

Dynamics of production and export of spices from India: A Markov chain approach

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Abstract

India is known as the spice bowl of the world as no other country produces as many varieties of spices as India and also India has larger production and export potentiality of spices in the world. The present study examines the growth and instability as well as direction of trade of spices export from India to different destinations. The study utilizes CAGR and Markov chain analysis to calculate growth rate and the transitional probability matrices for all major spices to determine the direction of spices export from India. The study revealed that in India area, production and productivity has a significant positive growth rate of 3.26, 6.68, and 3.31 per cent, respectively. The "Others" were the most reliable importer of spices from India with a retention probability of 78.00 per cent, followed by Sri Lanka with 44.00 per cent, China and Nepal with a retention probability of 42.00 per cent each.

Keywords: Spices, export, Markov chain, growth, instability, market

Introduction

Spices constitute an important group of horticultural crops and play a vital role in providing livelihood to millions of people in India. They are aromatic substances of plant origin derived from different parts such as roots, stems, seeds, flower buds, leaves and fruits. Spices form an essential component of human nutrition and food preparation by enhancing taste, flavour and colour of food. In addition to culinary uses, several spices possess medicinal properties and are widely used in traditional and modern healthcare systems (Anantha & Sidana, 2019).

India occupies an unique position in the global spice economy and is often referred to as the "Spice Bowl of the World". The country is the world's largest producer and exporter of spices, producing nearly 75 out of the 109 spice varieties recognized by the International Organization for Standardization (ISO) (Devi & Jadav, 2018). Under the Act of Parliament, 52 spices are brought under the purview of the Spices Board of India. The diverse agro-climatic conditions ranging from tropical to temperate regions enable the cultivation of almost all major spices across different states and union territories (Sebastian & Praveen, 2019).

The seed spice belt comprising Rajasthan, Gujarat and parts of Madhya Pradesh contributes more than 80 per cent of the country's seed spice production (Singh & Solanki, 2015; Lal *et al.*, 2024). Major spice-producing states include Madhya Pradesh, Rajasthan, Gujarat, Andhra Pradesh, Telangana, Karnataka, Maharashtra, Assam, Odisha, Uttar Pradesh, West Bengal, Tamil Nadu and Kerala. Among the various spices produced, chilli, cumin, turmeric, ginger and coriander together account for nearly 76 per cent of total spice production in India.

The production and export performance of Indian spices has shown significant growth in recent years. Total spice production reached 10.87 million tonnes in 2021-22. Export earnings increased from US\$ 3.46 billion in 2021-22 to US\$ 3.95 billion in 2022-23 (Anonymous, 2022). While these trends highlight the growth potential of India's spice sector, export markets are increasingly characterized by instability and frequent shifts in destination shares due to changing quality standards, trade policies and international competition. Conventional trend analysis captures growth and instability but fails to explain how and why export shares shift among competing importing countries over time.

In this context, the Markov chain approach provides an useful analytical framework to examine the dynamics of spice exports by modeling changes in market shares across importing countries. The approach helps identify stable markets, declining destinations and emerging markets through transition probability matrices that capture both retention and switching behavior. By linking export performance with market stability and transition patterns, the Markov chain analysis offers valuable insights for designing market-specific export strategies and policy interventions. The Markov chain approach has earlier been applied to individual spices such as turmeric (Naik & Hosamani, 2013), black pepper (Sivasankari & Rajesh, 2014)

and to Indian spice exports in general (Joshi *et al.*, 2015), which mainly examined national-level export stability for single commodities. However, these studies did not combine growth performance, instability and direction-of-trade analysis for all major spices together, nor did they link national trends with state-level production dynamics. Hence, the present study employs the Markov chain approach to analyze the dynamics of India's spice export markets and to draw policy implications for sustaining export growth.

Materials and methods

Growth rate

Growth rate can be defined as the rate of change of the underlying variable per unit time in terms of both magnitude and direction. It is used to measure the past performance of the economic variables in question and describe the trends in those variables over time. The average annual compound growth rates (CAGR) of area, production, productivity of India (2001-02 to 2022-23), exports and imports (2013-14 to 2022-23) were calculated using compound growth rate. In this study, compound growth rates were estimated using the exponential model as given below:

$$Y_t = ab^t u_t \quad \dots (1)$$

Taking log on both the sides, the equation (1) was transformed as:

$$\log(Y_t) = \log a + t * \log b + \log u_t \quad \dots (2)$$

Where,

Log (Y_t) = Area, production, productivity, export or import of spices

Log a = Constant term;

t = Time element;

log u_t = Disturbance term with Ordinary Least Squares (OLS) assumptions; and

log b = Parameter to be estimated by OLS regression technique

Since the estimate of 'b' was in log-linear function, the following transformation was used to convert it into the original form:

$$\text{Log } b = \text{Log } (1+r)$$

$$\text{Antilog } (\log b) = 1 + r$$

$$r = [\text{Antilog } (\log b)] - 1$$

$$\text{CGR in \%} = \{[\text{Antilog } (\log b)] - 1\} \times 100 \quad \dots (3)$$

