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CO- INTEGRATION OF SESAMUM MARKETS IN INDIA

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ABSTRACT

The present study empirically evaluated the spatial price integration and inter-market price transmission of sesamum in five major Indian markets Alwar, Guskara, Neemuch, Nizamabad and Rajkot using monthly modal price data. Stationarity properties of the series were first assessed through Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests, and all price series were found to be non-stationary in levels but stationary in first differences, indicating integration of order one, I(1). Given this, Johansen's multivariate co-integration procedure was applied and the trace and maximum eigenvalue statistics jointly confirmed the existence of multiple co-integrating vectors, implying a stable long-run equilibrium relationship among the selected sesamum markets. To delineate the direction of price discovery, pairwise Granger causality tests were conducted, these revealed bidirectional causality between Nizamabad and Neemuch and several unidirectional causal flows from Alwar, Nizamabad and Rajkot to other markets, indicating asymmetric price transmission and the presence of price-leading centres, with Nizamabad emerging as a key transmitter of price signals. A Vector Error Correction Model (VECM) was subsequently estimated to capture both the long-run adjustment mechanism and short-run dynamics. The error-correction terms in the Neemuch, Nizamabad and Rajkot equations were statistically significant, demonstrating that these markets bear the main burden of restoring long-run equilibrium following shocks, whereas Alwar and Guskara are driven more by own-lag effects in the short run. Overall, the findings confirm that the major sesamum markets in India are spatially integrated, price shocks are disseminated across locations, and market efficiency can be further enhanced through strengthened market information systems and reduction of spatial frictions.

Keywords: Market Integration, Sesamum, Co integration, Granger Causality, VECM

Sesamum (sesame) occupies a distinctive position among the world's oilseed crops owing to its superior seed quality, high oil content, and broad adaptability to diverse agro-ecological conditions. Widely referred to as the "queen of oilseeds," sesame seeds contain about 45–55% oil that remains naturally stable because of endogenous antioxidants such as sesamin and sesamol, which makes the oil highly desirable for premium edible uses as well as for traditional food preparations. In addition, sesame seed is a good source of high-quality protein (18–25%) and essential minerals, and the oilcake obtained after extraction serves as a valuable component in livestock and poultry rations, particularly in regions where conventional protein meals are limited. Sesame is predominantly grown by smallholder farmers under rainfed, low-input systems, where it contributes significantly to household income, nutritional security, and crop diversification across Asia and Africa. Globally, most of the sesame produced is crushed for edible oil and meal, while selected, high-grade seed lots are channelled to the confectionery, bakery, tahini, and health-food industries. A smaller proportion of the oil is utilized in pharmaceutical, cosmetic, and other specialty industrial products because of its oxidative stability, pleasant flavour, and functional properties. Thus, sesamum integrates effectively into sustainable farming systems and niche export markets, supporting the livelihoods of resource-poor farmers while meeting the growing consumer demand for natural, high-value vegetable oils.

World sesamum production in 2024-25 is estimated as 6.8 million tonnes from a total area of 11.71 million hectares. India ranks first in sesamum production with 0.86 million tonnes followed by Myanmar (0.72 million tonnes), Sudan (0.62 million tonnes) and Nigeria (0.45 million tonnes). (http://www.fao.org/faostat). India ranks second in area with 1.55 million hectares (3.86 million acres) accounting for 13.23% of the world area and first in production with 0.86 million tonnes. The major sesamum Producing states are West Bengal, Gujarat, Madhya Pradesh, Uttar Pradesh, Rajasthan, Tamil Nadu, Karnataka, and Telangana.

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Market efficiency is often examined indirectly through market integration, which in theory and empirical work is discussed in three forms inter-temporal (arbitrage across time), vertical (price transmission along the marketing and processing chain), and spatial (price co-movement across geographically separated markets). Of these, spatial integration is most commonly applied in agricultural market studies because it indicates whether price changes in one location are consistently and adequately transmitted to other locations for the same homogeneous commodity. In liberalizing and developing economies, a high degree of spatial market integration signals effective arbitrage, competitive conduct, and reliable price information, thereby reducing the need for costly government interventions to "correct" markets. Conversely, weakly integrated markets can transmit misleading price signals, distort producers' allocation decisions, depress consumer welfare, and ultimately slow agricultural growth. Evidence that the major sesame markets in India are highly integrated implies that these markets share common long-run price information, that short-run price deviations are corrected through inter-market arbitrage and stock or flow adjustments, and that marketing efficiency, alongside production efficiency, constitutes a critical determinant of overall agricultural sector performance.

