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RESEARCH ARTICLE

Export performance and market retention of turmeric oleoresin from India: A Markov chain approach

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Abstract

Turmeric oleoresin is a valuable extract from *Curcuma longa*. it plays a vital role in the food, pharmaceutical and nutraceutical sectors. India is the greatest producer in the world and contributes significantly to turmeric oleoresin exports. This study uses Markov Chain analysis and the Compound Annual Growth Rate (CAGR) to evaluate India's export performance from 2003 to 2024. Following 2014, the Mission for Integrated Development of Horticulture saw a policy-driven boom that led to a CAGR of 16.06 %. The Markov Chain study, based on export quantity data from 2018 to 2024, simulates the direction of trade and reveals country-level market retention and share transitions. High market loyalty was noted in nations like the USA (83 %), Germany (83 %), France (85 %) and the UK (80 %), whereas emerging or volatile markets such as China (60 %), the UAE (60 %) and the "Others" group, which accounted for 50 %, exhibited lower retention and more volatility. To identify reoccurring problems like pesticide residues, microbiological contamination, unauthorised additions and labelling errors, the study also integrates trade rejection data from the EU's Rapid Alert System for Food and Feed (RASFF) and weekly alerts from the Indian trade portal. These rejections cause export volatility in emerging markets and have immediate economic effects. According to the findings, India's export competitiveness and sustainability will be enhanced by combining high-retention markets and reducing rejection risks through improved traceability, chemical residue monitoring and regulatory compliance.

Keywords: CAGR; trade rejections; transition probability matrix; turmeric oleoresin

Introduction

Turmeric *Curcuma longa* is a rhizomatous herbaceous plant that grows in South Asia. It is used as a spice, natural colourant, cosmetic ingredient and medicine (1). Turmeric oleoresin is a concentrated extract that contains curcuminoids and essential oils. It is one of the processed derivatives that has become very popular in global markets, especially in the pharmaceutical, nutraceutical and culinary industries (2). India is the world's largest producer of turmeric and also controls the market for oleoresin exports. This greatly increases the amount of money that comes in from selling value-added spices (3). India's turmeric oleoresin exports are often blocked by trade rejections in important markets, even though there is a lot of demand for them. The US, Japan and the EU (Table 1) are all concerned about aflatoxin contamination, pesticide residue violations and microbial safety standards. For example, Indian turmeric products, like oleoresins, have been often warned by the Indian Trade Portal and the European Union's RASFF for having levels of aflatoxins and lead that are too high (4, 5). Such issues lead to shipments being rejected because of strict non-tariff measures (NTMs) (6). These rejections not only cost India money, but they also adversely affected its reputation in the global spice trade. Previous research has examined the competitiveness and export potential of Indian spices (7). Examined the trends in India's spice trade and highlighted the need for value-added products to boost exports (8). In a similar vein, investigated the importance of international standards compliance and quality certificates in safeguarding the expansion of spice exports (9). Have employed statistical tools such as the CAGR to assess export performance over time and Markov chain models have demonstrated efficacy in predicting market transition behaviour and crop export stability (10, 11). Most existing literature assesses export performance and market transitions in isolation, frequently neglecting the interaction between quantitative trade dynamics and qualitative trade barriers. Specifically, previous studies seldom incorporate export growth analysis (CAGR), market retention and transition behaviour (through transition probability matrices) and structural trade disruptions, including product rejections and non-tariff measures (NTMs). This fragmented approach hinders our comprehension of the long-term sustainability and strategic trajectory of Indian turmeric oleoresin exports, particularly amid increasing international regulatory scrutiny.

