Society of Krishi Vigyan
www.iskv.in

J Krishi Vigyan 2026, 14(1) : 12-21

DOI: 10.5958/2349-4433.2026.00003.3

ISSN 2319-6432 (Print)
ISSN 2349-4433 (Online)

Assessing Market Efficiency and Structure in Punjab's Tomato Supply Chain: Insights from Acharya's Method and Gini Coefficient Analysis

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ABSTRACT

Tomato is one of the most volatile horticultural commodities in India, frequently exposing farmers and consumers to extreme price fluctuations. This study examines the efficiency and structural characteristics of tomato markets in Punjab using Acharya's Marketing Efficiency Index and Gini Coefficient analysis. Primary data were collected from farmers and market intermediaries across four major tomato markets Ludhiana, Jalandhar, Amritsar, and Patiala selected on the basis of tomato arrivals during 2022. The analysis of the predominant farmer-wholesaler-retailer marketing channel revealed low levels of market efficiency, with efficiency indices ranging from 0.54 to 0.61 across the selected markets during 2022-23. The findings indicate that a substantial share of consumer expenditure is absorbed by intermediaries, resulting in farmers receiving only 31-34 percent of the final consumer price. Seasonal analysis further revealed pronounced price volatility, with prices reaching their peak during January-June and declining sharply during July-December. An inverse relationship between market arrivals and prices during 2018-2022 highlights the persistent challenge of oversupply-induced price crashes faced by tomato growers. The estimated Gini coefficient of 0.76 points to a highly concentrated market structure, suggesting the dominance of a limited number of market players and weak bargaining power among farmers. The study also observed that supply disruptions arising from adverse climatic conditions tend to strengthen the market influence of wholesalers, exacerbating vulnerabilities for both producers and consumers. These findings underscore the need for strategic interventions to improve market efficiency, reduce intermediary dominance, and stabilize producer prices. Strengthening market infrastructure, expanding processing and value-addition facilities, promoting farmer aggregation, and fostering public–private partnerships can play a crucial role in creating a more equitable and resilient tomato value chain in Punjab.

Keywords: Climatic, Gini coefficient, Market integration, Seasonality index, Tomato.

INTRODUCTION

India is endowed with diverse soils and agroecological regions, offering abundant opportunities for cultivating a wide array of horticultural crops (Guleria *et al,* 2022). The horticultural sector has witnessed remarkable progress in terms of expanding both area and production across various crops, thereby facilitating crop diversification. This sector serves a dual purpose by not only augmenting farm income through optimal land and water utilization but also generating increased employment opportunities due to its labor-intensive nature (Kumari *et al,* 2018; Jha *et al,* 2019). The extensive variety of horticultural crops presents farmers with significant possibilities through the adoption of multilayer cropping, mitigating the risk of crop failure and maximizing overall farm income ((Shende and Meshram, 2015).

From an economic perspective, the horticulture sector contributes 30 per cent to the agricultural GDP, covering approximately 14 per cent of the agricultural area and accounting for nearly 37per cent of the total agricultural export (GoI, 2018). Among the temperate horticultural crops, tomato holds a prominent position, being widely cultivated after potatoes and sweet potatoes in the Himalayas and Tarai region of Northern India (Bhardwaj *et al,* 2011). Punjab is also a major producer of tomato but the acreage and production of vegetables and fruits have gradually expanded over the past few decades. The total area

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under vegetables was 3.5 lakh ha and the production was about 61 lakh tons in the year 2020-21. Tomato crop accounted for about eight per cent (GoP, 2021) of the total vegetable area in the state. Punjab needs to be pulled out of the crisis erupted from an excessive usage of ground water, escalating costs of production due to the increased dosages of chemical fertilizers and stagnant yields in wheat-paddy rotation system. High-value horticultural crops emerge as a promising alternative for agricultural development. Expanding the cultivation of such crops not only contributes to elevating farm incomes and enhancing overall agricultural output in Punjab but also plays a pivotal role in conserving water resources. This is achieved by diverting cultivation away from rice and wheat, which are the most water-intensive crops in the state.Therefore, it becomes imperative to conduct studies to measure the efficiency of different horticultural crops. Keeping this in view, the present study was conducted to concentrate on these concerns highlighting the marketing efficiency for tomato in Ludhiana, Jalandhar, Amritsar and Patiala markets of Punjab. It also seeks to illustrate the market arrivals and prices scenario of tomato crop in selected markets of Punjab as an agent of change in cropping pattern. The study, therefore, aims at providing insight into the major narratives by estimating marketing costs and margins to measure market efficiency in the marketing of tomato.