All major sesamum markets in India were found to be highly integrated with respect to price movements. In an agricultural economy, markets constitute a key link between producers and consumers, and their efficiency directly influences the transmission of price signals and, consequently, resource allocation. When domestic agricultural commodity markets are well integrated, prices in one centre respond to changes in another, allowing policy reforms, supply shocks or demand shifts to be reflected more uniformly across regions. Thus, the overall performance of the agricultural sector depends not only on production or supply-side efficiency, but equally on marketing efficiency and the effectiveness of price discovery mechanisms. In this context, spatial market integration serves as an important indicator, as it measures the extent to which spatially separated markets trade or share a common long-run price for a homogeneous commodity.

Zhang *et al.* (2010) used the VEC model and the Granger test on the monthly data from 1989 to 2008 and reported that there is not any long run and short-run causality between the fuel (oil, gasoline and ethanol) and agricultural commodity (corn, soybeans, wheat, sugar and rice) prices. Aung et al. (2010) analyzed the market performance and price behaviour of sesame in Myanmar using marketing margin analysis, cointegration, error correction model (ECM), and Granger causality. The study found strong long-run integration among major domestic and export markets, with domestic wholesale prices significantly influencing export prices. Nazlioglu and Soytas (2012) investigated the relationship between the world oil prices and the agricultural commodity prices by using the monthly data from 1980 to 2010 using the panel co-integration and the Granger causality techniques. The results of their study showed that the change in oil prices and the weak dollar have a strong impact on many agricultural commodity prices. Esposti and Listorti (2013) investigate on national and international markets; trade policy regime has an important role in price transmission mechanisms and the trade policy intervention put forward to mitigate the impact of price exuberance is considered. The authors analyzed agricultural price transmission during price bubbles, in particular, considering Italian and international weekly spot (cash) price data over years 2006– 2010. Vijaya Kumari R *et al* (2019) used cointegration analysis to examine price movements in major redgram markets of India. The study found long-run market integration with both bidirectional and unidirectional price causality among markets. VECM results showed that lagged prices in Mumbai, Amravati, and Tandur significantly influenced current prices in Gulbarga, Vijayawada, and Amravati markets. Majumder *et al.* (2022) find strong long-run cointegration across ten major Indian potato wholesale markets, indicating a high degree of spatial market integration. VECM results show negative, significant error-correction terms Agra and Burdwan adjust fastest to shocks while Coochbehar, Chennai and Delhi act as efficient price signal transmitters. The study implies that short-run deviations are corrected over time, so long-term price interventions are likely ineffective and policy measures (storage, information systems, infrastructure) should be channelled through the key transmission hubs to stabilise prices. Baruah (2022) shows that paddy wholesale markets in Chhattisgarh exhibit some degree of long-run price interdependence but overall integration is weak and adjustment to equilibrium is slow. ARDL/ECM results identify a mix of lead and lag mandis, and demonstrate that price-transmission estimates are sensitive to paddy variety. The persistence of price shocks implies that blanket price-support alone is insufficient; targeted market reforms improving infrastructure, information flow (e.g., eNAM expansion) and reducing transaction costs are needed to strengthen intra-state integration and make MSP benefits more effective. Shubham *et al.* (2024) find that major tomato markets in India are well integrated in the long run, with Johansen co-integration and VECM evidence confirming long-term equilibrium among Delhi, Mumbai, Solan, Mandi and Kolar. Short-run linkages are weaker and asymmetric. Granger causality identifies Mumbai as a key receiver of price signals while Solan shows the fastest adjustment (H"35.25%). Impulse-response analysis indicates that price shocks dissipate and markets largely stabilise after about four–five months, implying that policy should emphasise infrastructure, market intelligence and value-addition to reduce short-term volatility. Shankar *et al.* (2025) find strong long-run cointegration among key north-Indian garlic markets (Chandigarh, Delhi, Dehradun, Shimla) with both bidirectional and unidirectional Granger-causal links. VECM results show Chandigarh and Dehradun converge quickly to short-run equilibrium, Shimla adjusts slowly, while Delhi shows no short-run correction. Overall, garlic markets are closely linked in the long run, implying that improvements in market infrastructure, information flow and targeted regional policy can help reduce short-term volatility and improve price transmission. Singh et al. (2025) combine long-term APY (1970–2023) and wholesale price (2014–2024) analysis of black gram across major Indian states, using CDVI, decomposition, Johansen cointegration, VECM, IRF and variance decomposition. They find strong long-run price integration, identify Madhya Pradesh as a dominant price-setting state, asymmetric adjustment speeds (Punjab as price-taker), and policy implications around resilient varieties, storage, e-market expansion and targeted procurement. Pavana *et al.* (2025) analyzed price transmission and market integration among major onion markets in India using monthly wholesale data from 2006–2020 through Johansen co-integration and Granger causality tests. The results revealed three co-integrating relationships, indicating strong long-run equilibrium and efficient price transmission across markets. Bidirectional causality among key markets such as Mumbai–Ahmedabad and Pune–Ahmedabad confirmed mutual price interdependence, while unidirectional causality in others reflected partial inefficiencies. Overall, the study concluded that India's onion markets are increasingly integrated and competitive, though regional disparities still influence short-term price adjustments.