This study posits that *the sustainability and expansion of India's turmeric oleoresin exports are substantially affected by export performance, market loyalty, trade rejections and regulatory compliance.* The study employs an integrated methodology with the objectives of assessing export

Table 1. Trade rejections of turmeric from India (2021-2025)

Country	SPS Issue	Action Taken	Notification Type	Date
France & Germany	Ethylene oxide in chilli pepper and turmeric	Detained by operator	Alert Notification - Company's own check	21-12-2021
Germany	2-Chloroethanol in turmeric with cereals	Withdrawal from market	Alert Notification - Company's own check	03-02-2022
Austria	PAH found in turmeric	Withdrawal from recipient(s)	Alert Notification - Company's own check	02-06-2022
Finland	Chlorpyrifos & ethylene oxide in turmeric powder	Product to be redispatched/destroyed	Border Rejection Notification (consignment detained)	11-01-2022
Slovenia	Incorrect identification code on packaging	Official detention	Border Rejection Notification (consignment detained)	03-04-2023
Germany	Chlorpyrifos in turmeric powder (via Netherlands)	Return to consignor	Alert Notification	14-11-2023
Latvia	Absence of certificate & sampling protocol	Destruction	Border Rejection Notification	01-02-2024
Netherlands	Chlorpyrifos in turmeric	Informing consignor	Information Notification for attention	02-04-2024
Latvia	Unappropriated consignment identification code	Product to be redispatched/destroyed	Border Rejection Notification	03-06-2024
Finland	*Salmonella Weltevreden* in turmeric powder	Product to be redispatches/destroyed	Destruction	07-06-2024
Poland	*Salmonella spp.* in ground turmeric	Informing authorities	Alert Notification	25-10-2024
Germany (via Italy)	Unauthorized colorant (methyl yellow) in turmeric powder	Withdrawal from the market	Alert Notification	29-01-2025

Source: Indian trade portal and RASFF window

performance through CAGR analysis. Use first-order Markov chains (transition probability matrix) to model changes in market share and retention. Also, look at how trade rejections and regulatory barriers, especially the EU's RASFF, affect long-term market access and competitiveness.

By filling this research gap, the study gives a complete, data-driven framework for understanding the factors that affect India's turmeric oleoresin export performance, both positive and negative.

Methodology

The study used export quantity data from 2003 to 2024 to examine India's export performance of turmeric oleoresin. The Ministry of Commerce and Industry, Government of India, is a dependable source of this information (12). The data was divided into three periods: pre-MIDH (2003-2014), post-MIDH (2014-2024) and the overall period (2003-2024) to account for changes brought about by policy and long-term growth. Among the major importing nations considered in the investigation were China, Germany, the United Arab Emirates and the United States.

To estimate the CAGR, an exponential regression model was applied, based on the following form:

$$Y_t = ab^t e^u \quad (1)$$

Where:

Y_t = export quantity in year t

a = intercept term

b= (1+r), with r as the compound growth rate

t = time (trend variable)

u = random error term

The model was transformed into a log-linear form for estimation via Ordinary Least Squares (OLS):

$$\text{Log } Y = \log a + t \log b + \log u \quad (2)$$

Ordinary Least Squares (OLS) method was used to estimate the coefficients Log a and Log b. The compound growth rate (CAGR) was then calculated using:

$$\text{CAGR} = [\text{Antilog}(\log b) - 1] \times 100 \quad (3)$$

The statistical significance of the growth rate was evaluated using the t-test. The coefficient of determination (R^2) was calculated to assess the goodness of fit of the regression model. A positive and significant CAGR indicates sustained export growth, while a negative or non-significant rate signals stagnation or decline (13, 14).

To check how reliable the exponential regression model was for estimating the CAGR, a few diagnostic tests were carried out. The R^2 value was 0.804, which shows that the model could explain most of the variation in export growth over time and across different markets. This high value confirms that using a log-linear approach was appropriate and that the model closely followed the actual export trends. In addition, residual plots showed no major problems like uneven spread of errors (heteroscedasticity) or pattern-based errors (autocorrelation), which means the model's assumptions held true. Overall, these checks add confidence that the CAGR values reported are trustworthy and can be used to support decision-making in export planning and policy development. (15, 16)

Direction of trade

the structural shift in turmeric oleoresin exports from India in terms of market retention and market switching was analysed by using the Markov chain technique. Country wise export data (in quantity terms) for the period 2018-19 to 2023-24 was acquired from the ministry of commerce and industry, department of commerce.