MATERIALS AND METHODS

The research in Punjab during 2023 utilized both primary and secondary data to study tomato markets. Secondary data from the agmarknet platform focused on tomato prices and arrivals in Ludhiana, Jalandhar, Amritsar, and Patiala, selected based on TE 2022 arrivals. Primary data on costs and margins of intermediaries were collected from the sample of 120 (10 farmers, 10 wholesalers, and 10 retailers from each market) through structured personal interviews. Acharya's Modified Marketing Efficiency Method was applied for market dynamics analysis (Acharya and Agarwal, 2001). Market efficiency was also assessed using the Johansen co-integration test and Granger causality test with EViews software. The Augmented Dickey-Fuller test checked the stationarity of time series data, and seasonal indices of prices and arrivals were computed to examine market gluts. The Gini coefficient was calculated to determine market concentration in Ludhiana. Data on traders and average tomato arrivals from the Ludhiana market committee were plotted to create a Lorenz curve. Various tests/formulae used in the present study are as follows:

Johansen Co-integration test

On the contrary, the maximum eigenvalue test assesses the null hypothesis of r cointegrating vectors in contrast to the alternative hypothesis of r+1 cointegrating vectors (Hjalmarsson and Osterholm, 2007).

$$\Delta Yt = \mu + \sum_{i=1}^{p-1} \Gamma i Y_{t-1} + \Pi Y_{t-1} + \varepsilon_t \quad \ldots\ldots\ldots (1)$$

$$J_{trace} = -T \sum_{i=r+1}^{n} In(1-\hat{\lambda_i}) \quad \ldots\ldots\ldots (2)$$

$$J_{\max} = -TIn\ (1-\hat{\lambda_r}+1) \quad \ldots\ldots\ldots (3)$$

Granger Causality test

The Granger causality test, implemented within the context of a Vector Autoregressive (VAR) model, serves to examine the presence and direction of a long-run causal relationship between markets, as initially proposed by (Granger,1969). This test involves an F-test to ascertain whether alterations in one price series exert an impact on another price series. Illustrating the causality relationship between the Azadpur and Chomu wholesale tomato markets, the test was conducted through the formulation of the following pairs of Ordinary Least Squares (OLS) regression equations within a bivariate VAR framework.:

$$PInA_t = \sum_{i=1}^{m} \gamma_i PInA_{i=1} + \sum_{i=1}^{m} PInC_{t-j} + \varepsilon_{2t} \quad \ldots\ldots\ldots (4)$$

In the provided equation, *A*is represents the Azadpur market, *P* ln denotes the logarithmic form of the price series, and t represents the time trend variable. The subscript j signifies the number of lags for both variables within the system.

The null hypothesis, as expressed in Equation (4) — *H0:*β*1* = β*2* = ... = β*j*=0 — contrasts against the alternative hypothesis, *H1*: Not *H0*. In simpler terms, the null hypothesis posits that *P* ln *At* does not Granger cause *P* ln *Ht*. Consequently, a rejection of the null hypothesis would indicate the presence of Granger causality between the variables, as elucidated by Gujarati in 2003.

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Seasonal Index

To estimate seasonality, the analysis is conducted on the average monthly data regarding prices and arrivals. The process involves converting monthly data spanning several years into a monthly index, with January selected as the base month for each year. This approach serves to partially eliminate any underlying overtime trend in the data, as suggested by (Ali,2000). Following this transformation, the monthly averages over the years are computed, leading to the subsequent estimation of

$$S_i = \frac{(I_h - I_l)}{I_l} * 100$$

'Where, *Ih*= Highest average monthly index value and'

'Il = Lowest average monthly index value'

RESULTS AND DISCUSSION

The following discussion highlighted the arrival and prices of tomato in the selected markets of the state showing seasonal indices of these markets, the marketing costs incurred and marketing margins received by different intermediaries of tomato to check market efficiency.