MATERIAL AND METHODS

For price integration, simple bivariate correlation coefficients measure price movements of a commodity in different markets. This is the simplest way to measure the spatial price relationships between two markets. Early inquiries on spatial market integration, for example Lele (1967) and Jones (1968) have used this method. However, this method clearly has some limitations, as it cannot measure the direction of price integration between two markets. The cointegration procedure measures the degree of price integration and takes into account the direction of price integration. This econometric technique provides more information than the correlation procedure, as it allows for the identification of both the integration process and its direction between two markets.

Our price data consist of monthly modal prices of Sesamum (Rs/qtl) in five major markets *viz.* Guskara, Neemuch, Rajkot, Alwar and Nizamabad of the India using monthly Sesamum prices over the period from January 2020 to October 2025. The data was taken from the websites of agriculture marketing government of Telangana http://tsmarketing.in/ and https://agmarknet.gov.in/

Market Integration Test

Market integration is tested using the cointegration method, which requires that

· Two variables, say P_{it} and P_{jt} are non-stationary in levels but

Stationary in first differences i.e. $P_{it} \sim I(1)$ and $P_{jt} \sim I(1)$.

· There exists a linear combination between these two series,

Which is stationary i.e. ε_{it} (=P_{it}- $\hat{\alpha}$ - $\hat{\beta}\, P_{jt}$) $\sim I(0)$.

So the first step is to test whether each of the univariate series is stationary. If they are both $I(1)$ then we may go to the second step to test cointegration. The Engle and Granger (1987) procedure is the common way to test cointegration.

Unit root test

The regression analysis of non-stationary time series produces spurious results, which can be misleading (Ghafoor, *et al.,* 2009). The most appropriate method to deal with non-stationary time series for estimating long-run equilibrium relationships is cointegration, which necessitates that time series should be integrated of the same order. Augmented Dickey- Fuller (ADF) and Phillips-Perron test (PP) is used to verify the order of integration for each individual series. The ADF test, tests the null hypothesis of unit root for each individual time series. The rejection of the null hypothesis indicates that the series is non-stationary and *vice-versa* (Dickey and Fuller, 1981). The number of the appropriate lag for ADF is chosen for the absence of serial correlation using Akaike Information Criterion (AIC). The ADF test is based on the Ordinary Least Squares (OLS) method and requires estimating the following model.

$$\Delta lnP_t = \alpha_0 + \delta_1 t + \gamma lnP_{t-1} + \sum_{j=1}^{q} \vartheta_j \Delta lnP_{t-j} + \varepsilon_t \qquad (1)$$

Where, P the price in each market, Δ is the difference parameters (i.e., $\Delta P_1 = P_t - P_{t-1}$, $P_{t-1} = P_{t-1} - P_{t-2}$ and $P_{n-1} = P_{n-1} - P_{n-2}$), α_0 is the constant or drift, *t* is the time or trend variable, *q* is the number of lags length and ε_t is a pure white noise or error term.

