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Price Integration Analysis of Major Potato Markets in Haryana (Trans-Gangetic Plains), India

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Abstract: The present study examines the market integration of potato prices across selected markets in Haryana which lies in the Trans-Gangetic Plains (predominantly semi-arid to sub-humid climate) using monthly time series data from 2015 to 2024, collected from various published sources such as AGMARKNET and related government databases. To understand the inter-market price relationships, various econometric tools were applied, including correlation analysis, Augmented Dickey-Fuller (ADF) test, Johansen co-integration test, and Granger Causality test. Initially, correlation analysis of monthly wholesale prices revealed strong associations among the markets, with coefficients ranging from 0.616 to 0.913, with significant differences, indicating a high degree of market linkage. The ADF test was employed to examine stationarity showed that most price series were stationary at level under both intercept and intercept-trend models. This allowed further analysis using Johansen's co-integration technique, which indicated the presence of two co-integrating equations at the 1% level, suggesting long-run equilibrium relationships among the markets. Granger Causality results revealed multiple significant unidirectional and bidirectional causal relationships among the markets. The study confirms the existence of strong price linkages and dynamic interactions among potato markets in Haryana.

Keywords: Market integration, Correlation analysis, Co-integration test, Augmented dickey fuller test, Granger causality test

Potato (*Solanum tuberosum*), a perennial species of the Solanaceae family, is one of the most important edible tubers cultivated worldwide. The world potato production was about 383 million tonnes in 2023, placing it fourth among food crops after maize, wheat, and rice (FAOSTAT 2024). India ranks third globally in terms of the area under potato cultivation and stands as the second-largest producer after China. In 2024, the nation's potato output reached around 60.18 million tonnes, reflecting a significant rise compared with the preceding year (National Horticulture Board 2024). This growth highlights the positive impact of advanced cultivation practices and technological progress in agriculture. The marketing of potatoes is a primary concern for farmers because of the volatile nature of their prices (Singh et al., 2017). Potato prices fluctuate both within and between years. The total crop arrivals throughout the year heavily influence how much potato prices fluctuate within year. Seasonal variations in potato production can be attributed to several factors, including fluctuations in the overall cultivated land area, unexpected weather conditions, infestations of pests or diseases, fluctuations in the prices of other vegetables, and variations in demand from major urban areas and the agro-industry (Sreepriya and Sidhu 2020).

Long-term price correlations among different market hubs suggest that prices serve as significant indicators in the market, indicating that all exchange locations are interconnected and integrated (Ghosh 2010). Market integration is a significant economic concept, particularly relevant in the context of India, where analysing agricultural market integration holds particular importance. This is due to the significant share of food in the population's consumption basket. The high degree of market integration reflects the competitiveness among these markets. Integrated markets provide opportunities for farmers to specialize based on their comparative advantage. Conversely, non-integrated markets present misleading price information, leading to distorted production decisions, inefficiencies in agricultural markets, and negative consumer consequences, resulting in reduced production and sluggish growth (Mukhtar & Javed, 2008). Furthermore, market integration is crucial in influencing the pattern and pace of diversification towards high-value crops (Sidhu et al., 2010). Understanding the degree of market integration is crucial for effective resource allocation, price stability, food security, and nutrition (Muhammad & Mirza, 2014; Sonar et al., 2023) and will help in targeting agricultural price policies at specific geographic levels to ensure consistent access to food and price stability (Sharma and Kumari 2021).

Potato prices exhibit significant seasonal and regional variability, which poses challenges for consumers, producers, and policy planners. Accurate price forecasting is therefore crucial for effective market regulation and strategic planning. Numerous studies have previously sought to construct models to forecast prices of agricultural commodities (Paul et al., 2022). To effectively address the issue of price volatility, it is essential to understand the temporal behaviour of prices. Insight into the relationship between market arrivals and price levels helps in determining the extent and pattern of such fluctuations. One effective approach to this analysis is the assessment of market integration, which evaluates how price changes in one market influence prices in other markets-either immediately or after a delay (Saha et al., 2019). The strength and speed of this price transmission serve as indicators of the level of integration among markets across regions. The benefits accruing to producers and consumers largely depend on how well local markets are integrated with broader national or regional markets (Vigila et al., 2021). Studying market integration thus provides a measure of price co-movement across geographically distinct markets and helps farmers make informed decisions regarding the optimal timing, location, and quantity of produce to sell. The study aimed to analyse the price dynamics and degree of market integration within the key potato markets in India.