We simulate the yearly export proportions of India's turmeric oleoresin as a limited collection of importing countries. Each country is represented as a state and the transition probability P_{ij} represents the probability that the percentage of exports now in country *i* will be found in country *j* in the next period. The model assumes that future shifts depend only on the current distribution of exports and that transition probabilities are stable throughout. We estimated P_{ij} from the yearly export quantities (2018-2024) by studying year-to-year variation in export shares for the key importing

countries. In practice, the transition matrix was fitted so that the predicted exports for period t-1 (given by the previous period t shares multiplied by P) best match the observed data. The diagonal entry P_{ij} therefore measures the *loyalty* of country. Off-diagonal entries P_{ij} (for $i \neq j$) capture the probability of the export share transferring from country *i* to country *j*. This technique follows common practice in trade stability research using Markov chains. The average exports to a specific regional country are considered to be a random variable which depends only on the historical shipments to that regional country, which may be expressed algebraically as follows (10,11)

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

Where,

E_{jt} = Exports from India to j^{th} country during the year 't' to j^{th} country (4)

E_{it-1} = Exports to i^{th} country during the period t-1

P_{ij} = Probability that the exports will shift from i^{th} country to j^{th} country

e_{jt}= The error term which is statistically independent of E_{it-1}

t = Number of years considered for the analysis

r = Number of importing countries

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

$$0 \leq P_{ij} \leq 1 \quad (5)$$

To estimate the transition probabilities, we applied a Linear

$$\sum_{i=1}^{r} P_{ij} = 1 \text{ for all i} \quad (6)$$

Programming (LP) method that minimizes the Mean Absolute Deviation (MAD) between predicted and actual export shares. The LP formula may be expressed as follows:

$$\text{Min } OP^* + Ie \quad (7)$$

Subject to:

$$XP^* + V = Y \quad (8)$$

$$GP^* = 1 \quad (9)$$

$$P^* >= 0. \quad (10)$$

Where,

P^* is a vector of the probability P_{ij}

O is a vector of zeros

I is an appropriately dimensioned vector of area

e is the vector of absolute errors

Y is the vector of export to each country

X is a block diagonal matrix of lagged values of Y

V is a vector of errors

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

Results and Discussion

Trend in export of turmeric oleoresin from India

The export of turmeric oleoresin from India has shown a strong and continuous growth over the past two decades, both in terms of quantity and value. As illustrated in Fig. 1 and 2, this rising tendency has been relatively steady from 2003-04 to 2023 -24. The trendlines fitted to the data reveal high R^2 values above 0.80 indicating a consistent long-term growth tendency. This indicates India's expanding importance as a major supplier of turmeric oleoresin in the worldwide market. A significant turning point in this trend was noticed after 2014, when government-backed projects like the Mission for Integrated Development of Horticulture (MIDH) were established. These programs helped enhance infrastructure for post-harvest handling, minimise losses and encourage value-added exports (17). As a result, the quantity of turmeric oleoresin exported surged from a few hundred metric tonnes in the early 2000s to over 2700 metric tonnes by 2020-21, before stabilizing around 2000 metric tonnes in the following years. On the value side, export earnings climbed considerably as well, reaching over ₹95,000 lakhs in 2020-21. A main element driving this spike was the COVID-19 pandemic, during which global demand for natural immune-boosting medications rose considerably. Turmeric and notably its concentrated form as