Johansen Cointegration

The maximum likelihood (ML) method of cointegration is applied to check long-run wholesale prices relation between the selected Sesamum markets of India (Johansen, 1988; Johansen and Juselius, 1990). The starting point of the ML method is vector autoregressive model of order (k) and may be written as:

$$P_t = \sum_{i=1}^{k} A_t P_{t-1} + \mu + \beta_t + \varepsilon_t: \ (t=1, 2, 3 \ldots T) \qquad (2)$$

Where, (n-1) denotes the vector of non-stationary or integrated at order one, i.e., I (1) prices series. The procedure for estimating the cointegration vectors is based on the Vector error correction model (VECM) representation given by:

$$\Delta P_t = \prod P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + +\beta\mu_t + \varepsilon_t \qquad (3)$$

Where,

$$\Gamma_i = -(I-\Pi_i-\ldots..,T);\ i=1,2,\ldots.k-1$$

$$\Pi = -(I-\Pi, -\ldots\ldots\ldots\Pi_k)$$

Both Γi and Πi are the n*n matrixes of the coefficient conveying the short and long run information respectively, μ is a constant term, t is a trend, and ε_t is the n-dimensional vector of the residuals that are independent and identically distributed(i.i.d). The vector ΔP_t is stationary P_t is integrated at order one I (1) which will make unbalance relation as long as Π matrix has a full rank of k. In this respect, the equation can be solved by inversing the matrix Π^{-1} for P_t and as a linear combination of stationary variable (Kirchgässner, *et al.,* 2012). The stationary linear combination of the Pt determines by the rank of Π matrix. If the rank r of the matrix Π r=0 the matrix is the null and the series underlying is stationary. If the rank of the matrix Π is such that 0 < rank of (Π) = r < n then there are n × r cointegrating vectors. The central point of the Johansen's procedure is simply to decompose Π into two n × r matrices such that $\Pi = \alpha\beta'$. The decomposition of Π implies that the β'Pt are r stationary linear combination.

Johansen and Juselius, (1990) proposed two likelihood ratio test statistics (Trace and Max Eigen test statistics) to determine the number of cointegrating vectors as follows:

$$J_{trace} = -T\sum_{i=r+1}^{N} \ln(1 - \widehat{\lambda}_1) \qquad (4)$$

$$\lambda_{max} = -Tln\,(1 - \widehat{\lambda}_{r+1}) \qquad (5)$$

Where, r is the number cointegrated vector, $\widehat{\lambda}_1$ is the eigen value and $\widehat{\lambda}_{r+1}$ is the$(r + 1)^{th}$ largest squared eigen value obtained from the matrix Π and the T is the effective number of observations. The trace statistics tested the null hypothesis of r cointegrating vector(s) against the alternative hypothesis of n cointegrating relations. The Max Eigen statistic tested the null hypothesis (r =0) against the alternative (*r* + 1).

Vector Error Correction Model (VECM)

If price series are *I* (1), then one could run regressions in their first differences. However, by taking first differences, we lose the long-run relationship that is stored in the data. This implies that one needs to use variables in levels as well. Advantage of the vector error correction model (ECM) is that it incorporates variables both in their levels and first differences. By doing this, VECM captures the short-run disequilibrium situations as well as the long-run equilibrium adjustments between prices. Even if one demonstrates market integration through cointegration, there could be disequilibrium in the short-run i.e. price adjustment across markets may not happen instantaneously. It may take some time for the spatial price adjustments. VECM can incorporate such short-run and long-run changes in the price movements.

A VECM formulation, which describes both the short-run and long-run behaviors of prices, can be formulated as:

$$\Delta P_{it} = \gamma_1 + \gamma_2 \Delta P_{jt} - \pi \hat{\upsilon}_{it-1} + v_{it}. \qquad (6)$$

In this model, γ_2 is the impact multiplier (the short -run effect) that measures the immediate impact that a change in P_{jt} will have on a change in P_{it}. On the other hand, π is the feedback effect or the adjustment effect that shows how much of the disequilibrium is being corrected, that is the extent to which any disequilibrium in the previous period effects any adjustment in the period of course $\hat{\upsilon}_{t-1} = P_{it-1} - \hat{p}_1 - \hat{p}_2 P_{ji-1}$ and therefore from this equation we also have being the long-run response.