Arrival and prices of tomato in the selected markets of Punjab

A perusal of Table1 reflects that the arrival of tomato in Punjab in the year 2018 was about 1.4 lakh tons which reached the lowest of 0.82 lakh tons in the year 2020 and slightly improved in the year 2022 (0.83 lakh tons). The four major markets of the state contributed around 81 per cent of tomato arrival in the year 2018 and the lowest contribution of approximately 62 per cent was in the year 2020 which may be attributed to the COVID-19 pandemic but it rose to around 77 per cent in the year 2022. seasonality patterns.

Amritsar district was the front runner in percentage terms of market arrival of tomato up to the year 2020 followed by Jalandhar and Ludhiana swapping the positions of second and third. Amritsar district lost its position to Ludhiana district in the years 2021 and 2022 where the arrival of Ludhiana market was 27.6 and 34.8 per cent, respectively for the aforementioned years. The average arrival across all the four selected markets was 73.1 per cent during the period 2018 to 2022 with Amritsar contributing the most of 27.4 per cent followed by Ludhiana 21.7 per cent, Jalandhar 15.4 per cent and Patiala 8.6 per cent but the TE 2022 arrival of Ludhiana market was the maximum (21.14 thousand tons) followed by Amritsar market (18.83 thousand tons).

The average annual prices from the year 2008 to 2022 have been presented in Table 2 which indicated that prices of tomato in all the selected markets stayed almost above Rs 1000/ q during the above said period. Jalandhar market was having prices less than Rs 1000 / q in quite many years which may be due to more arrival in these particular years. The prices reached their peak in all the selected markets in the year 2020 which can be ascribed to less arrival due to COVID-19 pandemic as transportation glitch was there which made it difficult to preserve tomato due to its being perishable commodity and hence prices rose.

It can clearly be noticed that prices in all the selected markets in Punjab were moving in the same direction (Figures 1 and 2). Prices were the highest in the year 2020 in all the selected markets of Punjab which can be attributed to COVID-19 pandemic in that particular year.

Seasonal indices of prices and arrival of tomato in Punjab

Table 3represents the seasonal indices of prices and arrival of tomato in the chosen markets during the period 2018 to 2022. It was brought out from the following figures that prices and arrival form an inverse relationship which meant prices went up when arrival was less and vice versa.

The graphical depiction of monthly arrival and prices in the selected markets of Punjab help us to reach the following observations. The arrivals were inversely related to the price and the calculation of coefficient of correlation of arrival and price in the selected markets provides much suport to this paradoxical situation (Chengappa *et al*, 2012) which was evident in Table 4 that the correlation of monthly arrival of tomato with its monthly prices was significantly high in all the markets.

Marketing Efficiency

The marketing efficiency, in this context, gauges the financial feasibility of implementing additional marketing services. A positive estimate implies that the application of such services is justified, while a negative estimate suggests 'otherwise (Abdou, 2004). The determination of marketing efficiency was carried out by employing the Johansen co-integration

Table1:Average annual quantity of tomato arrival in major markets of Punjab, 2018-2022 (Tons)

Year/Market	2018	2019	2020	2021	2022	Total
Amritsar	52803.46 (38.1)	23896.29 (27.3)	17900.99 (21.7)	20519.07 (21.6)	18077.3 (21.8)	133197.1 (27.4)
Jalandhar	19171.46 (13.8)	16941.75 (19.4)	13691.47 (16.6)	12886.11 (13.6)	12406.65 (15.0)	75097.44 (15.4)
Ludhiana	30595.66 (22.1)	11729.77 (13.4)	8460.34 (10.3)	26199.13 (27.6)	28763.72 (34.8)	105748.6 (21.7)
Patiala	9245.49 (6.7)	9827.44 (11.2)	10766.55 (13.1)	7652.53 (8.1)	4433.61 (5.4)	41925.62 (8.6)
Total quantity	(80.7)	(71.3)	(61.7)	(70.9)	(77.0)	(73.1)
Punjab	138653.5 (100.0)	87496.3 (100.0)	82383.44 (100.0)	94985.39 (100.0)	82761.46 (100.0)	486280 (100.0)

Note: i) 'Figures in parentheses indicate percentage' to Punjab

ii) Small quantity of tomato was sold to the traders and consumers directly in the village itself. It was not counted in the table.

