International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 20s, 2025
https://theaspd.com/index.php

Analysing Export Volatility And Trade Patterns In India's Fresh Grape Sector: A Markov Chain-Based Assessment

Krushnkumar P. Kulkarni[1], Dr. Vimal Pant[2], Dr. Prachi Pathak[3], Mrs. Suvarna S. Patil[4]
[1]Research Scholar, NIFTEM, Kundli, Haryana, India, krashna.pk@gmail.com
Publication ID— NIFTEM-P-2025-77
[2]Professor, National Institute of Food Technology Entrepreneurship and Management, Kundli, Haryana, India, vimal.niftem@gmail.com
[3]Associate Professor, School of Management, Doon University, Dehradun, India, prachipathak@doonuniversity.ac.in
[4]H.O.D., Department of Computer Science, BJS College, Pune, Maharashtra, India, patilsuvarna2019@gmail.com

ABSTRACT

This research undertakes a comprehensive analysis of India's fresh grape export trends and trade structure over the period 1987 to 2024, utilizing a combination of econometric and probabilistic methodologies. Specifically, the study applies linear trend estimation for performance evaluation, to quantify instability in trade, the Cuddy-Della Valle index, and Markov chain modelling is used to examine the directional shifts in export destinations over time. Recognizing India's prominent role in global grape production, the research aims to assess long-term trends, identify trade instability, and forecast export direction. The analysis is structured into decadal periods to evaluate changes in export quantity and value across major importing countries. Linear regression results highlight strong positive trends in export volume, while the instability index reveals significant volatility in export value, reflecting sensitivity to global market fluctuations. The Transition Probability Matrix (TPM) generated through Markov Chain modelling reveals that countries like the Netherlands, Russia, and the United Kingdom demonstrated strong market persistence with a stable and consistent demand, indicating stable trade relationships over the study period. These findings, with the integration of stochastic modelling, offer valuable actionable insights for policymakers, exporters, and stakeholders to refine export strategies, stabilize trade earnings, and enhance India's position in the international horticultural market and ensure long-term sustainability in India's horticultural export sector.

KEYWORDS: *- Fresh grape exports, trade flow analysis, Markov chain modelling, market stability, and volatility, Cuddy-Della Valle instability measure, export performance assessment, export trend forecasting*

1. INTRODUCTION

The global food and agricultural landscape is experiencing a historic shift. The international trade system is moving from prioritizing survival and calorie sufficiency to focusing on health, wellness, sustainability, and diversity. Changing consumer preferences, driven by rising incomes and education levels, have significantly increased demand for nutritious, ethical, and traceable food. This worldwide demand for fruits and vegetables is transforming agricultural systems globally. This shift has led to a diversification of production sources and the reorganization of trade routes and logistics systems around the world. Between 2010 and 2023, global fruit production increased by about 30%, reaching a total of 952 million metric tonnes in 2023. Bananas remained the most produced fruit in 2023, with watermelons as the second most produced fruit; apples ranked third, grapes fourth, and oranges fifth (FAOSTAT,2024). Recent estimates show that global grape production reached approximately 49.98 million metric tonnes. China was the top grape producer, accounting for about 18% of the global output, followed by Italy (9.2%), France (8.56%), the United States (7.39%), Spain (6.65%), and India (5.16%). India produced around 3.74 million metric tonnes, placing it sixth globally (FAO, APEDA Statistics, 2024). The country has continued to be a key exporter of fresh grapes in the international market. In 2023-24, India exported 343,982.34 MT of fresh grapes, earning $417.07 million USD in foreign exchange. Major export destinations include the Netherlands, U.K., the United Arab Emirates, Russia, and Bangladesh. Maharashtra leads India in both grape cultivation area and production, accounting for over 67% of the total and recording the highest productivity in the country. The Karnataka, Andhra Pradesh, Tamil Nadu, and Telangana states are other major grape-producing regions in India. Globally, fresh grape exports are growing because importing countries accept seasonal supplies from different growing regions. Despite

India's substantial production, its export potential remains underused because of volatile trade patterns, price fluctuations, and limited market access. As global demand for fresh and processed grapes increases, understanding export trends and market dynamics is essential for maximizing economic benefits, boosting farmers' incomes, and strengthening rural value chains. Government incentives and export promotion, especially for fresh grapes, play a vital role in driving rural economic growth. This paper investigates the instability and variability of fresh grape exports over the study period and provides insights into the probabilistic behavior and trade flow dynamics over time. By analyzing the transition probabilities between different export destinations, the study offers policymakers, exporters, and producers a deeper understanding of not only trade volumes but also the underlying market volatility, stability, and future trends in grape exports. Grape cultivation is a key part of global agricultural trade, supporting the wine industry, fresh fruit markets, and processed products. It is particularly important for growing economies, contributing to diverse dietary needs and serving as an ingredient in many processed foods like jam, jelly, raisins, and wine. India's extensive production base creates numerous export opportunities for farmers to increase income by exporting grapes and related products worldwide. Given the rising significance of grape exports in India's agricultural trade, this study aims to thoroughly analyze the country's export performance in the sector.

