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Statistical analysis of market cointegration and price dynamics for garlic in key northern Indian markets

S. Vishnu Shankar[1,3], Ashu Chandel[1], C. Nandhini[2], Adit Kumar Yadav[1] and Pranchal Gupta[1]

*[1]Department of Basic Sciences, Dr. YS Parmar University of Horticulture and Forestry, Solan (HP), India. [2]Department of Social Sciences, Kumaraguru Institute of Agriculture, Erode (TN), India. [3]Department of Physical Science & Information Technology, Tamil Nadu Agricultural University, Coimbatore (TN), India. *E-mail: s.vishnushankar55@gmail.com*

Abstract

India ranks as the second-largest country in land area and garlic production globally, following China. The study attempts to investigate the price transmission of garlic between the major north Indian markets of India. Attempts were also taken to determine the extent of integration between the markets. The Granger causality test confirmed the presence of bidirectional and unidirectional relationships between markets such as Chandigarh, Delhi, Dehradun, and Shimla. The results showed that garlic's price in Shimla mostly depends on the price in neighbouring markets. Both tests of Johansen cointegration confirmed the presence of long-run relationships among the markets. The vector error correction model revealed a positive relationship between Chandigarh - Delhi, and Chandigarh - Shimla markets. Chandigarh and Dehradun markets achieved short-term equilibrium quickly, while the Shimla market attained it more slowly. No short-run equilibrium was observed in the Delhi market. This research will help to understand the interdependencies and equilibrium dynamics among garlic markets, offering insights for market participants and policymakers.

Key words: Error correction, garlic, granger causality, market cointegration, prices

Introduction

Market cointegration holds significant importance in understanding the level of price transmission between the domestic markets. It helps in assessing the degree to which the markets are interconnected and influenced by common factors such as global supply, demand trends, economic policies, and weather conditions (Khedhiri, 2023). Such knowledge is invaluable for stakeholders in the agricultural sector, including farmers, traders, and policymakers in making informed decisions regarding production, sourcing, pricing, and risk management strategies. Furthermore, understanding market cointegration in the context of agricultural commodities contributes to improved market efficiency. It facilitates the identification of arbitrage opportunities and to get better insight into the price disparities between markets. This can lead to more efficient allocation of resources, enhanced market transparency, and reduced market inefficiencies. The price of commodities in one market compared to another indicates the extent of price transmission and the speed at which information flows between the two markets (Penone and Trestini, 2022). In well-integrated markets, prices tend to be similar, with any dissimilarities mainly attributed to the cost of transporting goods between the markets. The long-term relationship existing between the prices in spatially distinct markets is also estimated using market cointegration (Yang *et al.,* 2021). Exploring the market cointegration among the agricultural markets is indeed where a huge price transmission was recorded in recent years. Garlic plays a significant role in Indian markets and cuisines, adding flavour and health benefits to a wide range of dishes. Being a significant agricultural commodity, garlic is susceptible to various factors such as demand, supply, market structure, and trade policies. Understanding market cointegration provides valuable insights into the price transmission of garlic over time, which can have implications for farmers, traders, and consumers in examining the price behaviour. It in turn provides valuable insights into the degree of synchronization and convergence among spatially separated markets (Paul and Karak, 2022). The highest garlic production was recorded in Madhya Pradesh during the 2022 financial year.

There are different methods of cointegration that are applied based on the nature of the data. Kumari *et al.* (2022) examined the long-run spatial market integration among the soybean markets in India which showed bidirectional causal relations with other markets. Teja *et al.* (2017) discussed market cointegration in oilseeds prices using Johansen cointegration and granger causality techniques Tekalign and Goshu (2021) used vector error correction models. The evidence of co-integration between corn and soybean prices with crude oil prices during the period of 2006-2007 was observed using the vector error correction model. Lavanya *et al.* (2018) examined market integration between domestic and international prices of beverage crops in India (tea, arabica coffee, robusta coffee, and cocoa). Kumari *et al.* (2019) analyzed the co-integration of major red gram markets and price movements in India's major markets.