Table 2: Average annual prices of tomato in the selected markets of Punjab, 2008-2022 (Rs/q)

Year/Market	Amritsar	Jalandhar	Ludhiana	Patiala
2008	1243	893	831	965
2009	1083	919	823	1008
2010	1454	1181	1098	1141
2011	1317	943	944	1152
2012	968	906	986	1090
2013	1582	1288	1480	1180
2014	1262	1336	1193	1212
2015	1162	1172	1564	1479
2016	1009	787	1053	1205
2017	1379	1053	1158	1588
2018	834	578	1106	1169
2019	1471	1122	1392	1791
2020	1615	1236	2069	2057
2021	1187	1069	1626	1654
2022	1495	1035	1910	1786

Source: www.agmarknet

test on the chosen markets in Punjab.By using the Augmented Dickey Fuller Test, the stationarity of the time series data was first verified. The findings of the test have been presented in Table 5which indicates that there was no need to proceed to the first difference level because the data was stationary at the level form.

The findings of Granger Causality test revealed that all the markets were having uni-directional relationships (Table 6). This highlights the imperative for policymakers to prioritize and enhance the utilization of information technology for the regular flow of market information. Such initiatives are crucial in empowering farmers, ultimately contributing to an increase in their income. Similar outcomes were obtained by (Kumar and Gajanana, 2022). The uni-directional relationship may also be due to tomato being a perishable commodity which could not be stored for an extended period of time.

Acharya's Modified 'Marketing Efficiency' method

Marketing efficiency was also computed by using Acharya's Modified Marketing Efficiency method (Table 8). The primary data on the quantity of produce sold by different intermediaries in the market were collected in terms of number of crates of tomato (each weighing 25 kg) which has been converted into quaintal. The costs and margins of the intermediaries (10 farmers, 10 wholesalers and 10 retailers from each

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Figure 1: Average annual prices of tomato in major markets of Punjab, 2008-2022

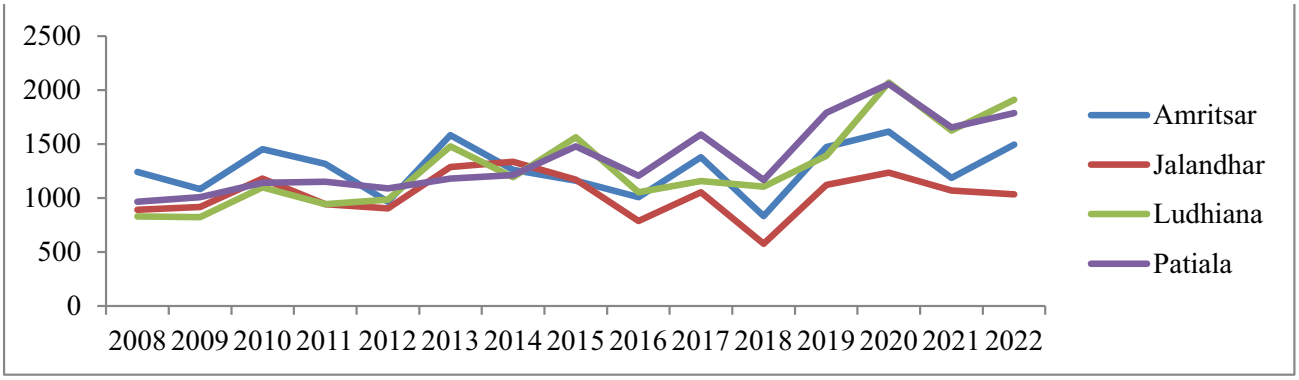
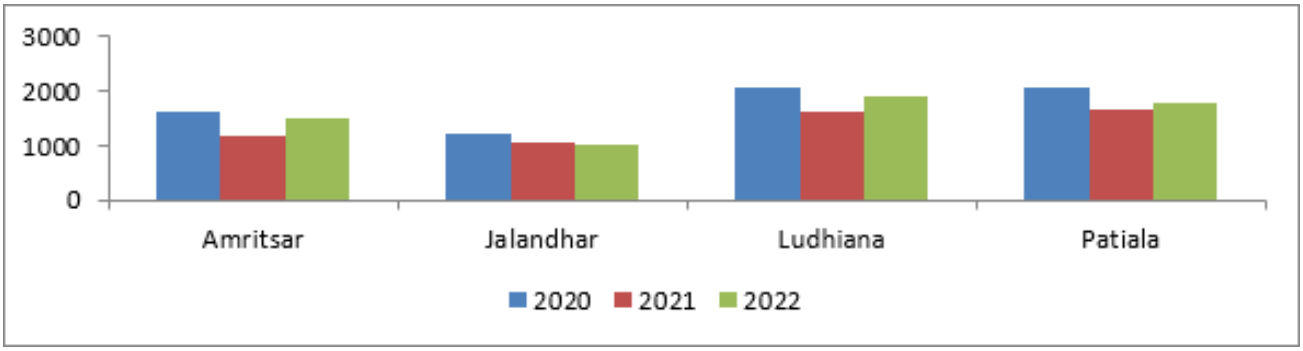


