typically peaked between September and November, while the lowest prices were recorded during the post-harvest window of January to March, confirming the seasonal nature of price behavior. Similarly, Purushottam *et al.* (2013) observed that pigeonpea prices in Kanpur were lowest in July-August and peaked in February and March, emphasizing regional differences in price cycles based on harvest timing and storage practices. Overall, the analysis reveals a clear and consistent seasonal price pattern for pigeonpea across markets. Prices tend to be highest during the monsoon to early post monsoon period (July to November) and lowest during the peak arrival months (January to March). Understanding these patterns is essential for farmers, traders, and policymakers to optimize storage, marketing, and procurement decisions, ultimately enhancing market efficiency and farmer income.

Table 2: Seasonality in Pigeonpea prices in major markets of India.

Month/Market	Kalburgi (KA)	Amarawati (MH)	Kanpur (UP)	Junagadh (GJ)	Katni (MP)
JAN	95.20	94.60	99.30	98.50	96.00
FEB	95.80	98.50	99.00	97.90	99.90
MAR	95.60	98.40	97.00	95.90	101.20
APR	98.70	99.90	98.20	99.90	101.50
MAY	100.60	100.60	102.10	101.90	104.20
JUN	100.40	99.10	102.90	100.70	106.40
JUL	100.70	102.50	103.50	100.40	99.60
AUG	104.10	102.70	101.40	100.00	104.50
SEP	104.70	103.30	99.60	103.20	101.10
OCT	106.80	103.00	99.30	106.00	97.10
NOV	100.70	101.00	98.30	100.40	93.80
DEC	96.80	96.40	99.40	95.30	94.70

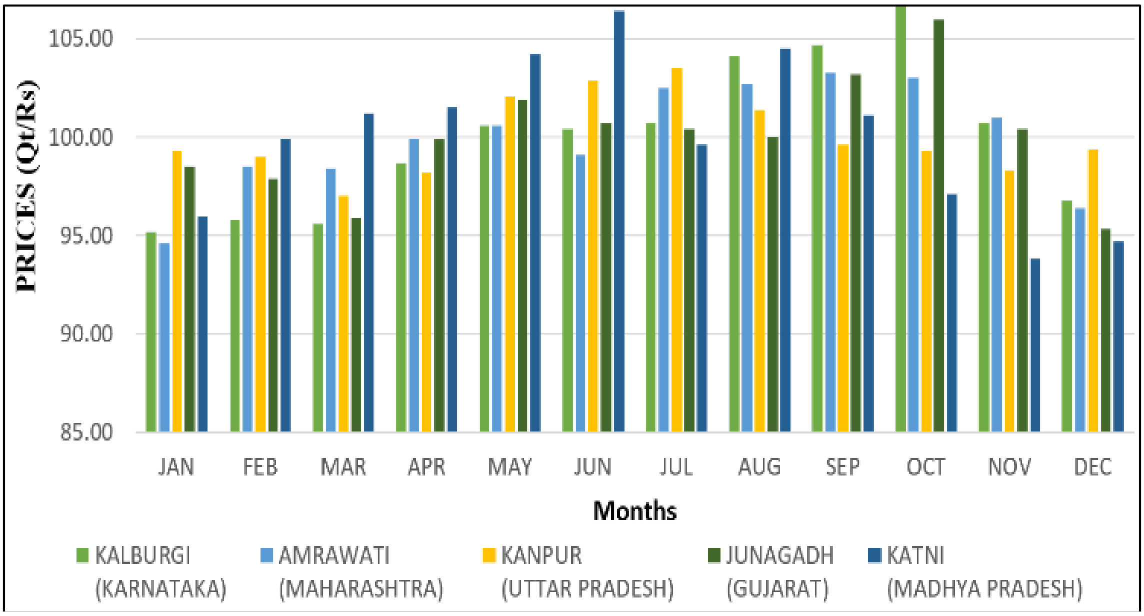

Fig 2: Seasonal indices of market prices of Pigeonpea in major markets of India.

Augumented Dickey-Fuller (ADF) test

The Augmented Dickey-Fuller (ADF) test, a standard method for detecting unit roots, was employed to statistically verify the stationarity of pigeonpea prices in these major markets for Johansen co-integration analysis, and the results are summarized in Table 3.

Table 3: Estimates of Augmented Dickey-Fuller Test for stationarity and order of integration