In recent years, the prices of vegetables have been fluctuating significantly. Garlic, an important ingredient in Indian cuisine, has also added to the list. Therefore, it is essential to understand the price patterns across different markets. Several studies have been reported in the spatial market cointegration domain. However, this study is unique as it focuses on the price of garlic in northern Indian markets, which has not been explored in any previous research. Econometric analysis such as the Augmented Dickey-Fuller (ADF) test, Johansen cointegration test, Vector Error Correction Model (VECM), and Granger causality test were employed in this research paper using the EViews and R software. The study has calculated the growth rates of garlic prices at different which was done using the R package - CGR developed by author.

Material and methods

Data: Monthly prices (Wholesale - Rupees per quintal, Rs. /qtl) of garlic collected from the National Horticultural Board from January 2008 to December 2020 were used for the study. Figs. 1 and 2 shows the study area map and time series pattern of garlic price taken for the study.

Unit root test: The level of cointegration existing between the two markets is confirmed by using the cointegration test. Before conducting any cointegration test, the data must be validated whether it is stationary or not. Because the lack of stationarity in data might make the association fake as well as useless. The Augmented Dickey-Fuller (ADF) test helps in determining the stationarity level of data (Shankar *et al.,* 2023). When the stationarity of the price series was established at the same level of differences, one can anticipate a good price relationship between the markets. The ADF test utilized to estimate the price stationarity was given by:

$$\Delta y_t = \mu + \delta y_{t-1} + \sum_{i=1}^{k} \beta_j \; \Delta y_{t-i} + e_t$$

Where Δy_t is the first difference of y_t *i.e.*, y_t-y_{t-1}, α is the coefficient of y_{t-1} and δ= α-1. The presence of a unit root in the price series is the null hypothesis of the test (δ=0). The presence of a unit root indicates that the data are non-stationary (Shilpa and Sharma, 2021). If the null hypothesis was accepted, then the data must be converted into stationarity by making appropriate differencing and verified again by conducting the unit root test.

Granger causality test: The Granger causality test is used to identify the causal relationships and directionalities between market price series (Mohapatra and Singh, 2021). Let Y and X be the price series in two markets. If Y and X are said to be cointegrated, then one of the following three relationships may exist: i) X influences Y, ii) Y influences X, and iii) X and Y influence each other. The relationships found in (i) and (ii) were one-way, while the relationships found in (iii) were two-way. If two variables are not cointegrated, then one does not cause an effect on the other and is said independent. The simple model of granger causality is given by:

$$\Delta Y_t = \sum_{i=1}^{n} \alpha_i \; \Delta Y_{t-i} + \sum_{j=1}^{n} \beta_i \; \Delta X_{t-j} + u_{1t}$$

$$\Delta X_t = \sum_{i=1}^{n} \lambda_i \; \Delta X_{t-i} + \sum_{j=1}^{n} \delta_i \; \Delta Y_{t-j} + u_{2t}$$