Granger Causality Test

If a pair of series is cointegrated then there must be Granger causality in at least one direction, which reflects the direction of influence between series (in our case prices). Theoretically, if the current or lagged terms of a time-series variable, say P_{jt}, determine another time-series variable, say P_{it}, then there exists a Granger causality relationship between and , in which is Granger caused by . Bessler and Brandt (1982) firstly introduced this test into research on market integration to determine the leading market.

From the above analysis, the model is specified as follows:

$$\Delta P_{it} = \theta_{11}\Delta P_{it-1} + \ldots + \theta_{1n}\Delta P_{it-n} + \theta_{21}\Delta P_{jt-1} + \ldots \theta_{2n}\Delta P_{jt-n} - \gamma_1(P_{it-1} - \alpha P_{jt-1} - \delta) + \varepsilon_{1t}\ .$$

$$\Delta P_{jt} = \theta_{31}\Delta P_{jt-1} + \ldots + \theta_{3n}\Delta P_{it-n} + \theta_{41}\Delta P_{it-1} + \ldots \theta_{4n}\Delta P_{it-n} - \gamma_2(P_{it-1} - \alpha P_{jt-1} - \delta) + \varepsilon_{2t}\ .$$

The following two assumptions are tested using the above two models to determine the Granger causality relationship between prices.

$$\theta_{21} = . \ldots = \theta_{2n} = \cdots = \gamma_1 = 0 \text{ (No causality from } P_{jt} \text{ to } P_{it}\text{)}$$
$$\theta_{41} = . \ldots = \theta_{4n} = \cdots = \gamma_2 = 0 \text{ (No causality from } P_{it} \text{ to } P_{jt}\text{)}$$

Software used for the analysis EViews

RESULTS AND DISCUSSION

Fig. 1 depicts the monthly modal prices of sesamum in the major selected markets, showing a broadly synchronized movement across Neemuch, Rajkot, Alwar and Nizamabad, indicating strong co-movement of prices. A common upward phase is observed from mid-2022 to late-2023, when prices peaked around ₹ 15,000–16,000/q, followed by a gradual decline in 2024–25. Guskara, however, remained consistently lower than the other markets throughout the period, suggesting a relatively weaker price level or different market conditions there.

Descriptive Statistics

Summary statistics (Table 1) show that Rajkot (₹ 11,360/q) recorded the highest mean sesamum price, followed by Nizamabad (₹ 10,769/q) and Alwar (₹ 10,118/q), while Guskara (₹ 6,849/q) had the lowest average price, indicating a relatively weaker market. Price instability, measured by the coefficient of variation, was highest in Nizamabad (22.11%) and Alwar (21.67%), implying greater month-to-month fluctuations in these markets, whereas Rajkot (19.30%) and Guskara (19.85%) exhibited comparatively stable prices. The highest maximum price was observed in Nizamabad (₹ 16,402/q), suggesting occasional demand surges in this market.

Order of the Integration

The results of the ADF and PP unit root tests for monthly modal prices of sesamum in the five markets (Table 2). At levels, all the series have test statistics with p-values greater than 0.05, so the null hypothesis of a unit root cannot be rejected, indicating that the price series of Guskara, Neemuch, Rajkot, Alwar and Nizamabad are non-stationary in levels. After first differencing, both ADF and PP statistics become highly significant at the 1% level for all markets (Δ series), implying rejection of the unit root. Thus, all sesamum price series are stationary in first differences and are integrated of order one, I (1).

Table 1. Summary Statistics of the monthly modal Prices for Sesamum in major markets for India from the period January, 2020 to October, 2025 (in Rs/100 kg)

	Guskara	Neemuch	Rajkot	Alwar	Nizamabad
Mean	6849	9665	11360	10118	10769
Median	6308	9000	10630	9597	10022
Maximum	9099	14136	15902	14603	16402
Minimum	4541	6731	8138	5098	7264
Std. Dev.	1360	1943	2192	2193	2381
CV	19.85	20.11	19.30	21.67	22.11