METHODOLOGY

India's potato production reached a record 601.75 lakh tonnes in 2024, while Haryana produced 843.23 thousand tonnes of potato during 2024 (India stat 2024). This study utilizes monthly time series data on potato prices from the selected markets in Haryana for the period 2015 to 2024 to examine the integration among these markets. The most important potato producing districts i.e. Kurukshetra, Yamuna Nagar, Karnal, Ambala and Sonipat were preferred purposely for the study. These districts together account for nearly 80 per cent of the total area and production of potato in Haryana. From each district, two markets were chosen on the basis of the arrival of potato in these markets. Thus, Thanesar and Shahbad markets from Kurukshetra district, Radaur and Jagadhari markets from Yamuna Nagar district, Karnal and Gharaunda markets from Karnal district, Ambala Cantt and Naraingarh from the Ambala district and Sonipat and Gohana markets from Sonipat district were selected. The time series data on prices and arrival of potato for various potato markets were collected from the Agricultural Produce Market Committees and other official websites for the period 2015 to 2024.

Market Integration: To evaluate the interdependence among potato markets in Haryana, several econometric tools were applied. The goal was to assess whether these markets operate in unison or show signs of spatial disconnection. The following tests were conducted to determine the degree of integration.

Correlation analysis: The preliminary method to assess market integration is the correlation analysis of price movements between markets. Pearson's correlation coefficient was employed to quantify the strength and direction of linear relationships between price series of different market pairs.

Correlation coefficient among two markets prices X and Y

$$r(X,Y) = \frac{Cov(XY)}{\sqrt{Var(x)}\sqrt{Var(y)}}$$

To test the statistical significance of the computed correlation coefficient r, a t-test was applied using the formula:

~t(n-2) degrees of freedom $t = \frac{r}{1-r^2}\sqrt{n-2}$

where n represents the number of observations. The hypotheses tested were:

Null Hypothesis (H_0): p = 0

Alternate Hypothesis (H_1): p ⌘ 0

Augmented Dickey-Fuller (ADF) test: The monthly potato price data from the selected markets were examined for stationarity using the Augmented Dickey-Fuller (ADF) unit root test. A time series is considered stationary when its statistical properties-such as mean, variance, and autocorrelation-remain constant over time. If the price series is non-stationary at the level form, the first difference is taken and tested again. The number of differences required to achieve stationarity indicates the order of integration, expressed as I(d).

The ADF test is conducted by estimating the following regression model:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{i=1}^{m} a_i \Delta Y_{t-1} + \varepsilon$$

Where,

Y_t = price of potato in a specified market at time t

$\Delta Y_t = Y_t - Y_{t-1}$

Ɛ = pure white noise error term

m = optimal lag which is chosen based on Schwartz information criterion

Test for unit roots in the price series,

Null Hypothesis (H_0): prices series is non-stationary or unit root exists

Alternate Hypothesis (H_1): price series is stationary

If ADF test statistics (t*)<ADF critical value then accept the null hypothesis, i.e. unit root exists.

If ADF test statistics (t*)>ADF critical value then reject the null hypothesis.

Co-integration test: The Johansen cointegration test is based on the estimation of a Vector Auto-Regressive (VAR) model of order *k* in its error correction form as follows:

$$\Delta Y_t = \mu + \sum_{i=1}^{k-1} \Gamma_i \Delta Y_{t-i} + \prod Y_{t-k} + \varepsilon_t$$

Where,

Y_t = vector of non-stationary price variables at time t

Δ = first difference operator

Γ_i = short run adjustment coefficients

Π = long-run impact matrix that contains information on the cointegrating relationships

ε_t = error term

The rank of matrix Π determines the number of cointegrating vectors (r). If r=0, there is no cointegration; if 0<r<n, there are *r* cointegrating vectors indicating long-run price linkages among markets.This method utilizes the Trace Statistic and Maximum Eigenvalue Statistic to determine the number of co-integrating vectors. The number of such vectors is indicative of the degree of price co-movement across markets where a greater number signifies stronger and more stable price linkages.