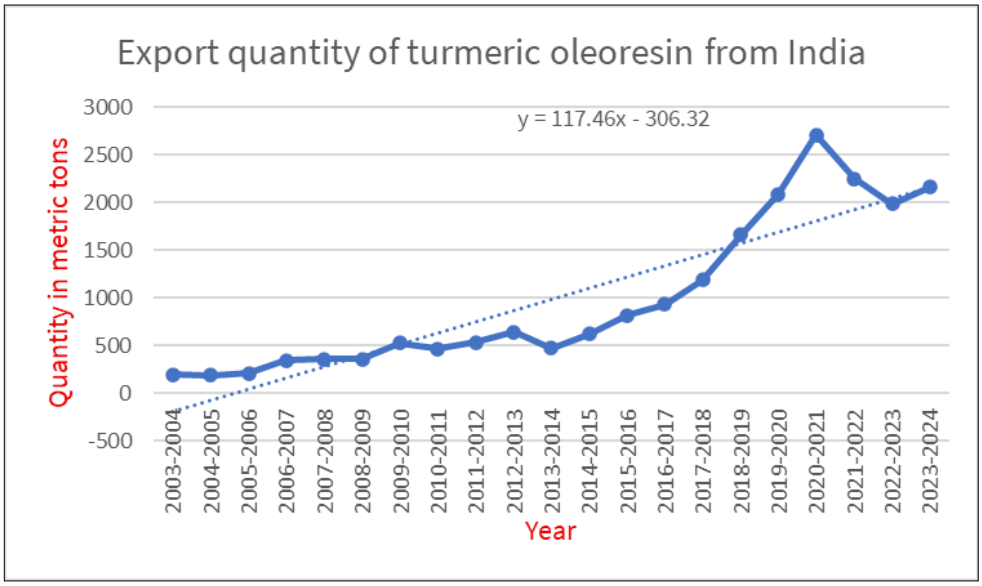

Fig. 1. Trend in total quantity of turmeric oleoresin exported from India (2003-2024).

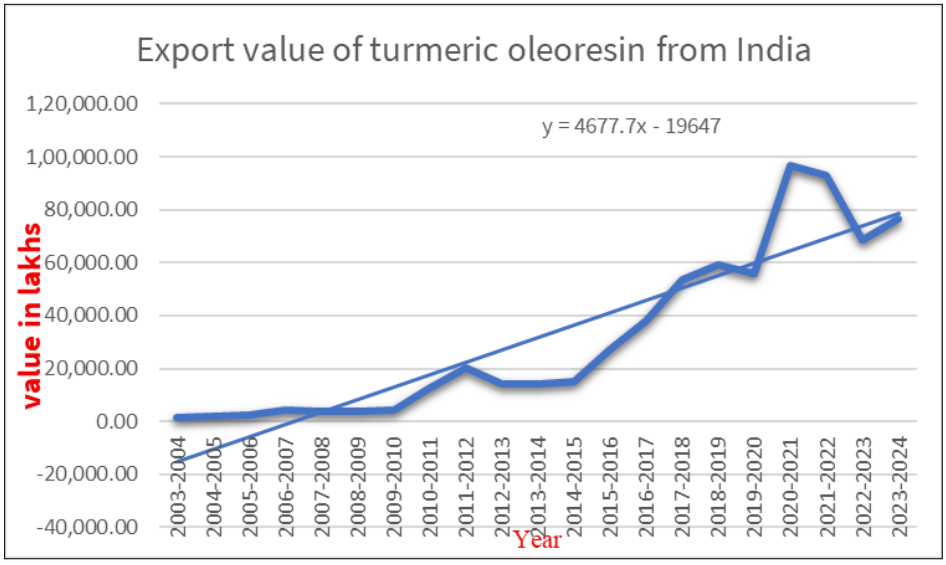

Fig. 2. Trend in total value of turmeric oleoresin exports from India (2003-2024).

oleoresin, became highly sought-after due to its anti-inflammatory and immunity-enhancing characteristics, which were widely advocated in both traditional and modern medicine systems (18). The USA has continually been the leading importer of Indian turmeric oleoresin, spurred by the expanding popularity of herbal supplements and natural culinary ingredients (19). Other nations like the UAE also exhibited tremendous development, with exports jumping from just 5.89 MT in 2018-19 to 83.27 MT in 2022-23. This significant increase can be attributed to improving trade links, strategic diplomatic engagements and a rise in the popularity of turmeric-based health supplements in the Gulf Cooperation Council (GCC) region (20), where natural remedies have become mainstream. Moreover, (21) projected the global curcumin market to grow at over 10.57 % CAGR through 2030, with high uptake in the Asia-Pacific regions, which aligns with India's expanding turmeric oleoresin shipments. While the overall trend is encouraging, there were short-term decreases in 2013-14 and again in 2021-22. These can be ascribed to global economic slowdowns, changes in import regulations and logistics challenges during the pandemic. However, the export performance came back swiftly, proving that the Indian oleoresin business is resilient and responsive to global market conditions (22). The group labelled "Others" which includes nations like France, Italy, Australia, Netherlands, Belgium and UAE shows minor swings due to intermittent demand and smaller trade volumes. These countries are lumped together in analysis because individually, they account for less than 2 % of the overall amount. The swings are generally caused by causes like seasonal procurement, regulatory changes, or temporary supply shortages (23). To handle missing data, a straightforward method was used: if a country's data was completely absent for a given year (such as Italy in 2004-05), it was omitted from that year's study. For years with partial data, linear interpolation was used to approximate missing values based on nearby years. These strategies helped maintain the accuracy of the overall trend without distorting the data. The ongoing development in turmeric oleoresin exports is further supported by global trends favouring natural, plant-based ingredients, especially in the food, cosmetic and pharmaceutical industries (24). Oleoresins are recommended for their high concentration, shelf stability and convenience of use in formulations. India's capacity to meet these growing demands along with government backing and increased quality standards has made it a trusted supplier in foreign markets (25). In summary, the data clearly reveal that India's turmeric oleoresin exports have expanded dramatically over the previous 20 years, underpinned by high demand, favourable legislation and durable production infrastructure. Despite a few setbacks, the sector has demonstrated significant recovery and resilience, underlining its relevance in the worldwide spice extract trade.