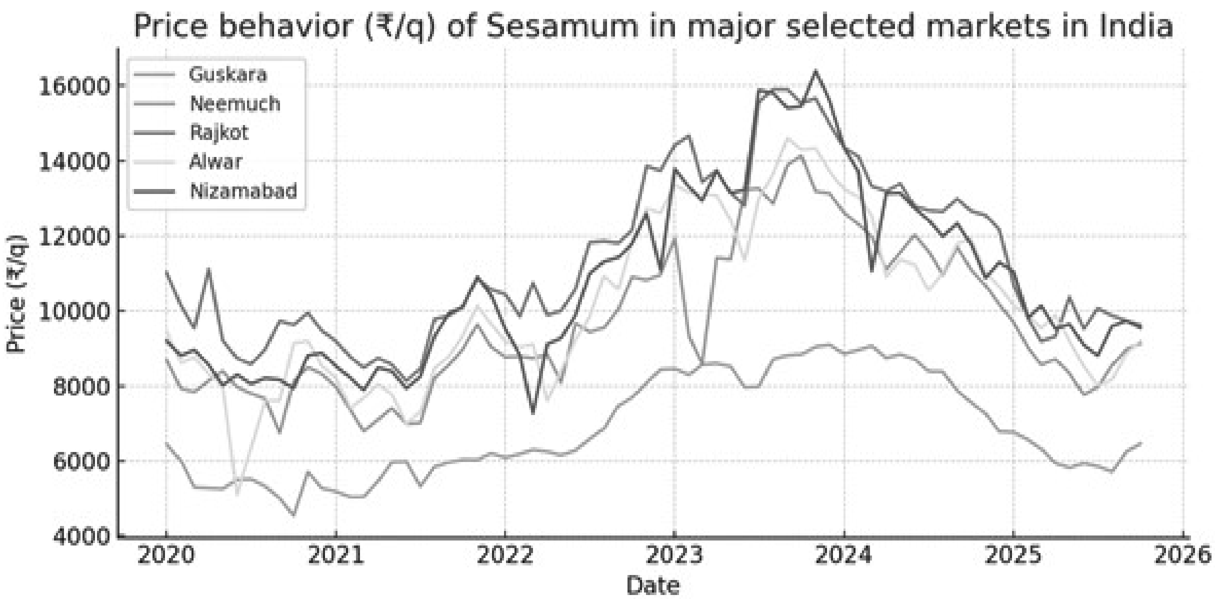

Fig. 1: Price behavior (‘Rs/quintal) of Sesamum crop in major selected markets in India

Table 2. ADF and PP Tests for Unit Root in the monthly modal prices of Sesamum

Augmented Dickey-Fuller test results at level				**Phillips-Perron test results at level**		
	t-Statistic	**Prob.***	**Remarks**	**t-Statistic**	**Prob.***	**Remarks**
Guskara	-0.99	0.75	Non-stationary	-1.10	0.70	Non-stationary
Neemuch	-1.65	0.45	Non-stationary	-1.61	0.46	Non-stationary
Rajkot	-1.27	0.63	Non-stationary	-1.34	0.60	Non-stationary
Alwar	-1.47	0.54	Non-stationary	-1.57	0.48	Non-stationary
Nizamabad	-1.56	0.49	Non-stationary	-1.49	0.53	Non-stationary
Augmented Dickey-Fuller test results after differencing				**Phillips-Perron test results after differencing**		
Guskara	-7.35*	0.00	Stationary	-7.33*	0.00	Stationary
Neemuch	-8.74*	0.00	Stationary	-8.79*	0.01	Stationary
Rajkot	-8.37*	0.00	Stationary	-8.37*	0.00	Stationary
Alwar	-7.54*	0.00	Stationary	-7.54*	0.00	Stationary
Nizamabad	-9.66*	0.00	Stationary	-9.63*	0.00	Stationary

Notes: ** denote significance at 1% levels of significance and Ä denote the first difference of the time series.*

Co-integration Analysis

Johansen's co-integration results for the five major sesamum markets (Table 3). Both the trace statistic and the maximum eigenvalue statistic reject the null hypothesis of "no co-integration" (r = 0) at the 5% level, as the test values (Trace = 140.53; Max-Eigen = 54.36) exceed their respective critical values and have p-values < 0.01. Similarly, the successive null hypotheses of "at most 1", "at most 2", "at most 3" and "at most 4" co-integrating vectors are also rejected, indicating the presence of multiple long-run equilibrium relationships among the five markets. This confirms that the sesamum prices in Alwar, Guskara, Neemuch, Nizamabad and Rajkot move together in the long run and that these markets are strongly spatially integrated.