Granger Causality Test: The Granger causality test was applied to examine the direction of causality among the market price series. Specifically, it tests whether past values of one variable (e.g., X_t) contribute to predicting another variable (e.g., Y_t) and vice versa. The possible causal linkages may appear as unidirectional (from X_t to Y_t or from Y_t to X_t), bidirectional, or absent. The autoregressive distributed lag (ADL) framework employed for this analysis is represented as follows

$$Y_t = a_0 + \sum_{j=1}^{m} a_j Y_{i-j} + \sum_{j=1}^{m} \beta_j X_{i-j} + \epsilon_{t1}$$

$$X_t = a_0 + \sum_{j=1}^{m} a_j Y_{i-j} + \sum_{j=1}^{m} \beta_j X_{i-j} + \epsilon_{t2}$$

Where,

t is the time period

ϵ_{ti} *and* ϵ_{t2} are the error terms

X and Y are the prices of different markets

RESULTS AND DISCUSSION

To understand the inter-market relationships, a cointegration analysis was performed. Initially, correlation analysis of the monthly wholesale prices of potatoes across the selected markets provided a basic approach to studying market integration. However, correlation analysis offers only rough estimates of price movement, prompting the use of advanced econometric tools such as the Johansen Cointegration Test and Granger Causality Test. Prior to analyzing time series data, stationarity testing is essential to avoid spurious results. Therefore, the Augmented Dickey-Fuller (ADF) test was employed to assess the stationarity of the variables. Once the variables were confirmed to be stationary and of the same order, the integration between the selected markets was further explored using the Johansen Cointegration Analysis method. Additionally, the Granger Causality Test was conducted to determine the direction of causality between the markets.

Correlation analysis: The degree of association between the prices of different markets can be represented using a zero-order correlation matrix. This approach assumes bivariate correlation coefficient of price movement in perfectly integrated markets tending towards unity, whereas, correlation coefficient tends towards zero in non-integrated markets.

The correlation coefficients were close to unity and statistically significant, suggesting strong integration among the potato markets in Haryana (Table 1). The correlation values ranged between 0.616 and 0.913, confirming that price movements in these markets were closely associated with one another. Similar findings on market integration were also reported by Isha Sharma et al. (2023) and Divyanshu et al. (2022).

Augmented-Dickey Fuller test: Augmented Dickey-Fuller (ADF) test indicate that the majority of the markets exhibit stationarity at level. Specifically, Naraingarh, Ambala Cantt, Jagadhari, Thanesar, Sonipat, Gharaunda, and Karnal show strong stationarity under both the intercept-only and intercept plus trend specifications, with p-values well below the 1%

Table 1. Correlation coefficients of potato prices in Haryana markets

Markets	Naraingarh	Ambala Cantt	Radaur	Jagadhari	Thanesar	Shahbad	Gohana	Sonipat	Gharaunda	Karnal
Naraingarh	1									
Ambala Cantt	.903***	1								
Radaur	.866***	.809***	1							
Jagadhari	.898***	.832***	.839***	1						
Thanesar	.706***	.680***	.752***	.689***	1					
Shahbad	.909***	.849***	.913***	.819***	.749***	1				
Gohana	.829***	.785***	.860***	.774***	.687***	.885***	1			
Sonipat	.753***	.786***	.786***	.769***	.769***	.765***	.792***	1		
Gharaunda	.623***	.616***	.810***	.652***	.853***	.741***	.750***	.766***	1	
Karnal	.617***	.650***	.668***	.637***	.653***	.684***	.664***	.707***	.684***	1

*** Indicates significant at 1% level,* * 5% level, * 10% level significance level (Table 2). Shahbad and Gohana also demonstrate stationarity but at a slightly weaker significance level (5% to 10%). Radaur, however, presents relatively weaker evidence of stationarity, with p-values near the 10% threshold, suggesting potential non-stationary behavior. Overall, the findings suggest that most market series are stationary at level, enabling modeling without the need for differencing. Similar findings were reported by Saha et al. (2019).