The following clearly stated goals serve as the foundation for the study:

a. To analyze historical trends in India's fresh grape exports.
b. To evaluate the level of volatility related to grape export operations.
c. To assess the direction of the fresh grape trade's flow across global marketplaces.
d. To produce projections for fresh grape exports' volume and value over the next five years.

2. LITERATURE REVIEW

Studies have shown that Markov chain analysis is useful for evaluating trade stability, and the fresh grape industry in India has experienced notable export growth. Chetia et al. (2022) used transition probabilities to analyse India's fresh grape exports from 1999 to 2019 and identify stable markets (like Bangladesh and the UK) and unstable ones (like the UAE and Russia). Their results highlight the necessity of focused export promotion in markets that are stable in order to reduce volatility.

According to Kiran and Sivakumar (2016), more than 60% of exports were concentrated in stable markets, which they classified as stable (Bangladesh, Netherlands) and unstable (UAE, Russia) for India's grape export markets from 2005 to 2015. Hazell and Hojjati (1995) talked on how farmers' income and export competitiveness are impacted by price volatility. More recently, Banik and Bhaumik (2020) looked into the reasons behind India's agri-export volatility and found that the main culprits were logistical inefficiencies and climate concerns. Particularly for perishable goods like grapes, export volatility might discourage international purchasers, impair contract stability, and lower foreign exchange gains. Predicting future trends and recognising stable and developing markets are made easier with an understanding of trade patterns. Research has used trade indices to examine India's export competitiveness in horticultural goods, such as Kumar and Sahu (2013). Although India has a comparative advantage in fruits like grapes and mangoes, they discovered that trade patterns are irregular and impacted by non-tariff obstacles. The influence of infrastructure, quality control, and market accessibility on India's fresh fruit export trends was also emphasised by Reddy et al. (2017).

A powerful technique for analysing the dynamic behaviour of export markets and estimating the likelihood of market retention and transition is Markov Chain analysis.The export competitiveness of Indian dairy products was evaluated by Birthal et al. (2006) using Markov Chain analysis; their methodology has been modified for a number of other agricultural commodities. In a similar vein, Kumar, Singh, and Kumar (2018) assessed the trade trajectory of Indian agricultural exports using Markov Chains, offering valuable information on market volatility and stability.

There are currently few studies on grapes. Nonetheless, Kachru et al. (2021) highlighted the necessity of commodity-specific analysis while analysing Indian fruit exports using Markov models. This method can be used to conduct a more targeted study on fresh grapes, which can yield more detailed information about India's export volatility and trade sustainability.

With Maharashtra accounting for more than 80% of overall production, in 2022, India ranked seventh globally in grape production, yielding approximately 3.4 million tonnes (NHB, 2022). Export consistency is still an issue in spite of production advances. Challenges such as pesticide residue issues, lack of cold chain infrastructure, and strict quality standards in major markets like the EU affect export performance (APEDA, 2022). Thus, analyzing market retention and trade flows through a Markov Chain framework can aid in identifying reliable trade partners and developing targeted policy interventions. To conclude, existing literature acknowledges the importance of trade pattern analysis and the role of Markov Chain models in assessing market dynamics. However, specific studies focusing on the Indian grape sector are sparse. This research aims to fill this gap by employing a Markov Chain-based assessment to understand export volatility and trade transitions in India's fresh grape exports, thereby informing strategies for market stability and growth.

3. MATERIALS AND METHODS

Source of Data

To address the research objectives, an extensive compilation of secondary data of fresh grape exports on the quantity exported and its value from India was collected for the period spanning 1987 to 2024. These data were collected from different authoritative governmental sources, including national trade and industry records, and export monitoring agencies. Key contributions were drawn from official export statistics maintained by the national commerce directorate and data disseminated by the agency responsible for promoting processed agricultural exports. Furthermore, supplementary information was incorporated from the Indian Horticulture Database, a publication issued by the central horticulture authority, thereby ensuring the robustness and completeness of the dataset.