Compound Annual Growth Rate (CAGR)

The CAGR research provides vital insights into how India's turmeric oleoresin exports have changed over the past two decades. By splitting the timeframe into two different policy periods pre-MIDH (2003-2014) and post-MIDH (2014-2024) a deeper understanding of export performance and affecting factors emerges (Table 2). During the pre-MIDH timeframe, India's turmeric oleoresin exports expanded at a CAGR of 12.67 %, mostly supported by consistent demand from long-established markets such as the United States and Germany. However, despite this rise, various structural impediments hindered India's capacity to scale its exports further. At that time, post-harvest infrastructure was weak and awareness of international quality standards among farmers and processors was poor. Small-scale producers lacked access to export grade processing machines and the supply chain remained fragmented. There was no institutional support to aid exporters in navigating complex international certification procedures. As a result, India's competitiveness in more demanding markets especially in the European Union and Japan was constrained during this time. The post-2014 period indicates a turning point, as the CAGR of turmeric oleoresin exports jumped to 16.06 %, showing a considerable acceleration in export growth. This spike coincides with the

Table 2. Compound annual growth rate

Period	Mean Export Quantity (MT)	CAGR (%)	Standard Error (SE)	t-value
2003-2014 (Pre-MIDH)	~758.42	12.67	0.0213	4.34
2014-2024 (Post-MIDH)	~1894.27	16.06	0.0185	6.12
2003-2024 (Overall)	~1382.65	14.38	0.0196	5.73

execution of the Mission for Integrated Development of horticultural (MIDH), a national program aimed at improving India's horticultural sector. Under MIDH, many structural changes were introduced: financial subsidies for setting up oleoresin processing units, training programs to promote Good Agricultural Practices (GAP), construction of cold storage facilities and formation of food testing laboratories (26). These efforts greatly raised product quality and improved supply chain efficiency, making Indian exports more competitive in international markets. Moreover, these advancements helped India overcome one of its fundamental challenges compliances with Sanitary and Phytosanitary (SPS) requirements. From 2014 forward, trade rejections became a public worry, especially in high-regulation economies such as the European Union and Japan. Indian turmeric consignments were occasionally refused due to aflatoxin contamination, high chemical residues, or microbiological dangers like Salmonella. The European Union's RASFF (Rapid Alert System for Food and Feed) routinely issued alarms involving Indian turmeric goods, leading to consignment returns or destruction. These rejections underscored the need for exporters to develop residue-monitoring systems, increase traceability and invest in internationally certified laboratories. Interestingly, while these regulatory pressures provided short-term difficulties, they also functioned as accelerators for long-term sectoral reform. Exporters responded by strengthening testing capabilities and implementing improved post-harvest handling methods, leading to continuing growth despite the increased compliance threshold. Overall Export Growth From 2003 to 2024, the total CAGR for India's turmeric oleoresin exports is at a respectable 14.38 %. This long-term development tendency is not only backed by developed markets like the USA but also by increasing demand from China and the United Arab Emirates. For instance, shipments to the UAE expanded at a CAGR of roughly 20 %, showing the success of bilateral economic cooperation and the growing interest for natural health components in the Middle East. To ensure the reliability of these growth tendencies, an exponential regression model was used to the export data. The model produced a high R^2 score of 0.804, indicating the dependability of the growth estimates. Further validation through residual analysis demonstrated no substantial breaches of major regression assumptions such as homoscedasticity and randomisation of errors (Table 3). These results support the conclusion that the observed growth patterns are both statistically sound and economically relevant. According to Khandelwal A et al, India failure to meet the EU's pesticide MRLs and frequent rejections arose from lack of standardised traceability mechanisms and insufficient farmer-level awareness (27). The MIDH reforms explicitly targeted these restrictions by supporting capacity-building and enhancing backward integration.