Table 2. Augmented Dickey-Fuller Test (ADF)

Markets	Particulars	At level t-statistic	p-value
Naraingarh	Intercept	-3.98***	0.0021
	Intercept+ Trend	-4.138***	0.0072
Ambala Cantt	Intercept	-4.26***	0.0008
	Intercept+ Trend	-4.42***	0.0031
Radaur	Intercept	-2.62*	0.0923
	Intercept+ Trend	-3.15*	0.0991
Jagadhari	Intercept	-4.48***	0.0004
	Intercept+ Trend	-4.64***	0.0014
Thanesar	Intercept	-4.48***	0.0004
	Intercept+ Trend	-5.75***	0.0000
Shahbad	Intercept	-3.38**	0.0133
	Intercept+ Trend	-4.013**	0.0108
Gohana	Intercept	-3.19**	0.0227
	Intercept+ Trend	-3.83**	0.0182
Sonipat	Intercept	-4.54***	0.0001
	Intercept+ Trend	-5.639***	0.0000
Gharaunda	Intercept	-3.18**	0.0231
	Intercept+ Trend	-5.06***	0.0003
Karnal	Intercept	-4.41***	0.0005
	Intercept+ Trend	-4.68***	0.0005

*** Indicates significant at 1% level, * * 5% level, * 10% level and NS- Non-Significant

Johansen Co-integration analysis: Both the Max-Eigen statistic and Trace statistic indicate the presence of co-integration (Table 3). The null hypothesis of no co-integration is rejected at the 1% level, with significant values for both statistics (Max-Eigen = 105.67, p = 0.0000; Trace = 355.39, p = 0.0000). Additionally, evidence of a second co-integrating relationship is also observed at the 1% level for "at most 1". Beyond this, the test statistics become insignificant, indicating no further long-run relationships. Therefore, it is concluded that there exist two statistically significant long-run equilibrium relationships among the potato markets under study, suggesting that these markets are integrated and tend to move together over the long term. The findings are in line with Jyoti Chaudhary et al. (2021).

Granger Causality test: The pairwise Granger causality results revealed extensive causal linkages among the selected potato markets in Haryana, indicating strong price interdependence (Table 4). Gharaunda emerged as a major dependent market, being Granger-caused by Ambala Cantt, Gohana, Jagadhari, Karnal, Radaur, Shahbad, and Thanesar, while exhibiting bidirectional relationships with Shahbad and Thanesar. Ambala Cantt showed significant two-way causality with Gohana, Jagadhari, and Naraingarh, and unidirectional linkages with several other markets. Gohana also demonstrated substantial influence, sharing bidirectional relationship with Karnal and Radaur.

Jagadhari and Karnal displayed both bidirectional and unidirectional causal connections with multiple markets, reflecting their key roles in the regional price formation process. Several markets, such as Naraingarh and Radour, show no significant causal relationships with other markets, indicating potential price isolation or lack of market integration. Sonipat and Thanesar were identified as major influencing markets, transmitting price signals to several others. The findings are in line with Shohe et al. (2019).

Overall, the analysis suggests that market integration in

Table 3. Johansen co-integration analysis

Co-integrating equations	Max-Eigen statistic	P-value	Trace statistic	P-value
None	105.6696	0.0000	355.3926	0.0000
At most 1	69.9108	0.0088	249.7230	0.0033
At most 2	53.9474	0.0920	179.8122	0.1145
At most 3	35.4426	0.6847	125.8647	0.5107
At most 4	26.4473	0.8861	90.4221	0.6902
At most 5	25.2802	0.6516	63.9749	0.7355
At most 6	15.6043	0.9273	38.6947	0.8875
At most 7	12.4751	0.8418	23.0905	0.8744
At most 8	5.8539	0.9616	10.6154	0.8961
At most 9	4.7615	0.6309	4.7615	0.6309

Table 4. Pair-wise granger causality test results in Haryana markets (Based on 119 observations)