Markets	At Level Data			First Differenced Data		
	None	Intercept	Trend and Intercept	None	Intercept	Trend and Intercept
APMC-KALBURGI						
't'-Statistics	-0.2000	-1.3418	-3.1644	-8.2289	-8.1880	-8.1751
Probability Value	0.6120	0.6079	0.0973	0.0000	0.0000	0.0000
Schwarz Criterion Value	-2.2065	-2.1797	-2.2314	-2.2542	-2.2102	-2.1735
APMC-AMARAWATI						
't'-Statistics	-0.0402	-1.2425	-2.9958	-10.0149	-9.9679	-10.1076
Probability Value	0.6672	0.6538	0.1383	0.0000	0.0000	0.0000
Schwarz Criterion Value	-2.1596	-2.1305	-2.1782	-2.1582	-2.1143	-2.0894
APMC-KANPUR						
't'-Statistics	0.5264	-0.1735	-2.3175	-9.2951	-9.2738	-9.8190
Probability Value	0.8280	0.9373	0.4207	0.0000	0.0000	0.0000
Schwarz Criterion Value	-3.0117	-2.9684	-3.0394	-3.0089	-2.9671	-2.9812
APMC-JUNAGADH						
't'-Statistics	-0.0764	-1.2991	-3.0485	-9.5457	-9.5016	-9.5253
Probability Value	0.6550	0.6280	0.1243	0.0000	0.0000	0.0000
Schwarz Criterion Value	-2.0854	-2.0577	-2.1006	-2.1071	-2.0633	-2.0286
APMC-KATNI						
't'-Statistics	0.2953	-1.0134	-3.3872	-13.9678	-13.9126	-14.0668
Probability Value	0.7695	0.7465	0.0585	0.0000	0.0000	0.0000
Schwarz Criterion Value	-1.3173	-1.2835	-1.3026	-1.3605	-1.3175	-1.2944

The ADF test showed that the price series for all five major Pigeonpea markets Kalburgi (Karnataka), Amarawati (Maharashtra), Kanpur (Uttar Pradesh), Junagadh (Gujarat), and Katni (Madhya Pradesh) were non-stationary in their level form across all model specifications (None, Intercept, and Trend and Intercept), as the test statistics did not exceed the corresponding critical values. The presence of high p-values further supported the failure to reject the null hypothesis of a unit root. However, when the series were tested in their first-differenced form, the ADF test statistics for all markets were highly significant under every model specification, with p-values of 0.0000 in each case. The test statistics were more negative than the critical values at both the 5% and 1% significance levels, leading to the rejection of the null hypothesis. This confirms that the Pigeonpea price series became stationary after first differencing in each market.

To ensure the robustness and reliability of the stationarity findings, the Phillips-Perron (PP) test, an alternative unit root testing approach, was also applied alongside the Augmented Dickey-Fuller (ADF) test. The PP test results reaffirmed that Pigeonpea prices in all five markets Kalburgi, Amarawati, Kanpur, Junagadh, and Katni were non-stationary in their level forms under all three model specifications (None, Intercept, and Trend & Intercept), with test statistics failing to exceed critical values and high p-values confirming the presence of a unit root. However, like the ADF test, the PP test showed strong evidence of stationarity after first differencing, confirming the integrated order of I(1) for the Pigeonpea price series. The conformity between the ADF and PP test results strengthens the reliability of the conclusion that Pigeonpea prices across the selected markets are non-stationary at level but become stationary after first differencing. These findings align with those of Paul *et al*. (2015), who observed similar stationarity characteristics in retail prices of Pigeonpea in Karnal, Haryana using both ADF and PP tests, highlighting the presence of long memory and integration in the price series.

Vector Autoregressive Model

A crucial step in estimating the Vector Autoregressive (VAR) model is selecting an appropriate lag length, as the model's accuracy and stability depend on it. Common criteria such as the Akaike Information Criterion (AIC), Final Prediction Error (FPE), Likelihood Ratio (LR) test, Bayesian Information Criterion (BIC), and Hannan-Quinn Criterion (HQC) help balance explanatory power with the risk of overfitting. Based on these criteria, particularly AIC, FPE, and LR, the optimal lag length was determined to be 2. Using this lag structure, the Johansen cointegration test (Table 5) confirmed the presence of cointegration among pigeonpea markets, indicating a long-run price association. A similar approach was adopted by Rani *et al*. (2017).

Cointegration among the markets

The test confirmed cointegrating vectors in multiple market pairs such as Kalburgi-Amarawati, Kalburgi-Kanpur, Kalburgi-Junagadh, Kalburgi-Katni, Amarawati-Kanpur, and Kanpur-Katni, where the trace statistics exceeded critical values at the 5% level showed in Table 4, confirming the presence of long-run equilibrium linkages. These results indicate efficient price transmission and integrated pricing behaviour among these markets over time. Similar evidence of long-run cointegration among Pigeonpea markets has also been reported by Pandey *et al.* (2020) and Srinatha *et al*. (2024), who observed multiple cointegrating vectors across wholesale and retail legume markets in India, thereby validating the existence of stable long-term price linkages using Johansen's approach

Table 4: Johansen's Cointegration test results for Pigeonpea major market of India