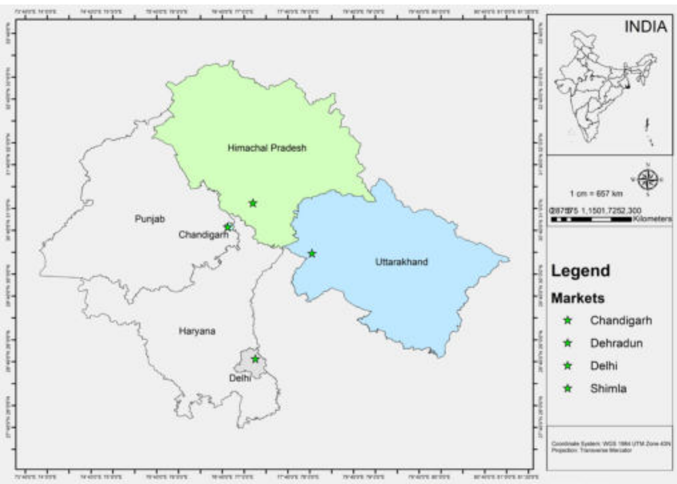

Fig. 1.The study area map

The equation of Δ shows that the current value of Δ is related to the past value of itself and the past value of ΔX. The null hypothesis was $\beta_j = 0$ which means, "ΔX does not cause granger ΔY". Similarly, the equation of Δ depicts that ΔX related to the past value of ΔX and the past value of ΔY with the null hypothesis δj = 0 "ΔYdoes not cause granger ΔX". The acceptance /rejection of the null hypothesis depends upon the F- statistics which was in conjunction with the *P*-value.

Johansen Cointegration test: Johansen cointegration test is a widely employed statistical procedure for assessing the presence and strength of long-run equilibrium relationships among non-stationary time series. It can be used only if the series were stationary at first order. Trace test and Maximum eigenvalue test are the two methods of analyzing the Johansen cointegration (Wani *et al.,* 2015). The model with n variable vectors was given as:

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

where X_t, ε_t are (n×1) vectors, is (n×n) matrix of parameter, I is (n×n) identity matrix.

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

Vector Error Correction Models (VECM): The Vector Error Correction Model (VECM) can be derived if the variables have a cointegration connection with I(1). The Johansen Cointegration test gives the long-run equilibrium between the markets whereas VECM gives the short-run characteristics of the long-run cointegrated variables (Bhowmik, 2019). Considering a bivariate relationship,

$$Y_t = \mu + \beta_1 X_t + \varepsilon_t$$

Based on the theorem, the link between the cointegration equation and the Error Correction model (ECM) was developed by transforming the above equation. The cointegration between two models and are as follows,

$$\varepsilon_t = Y_t - \mu - \beta_1 X_t$$

The error correction model for X_t and Y_t are as follows:

$$\Delta Y_t = \mu_y + \alpha_y \; \varepsilon_{t-1} + \sum_{h=1}^{l} a_{1h} \; \Delta Y_{t-h} + \sum_{h=1}^{l} b_{1h} \; \Delta X_{t-h} + u_{yt}$$

$$\Delta X_t = \mu_x + \alpha_x \; \varepsilon_{t-1} + \sum_{h=1}^{l} a_{2h} \; \Delta Y_{t-h} + \sum_{h=1}^{l} b_{2h} \; \Delta X_{t-h} + u_{xt}$$

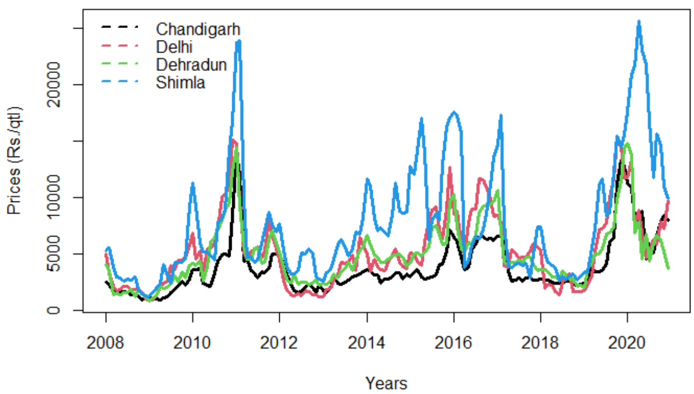

Fig. 2. Time series pattern of garlic price taken for the study.

Where u_{yt} and u_{xt} are the error terms for certain number lags of (stationary white noise).

The number of lags used in the model has been decided based on the Akaike information criterion. The coefficients of the cointegration equation provide the projected long-term link between the variables and coefficients on the ECM. The parameters α_y and α_x calculate the rates at which X_t and Y_t are changing *i.e.*, the speed of adjustments concerning to the long-run equilibrium.