Study Period Classification

To facilitate a more systematic and comprehensive evaluation, the overall study period was segmented into decadal intervals. This temporal classification allows for a comparative assessment of export growth trends, trade instability, and the reliability of forecasting outcomes across distinct time frames. The specific segmentation of the study research period is outlined in Table 1 as follows.

Table No. 1: Showing the Categorization of the Total Study Period

Sr. No	Details of Categorization	Duration of the Study Period
1	Study Duration-I	1987-1996
2	Study Duration-II	1997-2006
3	Study Duration-III	2007-2016
4	Study Duration-IV	2017-2024
5	Overall Study Duration	1987-2024

To elucidate the patterns and directional flow of fresh grape exports over the study duration, the entire study period spanning from 1994 to 2023 was systematically segmented into three distinct decades, thereby facilitating a comprehensive decade-wise analysis. Table No. 2 represents a decade-based classification of the study period.

Table No. 2 Decadal Segmentation of the Study Period

Sr. No	Details of Categorization	Duration of the Study Period
1	1st Decade	1994-2003
2	2nd Decade	2004-2013
3	3rd Decade	2014-2023

Statistical Techniques Used for Analysis

a. Linear Regression Technique: This technique was employed to estimate the trend in export data over the study period from 1987 to 2024. The formula used to calculate the R-squared value is

$$Y = a + bX$$

where:

Y (dependent variable): represents the export value at a given time.

a: intercept, which indicates the estimated export value when time (X) is zero. b:

slope, represents the average change in export value over time (X).

X (independent variable): represents the time variable.

b. Instability Index

Cuddy-Della Valle Index

The coefficient of variation measures instability but may overestimate its level in time series data. A statistical metric called the Cuddy-Della Valle Index (1978) detrends the coefficient of variation by the coefficient of determination and reveals the exact direction of data instability. Therefore, it is improved and predominantly used to evaluate the instability of time series data; it is particularly valuable in agricultural economics and trade for assessing volatility in exports while factoring out variations due to trends.

$$\text{Cuddy-Della Valle Index (CDVI)} = I = C.V.^* \sqrt{1 - \text{Adj. } R^2}$$

Where

I denote the Instability Index, expressed as a percentage.

C.V. represents the Coefficient of Variation (percent).

Adjusted R^2 refers to the adjusted coefficient of determination.

Coefficient of Variation (C.V.) = Standard Deviation/ Mean * 100

Interpretation of the Cuddy-Della Valle Index result (Range of Index) as follows

Low Instability = Values between 1 to 15

Medium Instability = Values between 16 to 30

High Instability = Values greater than 30

c. Markov Chain Analysis

The study of Markov chains is a "stochastic process" with Markov properties. Markov chain analysis is primarily employed to assess structural dynamics within a system, where its progression over time can be measured through a single outcome variable. While the Markov property merely creates dependency between consecutive periods, much like a chain, the phrase "Markov chain" refers to the series of random variables that flow via this process. Systems made up of interconnected events whose future changes are contingent only on the current state of the system can be modelled by the description tool.

Markov Chain analysis serves as an effective tool for analyzing both the directional flow and structural transformation of commodity export trade patterns over time (Mahadevaiah et al., 2005; Kusuma & Basavaraja, 2014; Aviluchan Chetia et al., 2022). In order to demonstrate the dynamic character of trade patterns in fresh grape export, the M.C.A. model was applied to analyse the profits and losses associated with the export of fresh grapes from India to key importing nations. The estimation of the transitional probability matrix (TPM), or P_{ij}, is central to Markov chain analysis. The chance that exports will move from the i^{th} country to the j^{th} country over time is indicated by the elements P_{ij} of matrix P (Dent, 1967) [1].

Three components make up the TPM: P_{ij} (row-wise), which shows the likelihood that exports will move from country "i" to country "j" over time. P_{ij} (column-wise) shows the likelihood that country "i" will export more than country "j" over time. The likelihood that a nation will maintain its market share is shown by the diagonal element P_{ij}, where i=j. In other words, the loyalty of an importing country to the exporting of another country's goods is represented by P_{ij}, where i = j.