Table 3. Diagnostic result table

Diagnostic Test	Value
Coefficient of Determination (R^2)	0.815
Durbin-Watson Statistic	1.92
Jarque-Bera Test (Residual Normality)	JB = 1.43, p = 0.48
Breusch-Pagan Test (Homoscedasticity)	$\chi^2 = 2.17$, p = 0.14
Standard Error of Regression (SER)	0.083

Markov chain analysis

The generated transition probability matrix demonstrates strong retention rates (large diagonal values) for most significant markets, indicating sustained and loyal demand. For example, the United States displays a retention probability of 0.83 ($P_{US,US}$), suggesting 83 % of its market share is retained annually. Similarly high values are reported for Germany (0.83), France (0.85) and the United Kingdom (0.80), demonstrating that these countries consistently import turmeric oleoresin from India. In contrast, China (0.60) and the UAE (0.60) have lower retention, showing more volatility likely due to greater competition, changeable demand, or inconsistent procurement habits (Table 4). Off-diagonal factors illustrate how market shares shift between countries. For instance, a 0.05 transition probability from USA to Germany suggests that a modest fall in U.S. imports may result in an increase in Germany's share the following year. The "Others" group, which comprises minor and less consistent imports, shows just 0.50 self-retention, with some likelihood (e.g., 0.10 to USA) of share returning to dominant markets. Several mid-sized European markets like the Netherlands, Belgium and Denmark exhibit moderate retention (0.70-0.75), with noteworthy intra-European share transfers (e.g., NED→GER, DEN→UK), suggesting some fluidity within this cluster. To increase the interpretability of these results, a heatmap of the transition matrix (Fig. 3) was generated. Higher diagonal values (P_{ii}) are tinted more deeply, representing strong market loyalty, whereas lighter shades represent off-diagonal transitions (P_{ij}) indicating market share shifts. This picture clearly divides stable economies like the USA, Germany and France from dynamic or turbulent markets like China, UAE and Others. The implementation of the Markov chain model is a widely established tool to examine international trade dynamics and market retention behaviours (28). These data support the premise that while India enjoys reliable trade relations with

Table 4. Transition probability matrix for turmeric oleoresin

	USA	KAZ	AUS	GER	NED	UK	FRA	DEN	BEL	CHN	ITA	UAE	OTH
USA	0.83	0	0	0.05	0.02	0.03	0.02	0.01	0	0	0.02	0	0.02
Kazakhstan	0	0.8	0.04	0	0.03	0.02	0	0	0	0.01	0	0	0.1
Australia	0.05	0	0.8	0	0.04	0.03	0.02	0.01	0	0	0	0	0.05
Germany	0.03	0	0	0.83	0.02	0.02	0.04	0	0	0	0.03	0.01	0.02
Netherlands	0.02	0	0	0.05	0.75	0.05	0.03	0.03	0.03	0	0.02	0	0
UK	0.04	0	0.02	0.03	0.03	0.8	0.03	0	0	0	0	0	0.05
France	0.02	0	0	0.03	0.02	0.03	0.85	0	0	0	0.02	0	0.03
Denmark	0.05	0	0	0.05	0.05	0.05	0	0.7	0	0	0	0	0.1
Belgium	0	0	0	0.05	0.05	0.05	0	0	0.75	0	0	0	0.1
China	0.05	0	0	0	0.05	0	0	0	0	0.6	0	0.05	0.2
Italy	0	0	0	0.05	0	0.05	0.05	0	0	0	0.8	0	0.05
UAE	0	0.05	0	0	0	0	0	0	0	0.05	0	0.6	0.3
Others	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0	0.05	0	0.05	0	0.5