Figure 2: Average annual prices of tomato in major markets of Punjab, 2020-2022



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Table3: Seasonal indices of prices and arrivals in the selected markets of Punjab, 2018-2022

Months	Amritsar		Jalandhar		Ludhiana		Patiala	
	Price	Arrival	Price	Arrival	Price	Arrival	Price	Arrival
April	78	105	93	112	58	120	83	110
May	56	105	58	144	49	115	51	106
June	54	126	48	127	55	128	55	109
July	97	38	108	59	102	72	106	63
August	130	85	130	76	126	92	127	90
September	128	86	124	86	139	87	127	90
October	165	84	147	82	162	86	153	80
November	146	76	132	89	156	93	173	78
December	116	90	99	113	117	124	111	128
January	79	97	88	119	98	136	83	121
February	74	105	89	109	78	105	71	139
March	76	107	84	115	61	123	60	110

of the selected market constituting a total sample of 120 respondents were worked out to calculate the marketing efficiency.

Profile of tomato growers

The socio-economic characteristics of the selected respondents are shown in Table 7. The sample included 40 farmers, with 10 from each selected district in Punjab. The study revealed that most farmers were young, aged between 42 and 46.5 yrs. The average family size was seven in Ludhiana, 6.6 in Jalandhar, 8 in Amritsar, and 7.6 in Patiala.Education levels indicated that only a small percentage were illiterate, mainly from Ludhiana and Amritsar, making up 5% of respondents. Most had a high secondary certificate, with 7 in Amritsar, 6 in Jalandhar, and 4 in Patiala and Ludhiana. The average size of owned land was 5.58 ha in Ludhiana, 4.29 ha in Jalandhar, 3.72 ha in Amritsar, and 3.12 ha in Patiala for 2022-23. The average area under tomato cultivation per farmer was highest in Patiala (2.02 ha), followed by Amritsar (1.25 ha), Jalandhar (0.77 ha), and Ludhiana (0.40 ha).

Table 4: Correlation analysis of monthly arrival and prices of tomato' in major markets of Punjab, 2018-2022

Market	Correlation	Price
Amritsar	Karl Pearson's Correlation Coefficient	-0.742***
	Sig. (2-tailed)	0.022
Jalandhar	Karl Pearson's 'Correlation Coefficient	-0.816***
	Sig. (2-tailed)'	0.001
Ludhiana	Karl Pearson's 'Correlation Coefficient	-0.618***
	Sig. (2-tailed)'	0.032
Patiala	Karl Pearson's 'Correlation Coefficient	-0.606***
	Sig. (2-tailed)'	0.037

***indicate that the correlation is significant at respective level of probability

Table5: Results of Augmented Dickey-Fuller test in selected markets of Punjab

Markets	t-statistic	Probability*
Amritsar	-3.467851	0.0000
Jalandhar	-3.466994	0.0000
Ludhiana	-3.467205	0.0000
Patiala	-3.465105	0.0000

*Note: *indicates significance at 1 percent level of probability*

Table 6: Findings of 'Granger Causality Test

Null Hypothesis:	Obs	F-Statistic	Prob.
Jalandhar does not Granger Cause Amritsar	178	0.12612	0.8816
Amritsar does not Granger Cause Jalandhar		1.08234	0.3411
Ludhiana does not Granger Cause Amritsar	178	6.75182	0.0015
Amritsar does not Granger Cause Ludhiana		0.97708	0.3785
Patiala does not Granger Cause Amritsar	178	1.29568	0.2764
Amritsar does not Granger Cause Ludhiana		5.09692	0.0071
Ludhiana does not Granger Cause Jalandhar	178	3.05938	0.0495
Jalandhar does not Granger Cause Ludhiana		1.19104	0.3064
Patiala does not Granger Cause Jalandhar	178	2.60769	0.0766
Jalandhar does not Granger Cause Patiala		3.01732	0.0515
Patiala does not Granger Cause Ludhiana	178	1.45182	0.2370
Ludhiana does not Granger Cause Patiala		9.80700	9.E-05