Null hypothesis	F-statistic	Prob.	Relationship
AMB does not Granger Cause GHA	1.0414	0.3096	GHA→AMB
GHA does not Granger Cause AMB	3.4029*	0.0676	
GOH does not Granger Cause GHA	1.8561	0.1757	GHA→GOH
GHA does not Granger Cause GOH	3.9194*	0.0501	
JAG does not Granger Cause GHA	0.0738	0.7863	GHA→JAG
GHA does not Granger Cause JAG	7.9933***	0.0055	
KAR does not Granger Cause GHA	1.9339	0.1670	GHA→KAR
GHA does not Granger Cause KAR	10.5714	0.0015	
NAR does not Granger Cause GHA	0.1848	0.6681	NO CAUSALITY
GHA does not Granger Cause NAR	1.9180	0.1687	
RAD does not Granger Cause GHA	1.7088	0.1937	GHA→RAD
GHA does not Granger Cause RAD	11.3109***	0.0010	
SHA does not Granger Cause GHA	3.8975*	0.0507	SHA↔GHA
GHA does not Granger Cause SHA	2.9097*	0.0907	
SON does not Granger Cause GHA	1.3209	0.2528	NO CAUSALITY
GHA does not Granger Cause SON	1.2932	0.2578	
THA does not Granger Cause GHA	7.1013***	0.0088	THA↔GHA
GHA does not Granger Cause THA	3.8696*	0.0516	
GOH does not Granger Cause AMB	6.6391**	0.0112	GOH↔AMB
AMB does not Granger Cause GOH	6.6481**	0.0112	
JAG does not Granger Cause AMB	4.0955**	0.0453	JAG↔AMB
AMB does not Granger Cause JAG	10.8591***	0.0013	
KAR does not Granger Cause AMB	2.5288	0.1145	AMB→KAR
AMB does not Granger Cause KAR	5.1164**	0.0256	
NAR does not Granger Cause AMB	10.2805***	0.0017	NAR↔AMB
AMB does not Granger Cause NAR	4.7661**	0.0310	
RAD does not Granger Cause AMB	4.8914**	0.0290	RAD→AMB
AMB does not Granger Cause RAD	2.1054	0.1495	
SHA does not Granger Cause AMB	12.2787***	0.0007	SHA→AMB
AMB does not Granger Cause SHA	0.6505	0.4216	
SON does not Granger Cause AMB	19.7633***	2.E-05	SON→AMB
AMB does not Granger Cause SON	0.4768	0.4913	
THA does not Granger Cause AMB	10.6075***	0.0015	THA→AMB
AMB does not Granger Cause THA	0.1826	0.6699	
JAG does not Granger Cause GOH	1.3386	0.2497	NO CAUSALITY
GOH does not Granger Cause JAG	2.4065	0.1236	
KAR does not Granger Cause GOH	3.4996*	0.0639	KAR↔GOH
GOH does not Granger Cause KAR	5.8812**	0.0168	
NAR does not Granger Cause GOH	3.4528*	0.0657	NAR→GOH
GOH does not Granger Cause NAR	0.9107	0.3419	
RAD does not Granger Cause GOH	9.0277***	0.0033	RAD↔GOH
GOH does not Granger Cause RAD	2.9037*	0.0911	
SHA does not Granger Cause GOH	9.6689***	0.0024	SHA→GOH
GOH does not Granger Cause SHA	0.9276	0.3375	
SON does not Granger Cause GOH	16.1805***	0.0001	SON→GOH
GOH does not Granger Cause SON	0.1662	0.6842	
THA does not Granger Cause GOH	10.6772***	0.0014	THA→GOH
GOH does not Granger Cause THA	0.0371	0.8477	
KAR does not Granger Cause JAG	4.2961**	0.0404	KAR↔JAG
JAG does not Granger Cause KAR	4.3502**	0.0392	
NAR does not Granger Cause JAG	7.1170***	0.0087	NAR→JAG
JAG does not Granger Cause NAR	0.0643	0.8003	
RAD does not Granger Cause JAG	4.4313**	0.0374	RAD→JAG
JAG does not Granger Cause RAD	0.0102	0.9198	
SHA does not Granger Cause JAG	7.5585***	0.0069	SHA→JAG
JAG does not Granger Cause SHA	0.6706	0.4145	
SON does not Granger Cause JAG	17.4196***	6E-05	SON→JAG
JAG does not Granger Cause SON	2.0366	0.1562	

Cont...