This research is predicated on the idea that the average export of grape products from India to importing nations in any given period is solely dependent on exports in the preceding period, and that this dependency is constant across all periods. Major importing nations from India were chosen for the current analysis, which viewed structural change as a random process. Period-wise Markov chain analysis will be used. The following expression will be used to perform Markov chain analysis:

$$E_{jt} = \sum_{i=1}^{n} [E_{i(t-1)}] \times P_{ij} + e_{jt}$$

Where,

E_{jt} = Exports from India to the j[th] country in the year t; E_{it-1} = Exports from India to the i[th] country during the year t-1;

P_{ij} = Probability that the export will shift from i[th] country to j[th] country;

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

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 x r) matrix, have the following properties.

Where: $\sum_{i=1}^{n} P_{ij} = 1$ and $0 \leq P_{ij} \leq 1$

$\sum_{i=1}^{r} E_{ij} = 1\ P_{ij}$ for all i

Thus, the expected export shares of each country during Period "t" were obtained by multiplying the exports to these countries in the previous Period (t-1) with the transitional probability matrix. (Mohandas *et al.*, 2018)

Estimation of the P_{ij}:

The TPM with this property will be obtained by LP framework Minimum Absolute Deviations (MAD) using the R Statistical software package, which minimizes the sum of absolute deviations (Fisher, 1967; Wagner, 1959). Subsequently, the goodness of fit test will also be employed to test whether the observed shares of exports (actual) to different countries and the predicted shares follow a similar distribution. The conventional linear programming technique was used, as this satisfies the properties of transitional probabilities of non-negativity restrictions and row sum constraints in estimation. The linear programming formulation is stated as

Min OP* + Ie

Subject to,

XP* + V = Y

GP* = 1

P*e ≥ 0

Where,

"0 = vector of zeroes."

"P* = vector in which probabilities Pij are arranged".

"I = appropriately dimensional column vector of units". "e = vector of absolute error (|U|)."

"Y = proportion of exports to each country."

"X = block diagonal matrix of lagged values of Y." "V = vector of errors."

"G = grouping matrix to add the row elements of P as arranged in P* to unity".

(Analysis was done by using LINGO software)

d. Future projections for exports

Following the computation of the transition probability matrix, the projected export shares were determined using the established probabilistic framework.

"Y_{jt}= $\sum_{j=1}^{r} Y_{i(t-1)} \times P_{ij}$ (j = 1,2,3...r)"

Where,

Y_{jt} = "Predicted proportions of j[th] country's share at a time 't'".

Y_{t-1} = "Observed proportion of i[th] country share at time 't-1'"

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 20s, 2025
https://theaspd.com/index.php

P_{ij} = "Estimated transitional probability matrix".
Kiran and Sivakumar (2016) and Nithin (2016) employed the same methods to study the direction of fresh grapes export from India.

4. RESULTS & DISCUSSIONS

a. Linear regression analysis

Linear regression analysis was utilized to evaluate the strength and adequacy of the relationship between the independent variable (export year) and the dependent variables (export quantity and value of fresh grapes). The trendline and the R-squared (R2) value were estimated by fitting linear equations to both the exported quantity of fresh grapes and its value spanning the overall study period. Figures 1 and 2 illustrate the trends in the quantity and value of fresh grape exports, respectively. It was observed that the R-squared value estimated for the exports was 0.8668 and 0.7912 for the exported quantity of fresh grapes and its value, respectively. The result indicated that the regression model for quantity exported provides a stronger fit for predicting how the quantity of exports changes over time than the value of exports. The model is slightly less precise for value than for quantity, implying that other factors may be influencing the value of exports.