The prices of the selected markets were taken for the period of November 2022 to June 2023 when tomato from different districts of Punjab arrives in the market for sale (Table 8). Apart from the selected districts, tomato from other districts namely Faridkot, Moga and Sultanpur Lodhi also comes to the selected markets of the state. Ludhiana market receives local tomato and tomato from Faridkot and Patiala districts. Tomato in Jalandhar market mainly comes from Sultanpur Lodhi and from the local growers. Amritsar market receives tomato from local producers and from Faridkot and Moga districts. Only native tomato is sold at Patiala market. Tomato from these markets is further sold to Rajasthan, Uttar Pradesh, Ahmedabad, and Srinagar which somehow leads to the hike in prices of tomato especially in the month of June. Further, tomato in Punjab comes from Bangalore, Himachal Pradesh and Nashik during the period of July onwards when

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Table 7: Socio-economic profile of tomato farmers in the selected districts of Punjab, 2022-23

Particulars	Ludhiana	Jalandhar	Amritsar	Patiala
Household pattern				
Average age of respondents (years)	42	46.5	44	42.2
Average family size (persons)	7	6.6	8	7.6
Educational status of the respondents (number)				
Illiterate	1	-	1	-
Primary level (up to class IV)	1	2	-	1
Secondary education (up to X)	1	1	1	2
Higher secondary level (up to class XII)	4	6	7	4
Graduation level	2	1	1	2
Beyond graduation level	1	-	-	1
Operational holding (ha)				
Average owned land	5.58	4.29	3.72	3.12
Average leased-in land	4.37	2.79	3.76	2.43
Average leased-out land	0.81	0.40	2.02	0.40
Average operational holding	9.14	6.67	5.46	5.14
Average area under tomato	0.40	0.77	1.25	2.02

Source: author's calculation from field survey

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local tomato ceases to arrive which is why prices remain high during this period as compared to the months when local tomato of Punjab is in the market. The data (Table 8) clearly shows that the market efficiency was highest in Ludhiana at 0.60 percent, followed by the same market at 0.59 percent. Producers/farmers received the highest price from the Ludhiana market at 1098 Rs/q, followed by Patiala at 946 Rs/q, and significantly lower in the Jalandhar market at 730 Rs/q.

Regarding marketing costs incurred by different intermediaries, retailers had the highest costs, followed by farmers and commission agents cum wholesalers. Retailers incurred marketing costs ranging from 250 to 350 Rs/q. The highest was in the Ludhiana market at 344.25 Rs/q, with the Valla market of Amritsar in second place at 325.13 Rs/q. For producers, costs were higher in Ludhiana and Amritsar markets, at 236.18 and 234.75 Rs/q respectively. Commission agents incurred costs of less than 100 Rs/q across all markets, with the highest costs in Ludhiana and Patiala markets at 87.84 and 75.68 Rs/q, respectively.

The margins were considerably higher for commission agents cum wholesalers, ranging from 35 to 40 percent, compared to retailers, who secured margins of 30 to 35 percent. Commission agents cum wholesalers had the highest margins in the Ludhiana market at 439.14 Rs/q, followed by the Valla market of Amritsar at 352.95 Rs/q. Retailers' margins were significantly higher in the Ludhiana and Patiala markets at 584.50 Rs/q and 469.85 Rs/q, respectively.