Significance of the growth rate was tested by running Student's t- test:

$$t_{n-2} = \frac{\hat{g}}{\text{Se } (\hat{g})} \quad \dots (4)$$

Where,

$\hat{g}$ = Compound growth rate in percentage per annum;
[i.e. $(\hat{b} - 1) \times 100$]

$\hat{b}$ = Antilog of $\log \hat{b}$;

$\text{Log } \hat{b}$ = Value of $\log b$;

$\text{Se } \hat{g}$ = Standard error of compound growth rate

Cuddy-Della Valle index

Cuddy Della Valle instability index (Cuddy and Della Valle, 1978) is a modification of coefficient of variation to accommodate trend present in the data, which is commonly present in economic time series data. This method is superior over the scale dependent measures such as standard deviation. The Cuddy Della Valle index (CDVI) is calculated as follows:

The specification of CDVI (%) to be used in the study is,

$$\text{CDVI} = \text{CV} \sqrt{1 - \bar{R}^2}$$

Where,

$\bar{R}^2$ = Adjusted coefficient of determination; and
CV = Coefficient of variation.

The instability was further categorized

into 0–15 (low instability); 15–30 (medium instability); and >30 (high instability) following the findings reported by Sihmar (2014).

Markov chain analysis

Markov chain analysis was employed to analyze the structural change in any system whose progress through time can be measured in terms of single outcome variable. In the present study, the dynamic nature of trade patterns of major spices exported from India was studied using the Markov chain model.

Markov chain analysis involving developing a transitional probability matrix 'P', whose elements, P_{ij} indicate the probability of exports switching from country 'i' to country 'j' over time. The diagonal element P_{ij} where $i=j$, measure the probability of a country retaining its market share or in other words, the loyalty of an importing country to a particular country's exports.

In the context of current application, structural change was treated as a random process with the top ten importing countries and a residual "Others" category for spices. The assumption was that the average export of spices from a country amongst importing countries in any period depends only on the export in the previous period and this dependence is same for all the periods. This was algebraically expressed as

$$E_{jt} = \sum_{i=1}^n E_{it-1} P_{ij} + e_{jt}$$

Where

E_{jt} = Exports from India to the j^{th} country in the year t

E_{it-1} = Exports of i^{th} country during the year t-1

P_{ij} = Probability that exports will shift from i^{th} country to j^{th} country e_{jt} = the error term which is statistically independent of E_{it-1}

n = the number of importing countries

The transitional probabilities P_{ij} , which can be arranged in a $(c \times r)$ matrix, have the following properties.

$$0 < P_{ij} < 1 = 1 \text{ for all } i$$

Thus, the expected share of each importing country during period 't' is obtained by multiplying the exports of spices to these countries in the previous period (t-1) with the transitional probability matrix. The probability matrices were estimated for the period from 2014-2023 thus, transitional probability matrix (T) was estimated using linear programming (LP) frame work by a method referred to as minimizing of Mean Absolute Deviation (MAD).

$$\text{Min, } O P^* + I e$$

$$\text{Subject to } X P^* + V = Y$$

$$G P^* = 1$$

$$P^* > 0$$

Where

P^* is a vector of the probabilities P_{ij} O is the vector of zeros

i is an appropriately dimensional vectors of areas e is the vector of absolute errors

Y is the proportion of exports to each country

X is a block diagonal matrix of lagged values of Y

V is the vector of errors

G is a grouping matrix to add the row elements of P arranged in P^* to unity.

The values in the transition probability matrix will have different interpretations. The value of diagonal elements indicates the probability of retention of the previous year's share, while values in the columns reveal probability of gain by a particular country from other countries, values in rows reveal probability that a country might lose to other countries in respect of a specific commodity exports.

A key assumption of the Markov chain model is that the transition probabilities remain stationary over the study period, i.e., no structural break occurs in the underlying export process. Since the study period (2014–23) spans the COVID-19 pandemic (2020–21), which disrupted global trade flows and logistics, this assumption was examined by comparing the pre-pandemic (2014–19) and post-pandemic (2021–23) transition probability matrices for the major destination countries. The comparison did not reveal any systematic departure in the direction of switching behaviour between the two sub-periods, indicating that the pandemic-induced disruption was transient rather than a permanent structural shift in India's spice export destinations; the single pooled matrix for 2014–23 was therefore retained for the analysis.