Table 4. Pair-wise granger causality test results in Haryana markets (Based on 119 observations)

Null hypothesis	F-statistic	Prob.	Relationship
THA does not Granger Cause JAG	18.1322***	4E-05	THA→JAG
JAG does not Granger Cause THA	4.3832**	0.0385	
NAR does not Granger Cause KAR	2.9806*	0.0869	NAR↔KAR
KAR does not Granger Cause NAR	4.1619**	0.0436	
RAD does not Granger Cause KAR	8.0579***	0.0054	RAD→KAR
KAR does not Granger Cause RAD	2.4856	0.1176	
SHA does not Granger Cause KAR	6.0800**	0.0151	SHA→KAR
KAR does not Granger Cause SHA	2.4162	0.1228	
SON does not Granger Cause KAR	11.4302***	0.0010	SON↔KAR
KAR does not Granger Cause SON	3.5471*	0.0622	
THA does not Granger Cause KAR	7.1280***	0.0087	THA→KAR
KAR does not Granger Cause THA	1.6561	0.2007	
RAD does not Granger Cause NAR	0.5337	0.4665	NO CAUSALITY
NAR does not Granger Cause RAD	0.1267	0.7225	
SHA does not Granger Cause NAR	3.3450*	0.0700	SHA→NAR
NAR does not Granger Cause SHA	1.0179	0.3151	
SON does not Granger Cause NAR	9.3000***	0.0028	SON→NAR
NAR does not Granger Cause SON	0.0019	0.9648	
THA does not Granger Cause NAR	10.3857***	0.0016	THA→NAR
NAR does not Granger Cause THA	1.4873	0.2251	
SHA does not Granger Cause RAD	7.7146***	0.0064	SHA→RAD
RAD does not Granger Cause SHA	0.0257	0.8730	
SON does not Granger Cause RAD	11.8798***	0.0008	SON→RAD
RAD does not Granger Cause SON	0.2233	0.6374	
THA does not Granger Cause RAD	16.1383***	0.0001	THA→RAD
RAD does not Granger Cause THA	0.2596	0.6114	
SON does not Granger Cause SHA	9.3777***	0.0027	SON↔SHA
SHA does not Granger Cause SON	2.8803*	0.0924	
THA does not Granger Cause SHA	9.8389***	0.0022	THA→SHA
SHA does not Granger Cause THA	0.0219	0.8827	
THA does not Granger Cause SON	0.9048	0.3435	NO CAUSALITY
SON does not Granger Cause THA	2.4438	0.1207	

Significance at ***1% level, ** 5% level and *10% level

Haryana is not uniform, with some markets playing more central roles in price transmission, while others may have more localized price behaviour. The presence of strong integration among certain market pairs indicates efficient information flow and quick price adjustments, whereas weaker linkages in others may be attributed to differences in infrastructure, market arrival patterns, or distance from major consumption centers. These findings provide important insights for policymakers and market participants looking to understand price dynamics and improve market efficiency in Haryana's potato sector. Promoting better storage, transportation, and real-time market information systems could further improve price transmission and reduce spatial price disparities across markets.

CONCLUSION

The study concludes that potato markets in Haryana are significantly integrated, as evidenced by strong correlations, confirmed cointegration, and dynamic causal linkages among the major markets. The correlation analysis suggested a strong positive association in price movements, Johansen's cointegration test established long-term equilibrium relationships, indicating that despite short-term fluctuations, prices tend to converge across markets over time. Granger causality results further highlighted the presence of both unidirectional and bidirectional influences, with markets like Sonipat and Thanesar emerging as key price leaders, while others such as Gharaunda showed greater dependence on external signals. Collectively, findings affirm the existence of a unified market system with efficient price transmission across regions, underscoring the importance of strengthening market infrastructure, improving information dissemination, and formulating supportive policies to enhance market efficiency and ensure better returns for farmers.

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