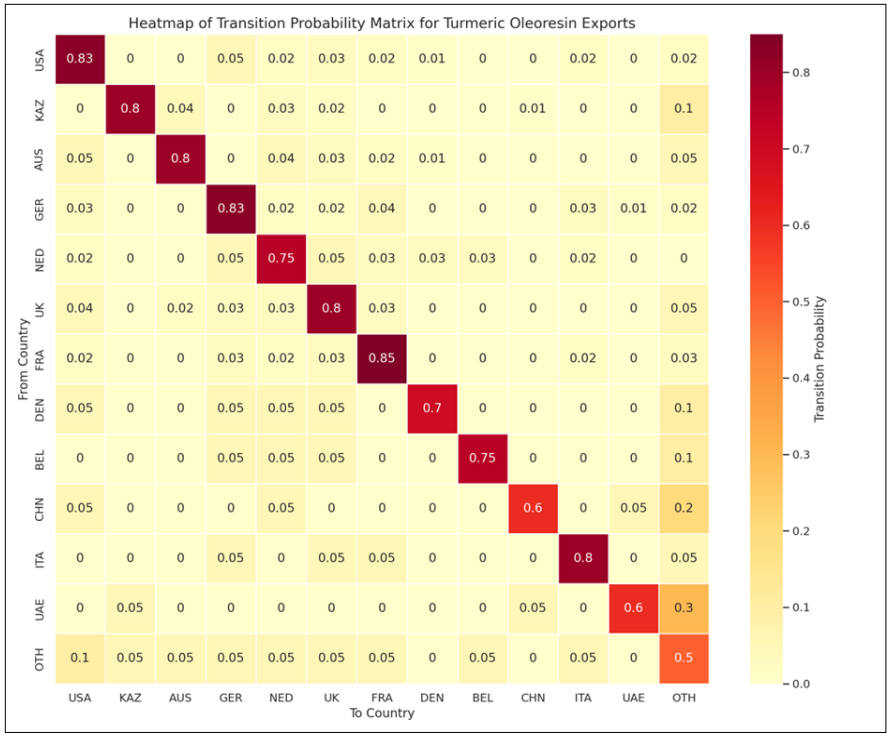

Fig. 3. Heatmap representation of the transition probability matrix for turmeric oleoresin exports from India. Darker shades indicate higher market retention P_{ii}, while lighter shades represent export share volatility and shifts to other countries P_{ij} (for) $i \neq j$.

major clients, there remains untapped potential and uncertainty in newer or smaller countries. Similar findings were found by (Ralte R), who indicated that India's retention in high-value spice markets corresponds with regulatory alignment and brand perception (29). Markets like China and UAE, while fast-growing, require continual investment in export promotion, label adaption and buyer interaction to stabilize share. Failure to invest in such adaptive trade tactics could lead to long-term opportunity loss. This information can assist governments and exporters prioritize retention measures in loyal markets while devising entry and engagement plans for more risky locations.

Conclusion

The study shows that while India's turmeric oleoresin exports expanded steadily especially post-MIDH (CAGR 16.06 %) market volatility persisted in regions like China and the UAE, often due to trade rejections. Markov analysis showed major loyalty in the USA and EU markets. To sustain and increase exports, India must enhance compliance and traceability, utilising solutions like the e-Spice Bazaar and blockchain traceability initiatives that digitally track pesticide usage, storage and certificates. These initiatives will lower regulatory risks and boost India's standing in the global spice trade through transparent, quality-driven exports.

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Authors' contributions

MG Carried out the survey, analysed the data and formulated the manuscript. DK Assisted in data collection and analysis as part of the research study. MM contributed by developing ideas, reviewing the manuscript and assisting with procuring research grants. KM helped in summarizing and revising the manuscript. AKG contributed to summarizing and provided additional support and contributions to the research study. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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