Results and discussion

Spice scenario in India

From 2001-02 to 2022-23, the area, production, and productivity of spices in India have shown significant growth, reflecting the sector's robust development (Table 1). The area under spice cultivation increased from 2,790.22 thousand hectares in 2001-02 to 4,544.253 thousand hectares in 2022-23, representing a Compound Annual Growth Rate (CAGR) of 3.26 per cent. Concurrently, spice production surged from 3,425.99 thousand tonnes to 11,827.48 thousand tonnes, achieving a CAGR of 6.68 per cent, indicating substantial improvements in agricultural practices and technology. Productivity also saw an upward trend, growing from 1,228 kg/ha in 2001-02 to 2,602 kg/ha in 2022-23, with a CAGR of 3.31 per cent. This period also experienced notable fluctuations, as evidenced by the Cuddy Della Valle Instability index (CDVI) of 7.55 for area, 8.27 for production, and 6.60 for productivity. These figures underscore the dynamic nature of the spice sector in India, driven by both expanding cultivation areas and enhanced yield per hectare, contributing significantly to

the agricultural GDP and positioning India as a major player in the global spice market.

India's spice exports showed a notable increase during the post-pandemic period, with export value rising from US\$ 3,110.63 million in 2019–20 to US\$ 4,178.80 million in 2020–21,

Table 1. Area, production and productivity of Spices in India (2001-02 to 2022-23)

Year	Area (‘000 ha)	Production (‘000t)	Productivity (kg/ha)
2001-02	2790.22	3425.99	1228
2002-03	2503.557	2950.94	1179
2003-04	2637.258	3923.32	1488
2004-05	2454.743	3875.84	1579
2005-06	2345.021	3896.86	1662
2006-07	2471.319	4106.54	1662
2007-08	2630.567	4460.17	1696
2008-09	2829.461	5078.98	1795
2009-10	2940.309	5267.74	1792
2010-11	3047.124	5875.62	1928
2011-12	3407.462	6746.07	1980
2012-13	3061.703	6067.18	1982
2013-14	3156.084	6361.42	2016
2014-15	3224.357	6764.63	2098
2015-16	3464.438	6989.72	2018
2016-17	4110.997	10469.72	2547
2017-18	3906.982	9566.99	2449
2018-19	4003.5	9300.30	2323
2019-20	4306.065	10171.45	2362
2020-21	4528.176	10679.22	2358
2021-22	4485.885	11039.88	2461
2022-23	4544.253	11827.48	2602
CAGR (%)	3.26*	6.68*	3.31*
CDVI	7.55	8.27	6.60

Note: *Significant at 1% level; Source: Annual report on spices 2022-23, Spices Board of India.

before moderating to US\$ 3,952.60 million in 2022–23 (Table 2). The increase in exports can be attributed to the growing global demand for spices, partly driven by increased consumer preference for products with perceived health and immunity-enhancing properties. In addition, exports of value-added spice products such as spice oils and oleoresins recorded growth in both volume and value, while curry powder/paste exports increased in value and mint products registered higher export volumes, contributing to the overall export performance during the period.

Table 2. Export of spices from India over the years (2013-14 to 2022-23)

Year	Quantity (‘000 t)	Value (US \$ Mill)	Y-O-Y growth (%)
2013-14	896.57	2497.30	
2014-15	923.27	2429.48	-3
2015-16	820.66	2502.52	3
2016-17	1007.88	2890.50	16
2017-18	1028.06	2789.35	-3
2018-19	1100.25	2805.50	1
2019-20	1208.40	3110.63	11
2020-21	1758.99	4178.80	34
2021-22	1530.66	4068.45	-3
2022-23*	1404.357	3952.6	-3
CAGR	7.54*	6.59*	

Note: * & * indicate significance at 1 and 5 per cent level of probability; Source: APEDA, 2023.

From 2013-14 to 2022-23, the import of spices from India experienced significant growth in both quantity and value (Table 3). The quantity surged from 130,010 tonnes to 376,900 tonnes, and the value escalated from Rs. 2,90,514 lakhs to Rs. 10,57,712 lakhs. Early years saw high growth rates, peaking in 2015-16 with increases of 19.61 per cent in quantity and 22.48% in value. However, growth rates stabilized or slowed in the subsequent years, with notable minimal increases in 2018-19 and

2021-22. A dramatic spike occurred in 2022-23, with a 67.96% increase in value, indicating a significant rise in demand or market changes. The Compound Annual Growth Rates (CAGR) were 7.54 per cent in quantity and 6.59 per cent in value, reflecting a steady upward trend overall.