Results and discussion

The descriptive statistics on the data provide the basic information on the garlic prices at different markets (Table 1). The mean garlic price was observed maximum at Shimla market with 7888.65 Rs. /qtl and minimum at Chandigarh market with 3857.44 Rs./qt. Similarly, the price deviation was high in the Shimla market and low in the Chandigarh market. The price series was found positively skewed at all the study markets. The growth rate of prices was increased by 8.70% in Chandigarh, 6.33% in Delhi, 6.99% in Dehradun, and 7.82% in Shimla in the last thirteen years. Chandigarh market recorded a high price rate during November month (11.95%) whereas Delhi (8.71%), Dehradun (9.50%), and Shimla (10.82%) were observed in April month. To avoid erroneous findings, the stationary conditions of the time series data should be checked before applying any of the cointegration methods. The type of cointegration techniques employed for each data was decided on the level of stationarity discovered.

The stationary condition of the price series was examined using the Augmented Dickey- (ADF) test. The results of the ADF test which indicates the level of stationarity of the price series at different markets are presented in Table 2. The results showed that all the price series were to have first-order stationarity *i.e.*, they are non-stationary at levels and appropriated differencing was done to convert them into stationarity. The presence of first-order stationarity suggests the application of Johansen cointegration techniques to examine the market integration.

Granger causality test: The information on the direction of price transmission between the markets provides a better insight to conduct the cointegration test. The Granger causality test helps in attaining that information and identifying the leading market among the groups (Dudhat *et al.,* 2017). It also helps in determining which market should be regressed on and by which market. The main framework behind the Granger causality is the VAR model and the test was conducted between two markets at a time by keeping the variables at the stationary level (Shojaie and Fox, 2022). The resultant tables contain the hypothesis (Market A does not granger cause Market B) with its F-statistics and P-value. If the P-value is greater than 0.05, the hypothesis would be accepted which means, there exists no cointegration between the markets. From the results of Table 3, it was observed that a bidirectional relationship exists between Chandigarh - Delhi markets. A unidirectional relationship exists between Chandigarh - Shimla *i.e.*, Chandigarh led to Shimla, Dehradun - Shimla *i.e.*, Dehradun led to Shimla, Delhi - Shimla *i.e.*, Delhi led to Shimla and Dehradun - Chandigarh *i.e.*, Dehradun led to Chandigarh. In unidirectional markets, Shimla will be the dependent variable for the first three cases, and Dehradun will be the dependent variable in the last one, respectively. Fig. 3 gives the graphical representation of granger casualty found among the markets.

Table 1. Descriptive statistics of prices of garlic

Statistics	Prices (Rs/qtl)			
	Chandigarh	Delhi	Dehradun	Shimla
Mean	3857.44	5311.38	4937.38	7888.65
SD	2527.85	3303.11	2780.09	5379.11
Skewness	1.86	0.94	1.32	1.25
Kurtosis	3.78	0.53	2.11	1.04
Range	13031	14335	13972	24489
CV (%)	65.53	62.19	56.31	68.19

Table 2. Results of Augmented Dickey-Fuller test for garlic prices

Markets	At level	*P* value	Stationarity	At 1st difference	*P* value	Stationarity
Chandigarh	-3.27	0.08	NS	-5.86	0.01	S
Delhi	-3.27	0.08	NS	-4.81	0.01	S
Dehradun	-3.34	0.07	NS	-5.81	0.01	S
Shimla	-3.16	0.1	NS	-6.92	0.01	S

NS-Non-Significant, S-Significant

Table 3. Results of Granger Causality test for garlic price

Null Hypothesis	F- statistics	*P*-value
Delhi market does not Granger cause Chandigarh market	38.16	0.00
Chandigarh market does not Granger cause Delhi market	4.22	0.04
Dehradun market does not Granger cause Chandigarh market	42.15	0.00
Chandigarh market does not Granger cause Dehradun market	1.05	0.31
Shimla market does not Granger cause Chandigarh market	2.91	0.09
Chandigarh market does not Granger cause Shimla market	5.97	0.02
Dehradun market does not Granger cause Delhi market	0.89	0.35
Delhi market does not Granger cause Dehradun market	7.89	0.01
Shimla market does not Granger cause Delhi market	1.31	0.25
Delhi market does not Granger cause Shimla market	12.17	0.00
Shimla market does not Granger cause Dehradun market	1.48	0.23
Dehradun market does not Granger cause Shimla market	18.54	0.00