Granger causality test

After confirming that the sesamum price series are integrated of the same order, pairwise Granger causality tests were conducted to identify the direction of price transmission among the five selected markets (Table 4). The results indicate the presence of one bidirectional causal relationship between Nizamabad and Neemuch (lag 8), suggesting that price changes in either market are transmitted to the other, and implying mutual information flow. In addition, several unidirectional causal links were observed. Alwar to Guskara (lag 1), Nizamabad to Alwar (lag 3), Nizamabad to Guskara (lag 6), Rajkot to Guskara (lag 7), and Neemuch to Rajkot (lag 9). These unidirectional relations imply that price formation in the originating market influences the dependent market, but not the reverse. The remaining market pairs did not exhibit Granger causality, indicating an absence of short-run predictive linkage between those price series. Overall, the results suggest that Nizamabad functions as a price-leading market in the sesamum marketing system, whereas Guskara largely behaves as a price-following market.

Short run and long run behavior of market prices

The Johansen co-integration test confirmed the existence of a common long-run equilibrium relationship among the five selected sesamum markets; therefore, a Vector Error Correction Model (VECM) was estimated to examine both the long-run adjustment mechanism and short-run price dynamics (Table 5). The error-correction term was found to be statistically significant in the equations for Neemuch, Nizamabad and Rajkot, indicating that these markets adjust to deviations from the long-run equilibrium and thereby contribute to restoring price parity within the system. In the short run, several own-lagged price terms, particularly for Alwar and Guskara, were significant, implying that part of the price formation in these markets is driven by their past prices. In addition, the significant lagged effects of Nizamabad on other markets point to its role as an important price-transmitting centre. Overall, the VECM results suggest that the major sesamum markets in India are integrated in the long run, while short-run adjustments occur through a combination of own-market corrections and selective inter-market price spillovers.

CONCLUSION

The present study analysed the spatial market integration and price behaviour of major sesamum markets in India using monthly modal price data January, 2020 to October 2025. The ADF and Phillips–

Table 3. Johansen's Co-integration Test Results of five major Sesamum Market prices in India

Hypothesized No. of CE(s)	H_0	H_1	Eigen value	Trace Statistics results			Max-Eigen Statistics results		
				Trace Statistics	0.05 Critical Value	P-Value	Max-Eigen Statistic	0.05 Critical Value	P-Value
None *	r=0	re≥1	0.56	140.53	69.81	0.000*	54.36	33.87	0.002*
At most 1*	rd≤ 1	re≥2	0.42	86.16	47.85	0.000*	36.70	27.584	0.002*
At most 2 *	rd≤ 2	re≥3	0.30	49.46	29.79	0.000*	24.34	21.131	0.017*
At most 3 *	rd≤ 3	re≥4	0.23	25.11	15.49	0.001*	17.25	14.2646	0.016*
At most 4 *	rd≤ 4	r=5	0.11	7.86	3.84	0.005*	7.86	3.8415	0.005*

Notes: *in represent the natural logarithm and * denote the rejection of null hypothesis at 5% level of significance*

Tables 4. Market pair wise results of the Granger Casualty test

Lagged Periods	Markets Pairs	F-Statistic	P-Value	Decision of null hypothesis	Remarks
1	Guskara → Alwar	0.246	0.782	Reject	No causality
	Alwar → Guskara*	**5.222***	**0.008***	**Do not reject**	**Unidirectional**
2	Neemuch → Alwar	0.014	0.985	Reject	No causality
	Alwar → Neemuch	0.483	0.618	Reject	No causality
3	**Nizamabad → Alwar***	**5.054***	**0.009***	**Do not reject**	**Unidirectional**
	Alwar → Nizamabad	0.520	0.597	Reject	No causality
4	Rajkot → Alwar	2.641	0.079	Reject	No causality
	Alwar → Rajkot	2.512	0.089	Reject	No causality
5	Neemuch → Giscard	1.380	0.259	Reject	No causality
	Guskara → Neemuch	1.111	0.335	Reject	No causality
6	**Nizamabad → Guskara***	**3.641***	**0.032***	**Do not reject**	**Unidirectional**
	Guskara → Nizamabad	0.681	0.509	Reject	No causality
7	**Rajkot → Guskara***	**4.185***	**0.019***	**Do not reject**	**Unidirectional**
	Guskara → Rajkot	1.585	0.213	Reject	No causality
8	**Nizamabad → Neemuch***	**3.275***	**0.044***	**Do not reject**	**Bi-directional**
	Neemuch → Nizamabad*	**3.235***	**0.046***	**Do not reject**	
9	Rajkot → Neemuch	1.432	0.246	Reject	No causality
	Neemuch → Rajkot*	**3.590***	**0.033***	**Do not reject**	**Unidirectional**
10	Rajkot → Nizamabad	1.011	0.369	Reject	No causality
	Nizamabad → Rajkot	1.084	0.344	Reject	No causality