The heat wave in Rajasthan and Gujarat significantly disrupted the supply chain of tomatoes in Punjab, causing consumer prices to skyrocket (Kandwal Shruti 2021). Consumers paid the highest prices for tomatoes in the Ludhiana market at 2553.73 Rs/q, followed by the Patiala market at 2134.69 Rs/q in the study. Any climatic conditions that affect the supply of tomatoes empower the wholesalers' lobby, making farmers and consumers more vulnerable.**Market Structure**

The Gini Coefficient (GC) technique was employed to gauge the degree of market concentration. The Gini Coefficient's value falls within the range of zero to one. A higher coefficient indicates a greater level of concentration, serving as an indicator of high inefficiency within the market structure (Giroh et al., 2010).Gini coefficient was worked out by taking the proportion of number of tomato traders and the arrival of tomato with these traders in the year 2022-23. Ludhiana market was selected for examining the market concentration because it has the maximum Triennium Ending (TE) 2022 arrivals of the state. The results showed that Gini coefficient obtained from the Lorenz curve turned out to be 0.76 which meant that the market was highly concentrated. It was found that around 72 per cent of total tomato arrival in Ludhiana

Table 8: Price spread of tomato in the selected markets of Punjab, 2022-23 (Rs/q)

Particulars	Ludhiana	Jalandhar	Amritsar	Patiala
Net price received by the producer	861.82	560.2	630.25	717.2
Marketing cost incurred by the producer	236.18	169.8	234.75	228.76
Transportation	132.0	79.0	133.0	129.0
Loading andUnloading	65.5	56.3	67.4	63.5
Cleaning andgrading	27.7	27.2	25.7	26.8
Wastage	10.98	7.3	8.65	9.46
Producer's sale price/ Wholesaler's purchase price	1098.0	730.0	865.0	946.0
Marketing cost incurred by the Commission agent cum wholesaler	87.84	58.4	69.20	75.68
Market fee @ 1percent	10.98	7.3	8.65	9.46
RDF @ 1percent	10.98	7.3	8.65	9.46
Commission paid to the commission agent @ 5percent	54.9	36.5	43.25	47.3
Miscellaneous expense	10.98	7.30	8.65	9.46
Margin of the Wholesaler	439.14	310.0	352.95	337.18
Wholesaler's sale price/ Retailer's purchase price	1624.98	1098.4	1287.15	1358.86
Marketing cost incurred by the Retailer	344.25	284.40	325.13	315.45
Transportation	48.75	32.73	38.36	40.48
Wastage	81.25	54.56	63.93	67.47
Other charges	98.0	98.2	115.07	99.0
Cost of plastic bags	100.0	90.0	95.0	95.0
Miscellaneous expense	16.25	10.91	12.79	13.49
Margin of the Retailer	584.5	408.94	433.03	469.85
Sale price of the Retailer/Consumer's purchase price	2553.73	1786.44	2036.66	2134.69
Net price received by the producer	861.82	560.2	630.25	717.2
Total costs and margins of the intermediaries	1455.73	1063.74	1180.31	1198.15
Marketing Efficiency	0.59	0.53	0.53	0.60