Since all the markets of garlic were found to attain stationarity at first differencing, the Johansen cointegration test can be applied to this series (Vasisht *et al.*, 2008). Both the trace and maximum eigen statistics were attempted for performing the Johansen

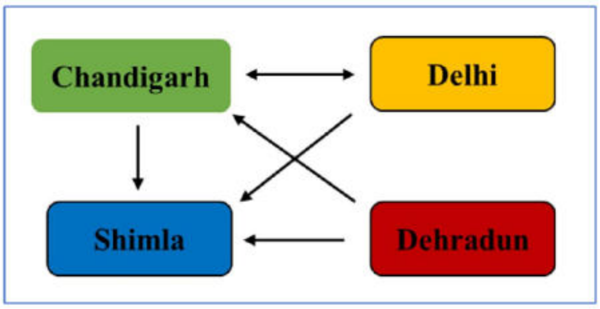

Fig . 3. Causal relationship between crop prices across different markets

Table 4. Results of trace test on garlic across different markets

Hypothesized No of CE(s)	Eigenvalue	Trace statistics	0.05 Critical value	*P*-value
None	0.21	88.11	53.12	NS
At most 1	0.2	52.11	34.91	NS
At most 2	0.06	18.32	19.96	NS
At most 3*	0.06	8.74	9.24	Significant

NS: Non significant

Table 5. Results of Maximum Eigenvalue test on garlic across different markets

Hypothesized No of CE(s)	Eigenvalue	Max-Eigen statistics	0.05 Critical value	*P*-value
None	0.21	36.01	28.14	NS
At most 1	0.2	33.79	22	NS
At most 2	0.06	16.54	15.67	NS
At most 3*	0.06	8.74	9.24	Significant

cointegration test with appropriate lags in which both tests showed the existence of three cointegrating relations among the markets. The results of Table 4 and Table 5 showed that the eigenvalue of the selected cointegrating equation was 0.06 with test statistics of 8.74 in both cases. This result confirms the presence of a long-run relationship between the garlic markets. Therefore, Vector Error Correction Model (VECM) can be applied to find the long-run model and short-run estimates (Sahu *et al.*, 2019).

To determine short- and long-term price equilibrium among the chosen markets, the VECM was used (Singh *et al.*, 2022). As the long-run equilibrium was confirmed between the markets, the long-run equation can be given by:

ECT(-4) = Chandigarh (-4) + 4.02*Delhi(-4) - 4.61*Dehradun(-4) + 0.34*Shimla (-4)+ 2769.86

The long-run model was fitted with four lags which were selected based on AIC and BIC values (Adugna *et al.*, 2023). The equation depicts that there existed a positive relation for Chandigarh with Delhi (4.02) and Shimla (0.34) markets. The price of garlic at the Dehradun market has a negative relation with the price at the Chandigarh market with statistics -4.6 and intercept 2769.86. The coefficient with standard error in parentheses analyzed for the short-run model is presented in Table 6. Chandigarh and Dehradun markets attain short equilibrium quickly whereas Shimla market would attain it slowly. No short-run equilibrium was found in the Delhi market. Three lags were chosen to perform short-run equilibrium in which the price at the Chandigarh market was influenced by one lag of the Dehradun market (0.48), two lags of the Chandigarh market (-0.33), and three lags of Dehradun market (0.21). The price at the Dehradun market was influenced by one lag of the Dehradun market (0.29) and three lags of the Shimla market (0.08). The price at Shimla market was influenced by two lags of Chandigarh market (-0.56). The ECT indicates the speed of adjustment in which ECT for Chandigarh (-.0.06) and Dehradun (-0.12) indicates that the mean deviation from the long run equation was corrected at the rate of 6% and 12% shortly.