Table 3. Import of spices from India over the years (2013-14 to 2022-23)

Year	Quantity (t)	Value (Rs. In lakh)	Y-O-Y growth (%)
2013-14	130010	290514	
2014-15	138715	384382	6.70
2015-16	165920	446622	19.61
2016-17	203225	460693	22.48
2017-18	206205	500217	1.47
2018-19	207300	503206	0.53
2019-20	220305	665241	6.27
2020-21	223626	703056	1.51
2021-22	224393	810685	0.34
2022-23	376900	1057712	67.96
CAGR	7.54*	6.59*	

Note: Significant at 1% level; Source: APEDA, 2023.

Major markets for the spice exports of India for the year 2022-23 are presented in Table 4. Amongst the individual countries, the biggest importer was China with imports valued at US \$ 793.41 million, next came the USA (US\$ 527.12 million), Bangladesh (US\$ 257.03 million), UAE (US\$ 205.76 million), and Thailand (US\$ 183.97 million). Some other important markets for the spice exports of India included Indonesia (US\$ 141.96 million), Malaysia (US\$ 139.45 million), Sri Lanka (US\$ 114.12 million), the UK (US\$ 98.94 million), and Saudi Arabia (US\$ 91.08 million). As can be seen from above, these important markets made up a sizable proportion of the Indian spice export proceeds, with exports to other countries classified under 'Other countries' being worth US\$ 1,234.24 million.

Table 4. Export of spices from India to top ten destinations (2022-23)

Sl. No.	Importing country	Qty (t)	Million US\$
01	China	256948.26	793.41
02	U S A	82227.98	527.12
03	Bangladesh	204095.07	257.03
04	UAE	73302.40	205.76
05	Thailand	61307.86	183.97
06	Indonesia	44090.81	141.96
07	Malaysia	63371.48	139.45
08	Sri Lanka	52429.67	114.12
09	U K	25157.47	98.94
10	Saudi Arabia	34923.78	91.08
11	Other countries	412392.43	1234.24
	Total	1310247.21	3787.08

Source: APEDA, 2023.

Direction of trade

To analyse the direction of India's spice exports, a transition probability matrix was estimated using the Markov chain framework based on annual export data for the period 2014–2023 (Table 5). The diagonal elements of the transition probability matrix represent the probability of retaining market share and indicate the loyalty or stability of each importing market for Indian spice exports. The results revealed that the major importing countries, Sri Lanka exhibited the highest retention probability (44.00 per cent), followed by China and Nepal, each with a retention probability of 42.00 per cent and Others category had the retention probability of 78.00 per cent, indicating that it retained the highest proportion of its market share from one period to the next. In contrast, the USA, Thailand, and Saudi Arabia recorded zero retention probabilities, indicating that they did not retain their market shares during the study period and were therefore the least stable export destinations. Malaysia (29.00 per cent), Indonesia (28.00 per cent), and the UAE (18.00 per cent) exhibited moderate levels of market retention. The relatively high retention

probability observed for the 'Others' category suggests that several smaller and emerging markets have maintained stable demand for Indian spices. This indicates potential opportunities for further market diversification through appropriate export promotion measures, including buyer outreach, quality certification support, and trade facilitation.

Table 5 presents the transition probability matrix depicting the dynamics of India's spice export markets during 2014–2023. The row elements represent the probability of a country retaining or losing its import share to competing destinations, while the column elements reflect the probability of gaining market share from other importing countries.

Market retention and loss of import share

The diagonal elements indicate market retention. Countries such as Bangladesh (0.06), USA (0.00), Thailand (0.00) and Saudi Arabia (0.00) show very low or zero probabilities of retaining their import share, indicating high instability in India's spice exports to these markets.

The transition probability matrix indicates that the USA, Thailand, and Saudi Arabia are the most unstable markets for Indian spice

exports, as they retained 0 per cent of their previous import share and therefore lost 100 per cent of their market share. Bangladesh (94%), Indonesia (72%), Malaysia (71%), China (58%), Nepal (58%), and Sri Lanka (56%) also recorded high market losses due to their low retention rates. In contrast, the 'Others' category retained 78 per cent of its market share and lost only 22 per cent, indicating higher stability and diversification of export destinations.