Markets	Hypothesized No. of CS	Trace Statistics	Critical Value at 5%	Probability Value	Max Eigen Statistics	Critical Value at 5%	Probability Value	Lag Length (AIC)
Kalburgi-Amarawati	None	34.19	15.50	0.0000	32.19	14.27	0.0000	1
	At most 1	2.00	3.84	0.1572	2.00	3.84	0.1572	
Kalburgi-Kanpur	None	37.55	15.50	0.0000	34.66	14.27	0.0000	
	At most 1	2.89	3.84	0.0887	2.89	3.84	0.0887	3
Kalburgi-Junagadh	None	21.09	15.50	0.0065	18.36	14.27	0.0107	
	At most 1	2.73	3.84	0.0984	2.73	3.84	0.0984	4
Kalburgi-Katni	None	22.20	15.50	0.0042	20.69	14.27	0.0042	1
	At most 1	1.50	3.84	0.2202	1.50	3.84	0.2202	
Amarawati-Kanpur	None	21.17	15.50	0.0063	20.58	14.27	0.0044	
	At most 1	0.59	3.84	0.4436	0.59	3.84	0.4436	1
Amarawati-Junagadh	None	19.56	15.50	0.0115	17.35	14.27	0.0157	
	At most 1	2.21	3.84	0.1375	2.21	3.84	0.1375	4
Amarawati-Katni	None	21.73	15.50	0.0050	20.76	14.27	0.0041	1
	At most 1	0.97	3.84	0.3250	0.97	3.84	0.3250	
Kanpur-Junagadh	None	29.05	15.50	0.0003	26.08	14.27	0.0005	
	At most 1	2.97	3.84	0.0848	2.97	3.84	0.0848	3
Kanpur-Katni	None	36.52	15.50	0.0000	35.50	14.27	0.0000	3
	At most 1	1.02	3.84	0.3113	1.02	3.84	0.3113	
Junagadh-Katni	None	19.46	15.50	0.0119	18.38	14.27	0.0106	1
	At most 1	1.08	3.84	0.2979	1.08	3.84	0.2979	

Granger Causality test

The Granger causality test (Table 5) revealed strong price interdependencies among pigeonpea markets in Amarawati, Kalburgi, Kanpur, Junagadh, and Katni. Bidirectional causality was observed in key pairs such as Amarawati-Katni and Kanpur-Katni, indicating robust price integration and mutual influence between these markets. Several unidirectional linkages were also identified, including Amarawati → Kalburgi, Amarawati → Kanpur, Amarawati → Junagadh, Amarawati → Katni, Kalburgi → Kanpur, Kalburgi → Junagadh, Kalburgi → Katni, Kanpur → Katni, and Junagadh → Katni, highlighting the price leadership roles of Amarawati, Kalburgi, and Kanpur. In contrast, no significant causality was found in pairs such as Kalburgi-Amarawati, Kanpur-Kalburgi, Junagadh-Kalburgi, Katni-Kalburgi, Kanpur-Amarawati, Kanpur-Junagadh, and Katni-Junagadh, aligning with Jainuddin *et al*. (2024), who also reported both bidirectional and unidirectional price transmissions among major pigeonpea markets.

Table 5: Pair-wise granger causality of Pigeonpea prices in major market of India.

Markets	F-Statistics	Probability Value	Grange Cause	Direction
Kalburgi Amarawati	13.02	0.7730	No	Unidirectional
Amarawati-Kalburgi	0.08	0.0005	Yes	
Kalburgi-Kanpur	57.67	0.0001	Yes	Unidirectional
Kanpur-Kalburgi	0.01	0.9102	No	
Kalburgi-Junagadh	4.35	0.0393	Yes	Unidirectional
Junagadh-Kalburgi	0.84	0.3599	No	
Kalburgi-Katni	18.19	0.0001	Yes	Unidirectional
Katni-Kalburgi	3.24	0.0747	No	
Amarawati-Kanpur	56.63	0.0001	Yes	Unidirectional
Kanpur-Amarawati	0.82	0.3671	No	
Amarawati-Junagadh	0.46	0.4952	No	No causality
Junagadh-Amarawati	2.02	0.1579	No	
Amarawati-Katni	14.39	0.0002	Yes	Bidirectional
Katni-Amarawati	4.90	0.0209	Yes	
Kanpur-Junagadh	0.00	0.9453	No	Unidirectional
Junagadh-Kanpur	53.01	0.0001	Yes	
Kanpur-Katni	6.21	0.0142	Yes	Bidirectional
Katni-Kanpur	21.57	0.0001	Yes	
Junagadh-Katni	12.37	0.0006	Yes	Unidirectional
Katni-Junagadh	3.86	0.0519	No	

Conclusion

The study revealed clear seasonal patterns in pigeonpea arrivals and prices, with arrivals peaking during January-March, aligning with the harvest season, while prices reached their highest levels from June to October, reflecting the inverse relationship between supply and price. Stationarity tests (ADF and PP) confirmed that price series are non-stationary at levels but become stationary after first differencing, indicating an integrated order of I(1). The Johansen cointegration test demonstrated strong long-run price linkages among key market pairs, confirming the existence of price co-movement across regions. Granger causality analysis further identified both bidirectional and unidirectional price transmissions, with Amarawati, Kalburgi, and Kanpur emerging as key price-leading markets. These findings confirm that pigeonpea markets in India are increasingly integrated, with prices exhibiting long-term relationships and coordinated movements, although regional disparities and supply-side volatility continue to affect market efficiency. Strategic policy interventions focusing on warehousing, timely market releases, and infrastructure development are essential to enhance price stability, reduce distress sales, and support sustainable growth in the pigeonpea sector.

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