Table 6. Results of the vector error correction mechanism on garlic across different markets

Estimates	Chandigarh	Delhi	Dehradun	Shimla
ECT	-0.06(0.02)*	-0.02(0.04)	-0.12(0.03)**	0.06(0.06)
Intercept	202.72(98.34)*	130.50(158.96)	336.54(119.14)**	-123.19(251.66)
Chandigarh (-1)	-0.10(0.10)	-0.22(0.16)	-0.0532(0.12)	-0.01(0.25)
Delhi (-1)	0.02(0.12)	-0.01(0.17)	-0.11(0.13)	0.36(0.26)
Dehradun (-1)	0.48(0.11)**	0.18(0.17)	0.29(0.13)*	0.32(0.27)
Shimla (-1)	0.03(0.03)	-0.01(0.06)	-0.07(0.04)	0.08(0.09)
Chandigarh (-2)	-0.33(0.10)**	-0.11(0.15)	0.03(0.12)	-0.56(0.24)*
Delhi (-2)	0.03(0.09)	0.11(0.15)	-0.00(0.11)	0.33(0.24)
Dehradun (-2)	-0.03(0.10)	-0.05(0.16)	0.10(0.12)	0.28(0.26)
Shimla (-2)	0.01(0.04)	-0.11(0.06)	0.03(0.04)	-0.17(0.09)
Chandigarh (-3)	-0.08(0.09)	0.17(0.14)	0.09(0.11)	-0.43(0.22)
Delhi (-3)	0.07(0.08)	0.12(0.13)	-0.02(0.10)	0.24(0.20)
Dehradun (-3)	0.21(0.09)*	-0.09(0.14)	-0.19(0.10)	0.26(0.23)
Shimla (-3)	-0.04(0.04)	-0.11(0.06)	-0.08(0.04)*	0.07(0.09)

* Significant at 5%, ** Significant at 1%

Cointegration analysis provides valuable insights into the persistent and stable relationships among the markets. The more crucial part is the selection of the appropriate type of methods for the data. The selection of appropriate techniques depends on the level of stationarity in the data which is found using the ADF test. The study aims to explore the price transmission in garlic among the major north Indian markets. All markets exhibited positive growth rates for prices, with Chandigarh, Delhi, Dehradun, and Shimla experiencing significant price rate increases over the same period. Chandigarh recorded the highest price rate in November, while Delhi, Dehradun, and Shimla had notable rates in April. The Granger causality test was conducted to find the direction of causality among the markets. the test confirmed the existence of bidirectional and unidirectional relationships among the markets. The bidirectional changes were observed between Chandigarh and Delhi where in the unidirectional direction, the Shimla market acted as the dependent variable in most of the cases. The results of the ADF test confirmed the presence of first-order stationarity in the garlic price series, suggesting the application of the Johansen cointegration technique. The trace statistics and Maximum eigenvalue statistics of Johansen's co-integration test confirmed the presence of long-run relationships in the study markets. This finding not only indicates the presence of a stable relationship between the prices but also suggests strong and consistent price linkages among the selected markets. the estimate of long-run and short-run models were derived using the VECM. The results of VECM shows that no short-run equilibrium was found in the Delhi market where Chandigarh and Dehradun markets attain their short equilibrium quickly. The Shimla market is expected to attain their equilibrium in slow rate. Thus, the result of the study is expected to provide a better understanding of the market cointegration and price transmission prevailing in the garlic markets. These finding would help the various stakeholders, consumers and farmers in concentrating the gaps in marketing and production of garlic.

The study confirms strong long-run price linkages among major North Indian garlic markets, with Johansen's cointegration and Granger causality tests revealing stable relationships and market dependencies. While Chandigarh and Dehradun adjust quickly to short-run equilibrium, Shimla lags behind. These findings offer valuable insights for addressing gaps in garlic marketing and production, benefiting stakeholders, including farmers and consumers.

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