The observed market shifts can be explained by the current scenario in global spice trade. The USA market has become more competitive due to strict US Food and Drug Administration (FDA) food safety regulations, pesticide residue limits, and competition from Vietnam, China, and other exporters. Thailand's complete market loss may be due to changing trade patterns, as it acts mainly as a processing and re-export hub, with import shares shifting towards Bangladesh (75%) and the USA (25%). In the case of Saudi Arabia, the loss of market share is associated with changes in sourcing preferences among Gulf countries, with exports shifting mainly towards the UAE (50%), Malaysia (20%), and Others (30%). The declining retention in China, Bangladesh, Indonesia, Malaysia, Nepal, and Sri Lanka reflects increased competition, changing

Table 5. Transition probability matrix for spice export (2014-2023)

Country	China	Bangla- desh	USA	UAE	Malaysia	Thailand	Nepal	Sri Lanka	Indonesia	Saudi Arabia	Others
China	0.42	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bangladesh	0.66	0.06	0.07	0.06	0.01	0.00	0.04	0.02	0.03	0.00	0.06
U S A	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.33	0.51
UAE	0.00	0.00	0.21	0.18	0.28	0.15	0.00	0.00	0.15	0.03	0.00
Malaysia	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.71
Thailand	0.00	0.75	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepal	0.00	0.00	0.23	0.31	0.00	0.00	0.42	0.04	0.00	0.00	0.00
Sri Lanka	0.00	0.00	0.10	0.00	0.00	0.22	0.00	0.44	0.25	0.00	0.00
Indonesia	0.00	0.00	0.00	0.00	0.00	0.17	0.55	0.00	0.28	0.00	0.00
Saudi Arabia	0.00	0.00	0.00	0.50	0.20	0.00	0.00	0.00	0.00	0.00	0.30
Others	0.00	0.00	0.05	0.00	0.04	0.07	0.00	0.06	0.00	0.00	0.78

import requirements, price competitiveness, and diversification of sourcing countries. The higher stability of the 'Others' category indicates that expanding into emerging and smaller markets helps reduce dependence on a few major destinations and improves the resilience of India's spice exports.

Market gains and shifts in export destinations

The column-wise interpretation shows that 'Others' emerge as the largest gainer, with a cumulative gain probability of 158 per cent, highlighting India's increasing penetration into non-traditional and emerging markets. This suggests a strategic diversification away from traditional destinations.

Bangladesh (133%) and UAE (103%) also register high probabilities of gaining market share, indicating their growing importance in India's spice export basket. The UAE's gain reflects its role as a regional trade hub and re-export center, particularly for West Asia and Africa. The USA (91%) continues to attract exports from other destinations despite losing its own retention capacity, indicating that while the market is volatile, it remains attractive due to high-value demand. On the other hand, Sri Lanka records the lowest gain probability (12%), suggesting limited expansion of India's spice exports to this market during the study period.

Policy implications

The transition probability results clearly indicate a shift in India's spice exports from traditional developed markets towards emerging and regional markets. The high instability in markets such as the USA and Thailand underscores the need for:

- Strengthening quality compliance and certification systems,
- Reducing export rejections through better traceability and Sanitary and Phytosanitary (SPS) harmonization,

- Negotiating trade facilitation measures with high-value markets.

At the same time, the growing gains in Bangladesh, UAE and other markets suggest that regional integration, proximity advantages, and demand-driven diversification are shaping future export dynamics. Policy efforts should therefore balance market stabilization in traditional destinations with strategic expansion into emerging markets to ensure sustainable growth of India's spice exports.

Conclusion

The study highlights that India's spice sector has recorded strong and statistically significant growth in area, production and productivity over the study period, reflecting technological progress, expansion in cultivation and rising global demand. However, the observed production instability—with a Cuddy-Della Valle instability index of 8.27 at the national level indicates that growth has not been uniform across regions and remains sensitive to climatic variability, market demand fluctuations and price volatility, with state-level production considerably more volatile than the national trend. Although exports of spices have increased steadily in both quantity and value, the coexistence of growth and instability suggests that export performance alone does not guarantee market sustainability. This underlines the need for analytical tools that go beyond trend analysis to capture the dynamic nature of export markets.

The Markov chain analysis reveals that India's spice exports are undergoing continuous reallocation across importing countries, with emerging and diversified markets grouped under "Others" showing the highest retention and stability. In contrast, traditional high-value destinations such as the USA, Thailand and Saudi Arabia exhibit complete loss of market share, indicating structural instability driven by stringent quality standards, strong international competition and re-export

dynamics. The increasing gains observed in Bangladesh and UAE reflect the growing importance of proximity, price competitiveness and regional trade hubs in shaping export flows. These findings suggest that export policy should simultaneously focus on stabilizing access to developed markets through quality compliance and traceability, while strategically strengthening India's presence in emerging and regional markets to ensure sustainable and resilient growth of spice exports.

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