Note: ** represents the level of significance at 5% level*

Perron unit root tests indicated that the price series of Alwar, Guskara, Neemuch, Nizamabad and Rajkot were non-stationary in levels but became stationary after first differencing, confirming that all series are integrated of order one, I(1). Johansen's co-integration test further established the existence of multiple co-integrating relationships among the five markets, implying a stable long-run equilibrium and a high degree of spatial integration in the sesamum marketing system. The pairwise Granger causality results revealed one bidirectional causality between Nizamabad and Neemuch and several unidirectional causal linkages (Alwar '! Guskara, Nizamabad '! Alwar, Nizamabad '! Guskara, Rajkot '! Guskara, and Neemuch '! Rajkot), indicating that certain markets function as price-leading centres while others behave as price-following markets in the short run. The Vector Error Correction Model (VECM) showed that Neemuch, Nizamabad and Rajkot adjust significantly to deviations from the long-run equilibrium, whereas Alwar and Guskara are influenced more by their own past prices, suggesting heterogeneous adjustment speeds across markets. Overall, the empirical evidence confirms that the major sesamum markets in India are well integrated, price information is transmitted across locations, and strengthening market intelligence and infrastructure can further enhance price efficiency and welfare of sesame growers.

Table 5. Vector Error Correction Model for Sesamum prices for Major five selected markets in India

Error Correction:	Alwar	Guskara	Neemuch	Nizamabad	Rajkot
CointEq1	0.030	-0.019	**-0.124****	**0.233****	**0.175****
	(0.065)	(0.026)	(0.061)	(0.074)	(0.048)
Alwar(-1)	**-0.460****	0.086	0.045	-0.213	0.100
	(0.143)	(0.059)	(0.136)	(0.164)	(0.106)
Alwar(-2)	-0.258	-0.015	-0.204	-0.235	0.117
	(0.141)	(0.058)	(0.134)	(0.162)	(0.104)
Guskara(-1)	-0.293	**-0.356****	0.468	-0.213	**-0.352****
	(0.299)	(0.123)	(0.284)	(0.344)	(0.221)
Guskara(-2)	-0.234	**-0.476****	-0.049	-0.147	**-0.146***
	(0.299)	(0.123)	(0.284)	(0.343)	(0.221)
Neemuch(-1)	-0.248	0.162	-0.013	-0.419	**-0.123****
	(0.243)	(0.100)	(0.231)	(0.279)	(0.180)
Neemuch(-2)	**-0.241****	0.042	-0.091	-0.321	**-0.146****
	(0.167)	(0.068)	(0.159)	(0.192)	(0.123)
Nizamabad(-1)	**0.156***	0.001	**-0.576****	**-0.207****	**0.170****
	(0.145)	(0.060)	(0.138)	(0.167)	(0.107)
Nizamabad(-2)	0.234	0.002	-0.206	**-0.179***	0.139
	(0.125)	(0.051)	(0.119)	(0.144)	(0.093)
Rajkot(-1)	0.300	-0.057	-0.370	**0.533***	-0.229
	(0.212)	(0.087)	(0.201)	(0.243)	(0.157)
Rajkot(-2)	-0.010	0.045	-0.062	0.315	-0.132
	(0.159)	(0.065)	(0.151)	(0.183)	(0.118)
C	-32.580	-13.615	-0.659	-20.940	-3.489
	(105.271)	(43.157)	(99.953)	(120.765)	(77.807)
	[-0.309]	[-0.315]	[-0.007]	[-0.173]	[-0.045]

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