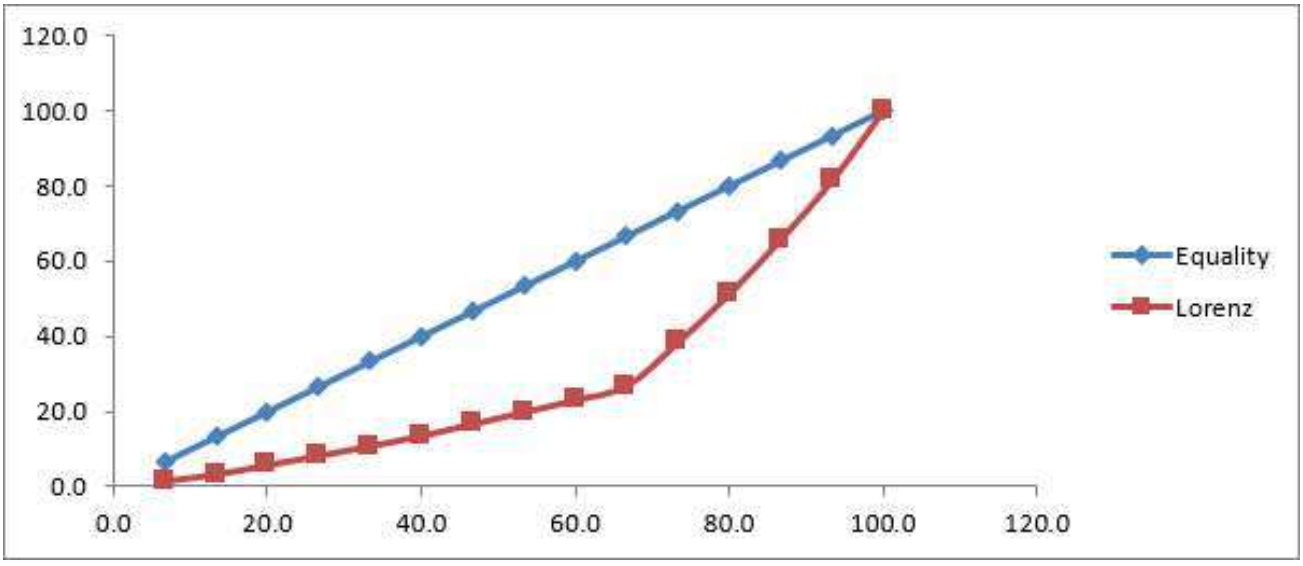


Figure 7: Lorenz curve for tomato trade in Ludhiana market in Punjab

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market was handled by around 33 per cent of the traders which clearly demonstrates that very few traders control the tomato market in Ludhiana market. The data is represented graphically, demonstrating the concentration of the tomato market in Ludhiana, making the farmer a price taker with no influence over market prices. (Vedamurthy*et al*, 2022) observed similar results.

Conclusion and Policy implications

The study revealed significant inefficiencies in Punjab's tomato marketing system, primarily driven by the dominance of multiple intermediaries and a highly concentrated market structure. The estimated market efficiency indices indicate that a substantial proportion of the consumer's rupee is captured by intermediaries, leaving tomato growers with a relatively small share of the final retail price. The high market concentration, particularly in the Ludhiana market, has weakened farmers' bargaining power, effectively positioning them as price takers within the value chain.

The analysis further demonstrated a pronounced inverse relationship between tomato arrivals and market prices. Peak arrivals during the harvest season (November–June) were associated with sharp declines in prices, while reduced arrivals during the lean season (July–December) resulted in significant price increases. Such fluctuations expose both producers and consumers to considerable economic risk and highlight the urgent need for institutional mechanisms to stabilize prices during periods of excess supply.

To enhance market efficiency and reduce price volatility, investment in decentralized storage facilities, pack houses, and cold-chain infrastructure at the farm and cluster levels is essential. Strengthening market intelligence systems and real-time price dissemination platforms can empower farmers to make informed production and marketing decisions, thereby improving their bargaining position and reducing information asymmetry.

Punjab possesses considerable potential to expand tomato exports and strengthen its horticultural economy through greater integration with domestic and international markets. Institutions such as the Punjab Agri Export Corporation (PAGREXCO), in collaboration with the Punjab Mandi Board and Punjab Agro Industries Corporation, can play a pivotal role in promoting exports, facilitating market access, and ensuring higher returns to producers. Rising consumer demand for safe, quality-assured, and value-added agricultural products also presents opportunities for diversification into processed tomato products, thereby generating additional income and employment across the value chain. Despite its agricultural leadership, Punjab continues to face challenges in food processing and value addition. The findings reinforce the relevance of the "Second Push in Punjab Agriculture and Allied Sectors" strategy, which advocates diversification towards high-value and resource-efficient crops such as fruits and vegetables. However, diversification alone will not be sufficient. Sustainable transformation requires the development of integrated value chains that effectively connect farmers, traders, processors, retailers, financial institutions, and consumers.

Farmer Producer Organizations (FPOs), contract farming arrangements, and producer-led marketing models can help reduce transaction costs, improve access to quality inputs and technical knowledge, and strengthen farmers' market participation. Equally important is the provision of accessible credit, insurance services, and risk-management instruments to support efficient value-chain functioning. The study also highlights the importance of continuous innovation, technological advancement, and market-oriented research in enhancing competitiveness within the tomato sector. Transparent relationships among value-chain actors, supported by robust institutional frameworks, can foster trust, improve market coordination, and ensure equitable distribution of benefits. Particular attention must be given to mitigating the market power of intermediary groups, whose influence tends to intensify during climatic shocks and supply disruptions, often to the detriment of both producers and consumers. A coordinated approach involving government agencies, private sector stakeholders, and farmer organizations is therefore essential for building a more efficient, resilient, and inclusive tomato value chain in Punjab.

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Received on 09/01/2026 Accepted on 20/02/2026

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