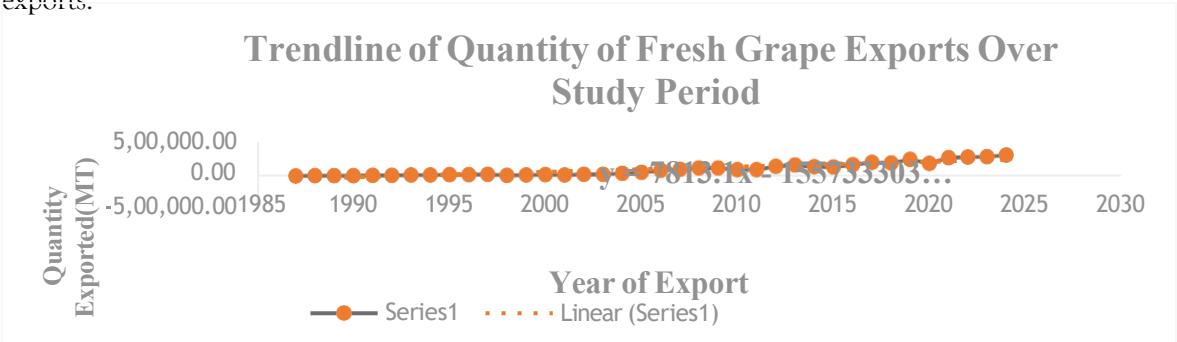

Figure 1: Trend line of Quantity of Fresh Grape Exports Over the Study Period

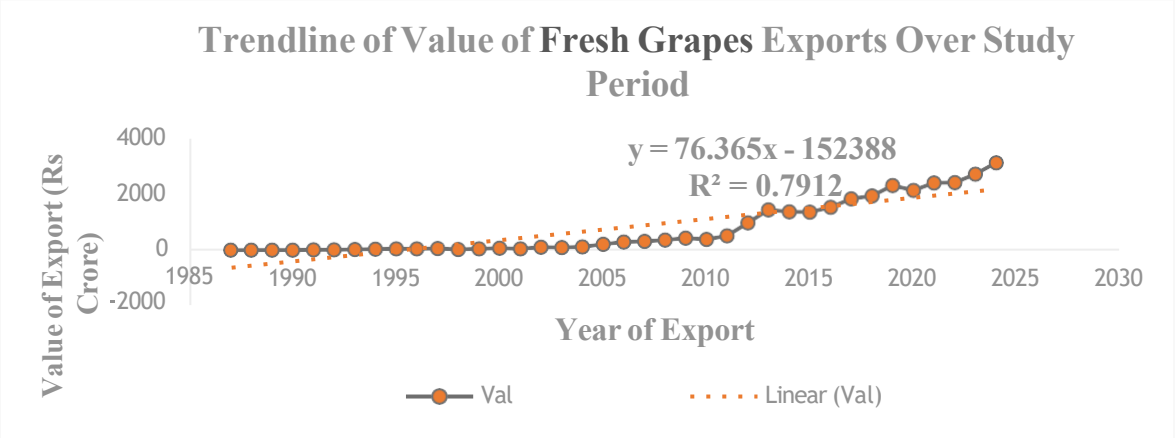

Figure 2: Trend line of Value of Fresh Grapes Exports Over the Study Period

b. Cuddy Della Valle Index

Table No. 3: Results of the CDVI On Export Instability Over the Study Period

Study Period	Results of Cuddy Della Valle Analysis	
	Quantity Exported	Value of Export
Study Duration-I	16	20
Study Duration-II	45	39
Study Duration-III	15	22
Study Duration-IV	11	7
Overall Study Period	36	58

Table No. 3 presents the results of the (CDVI) analysis for fresh grape exports from 1987 to 2024. From early-stage instability to current maturity and stability in both quantity and value, it shows a convincing pattern. Quantity changes were especially noticeable during Study Duration-II, which was the most volatile phase. Nonetheless, the entry into Study Duration-IV (2017–2024) reveals a CDVI that is historically low, indicating a robust and effective export system. The whole study period shows a greater CDVI for value (58%) than for quantity (36%), despite these gains. This highlights the fact that although export volumes may have stabilized, prices and economic returns have remained more susceptible to fluctuations in the global market. This disparity emphasizes the necessity of value chain actions to lessen export value volatility, such as branding, quality differentiation, or currency hedging. These results suggest that although trade policy, infrastructure development, and structural supply-side reforms have successfully stabilized production and export flows, in order to reduce export value volatility, focus must now be directed towards price stabilization mechanisms, product diversification, and market intelligence. In conclusion, the combination of the Markov Chain and CDVI provides a quantitative basis for evidence-based export planning and sustained competitiveness in the world fruit market. This research paper emphasizes how crucial it is to stabilize exports and expand it, in order to maintain agricultural trade performance and farmer income security.

c. Markov Chain Analysis results

By estimating the Transition Probability Matrix (TPM), the study demonstrated the dynamics in the international commerce of fresh grapes from India from 1994 to 2023, both in terms of the amount exported and its value. Examining the changing trajectory of fresh grape imports across nations becomes crucial considering the possible changes in preferences for international commerce in order to facilitate well-informed decision-making and the development of strategic policies (Kumar et al., 2007).

Table No. 4 through Table No. 9 present the Transition Probability Matrix for the amount and value of fresh grape exports across the chosen study period, decade by decade. Table No. 3 goes into greater detail about this, giving a summary of how India's fresh grape exports to key importers changed throughout the study. Within the Transition Probability Matrix (TPM), the row elements represent comparative trade loss indicators, indicating the degree to which a nation's export volume shifts to other markets.

To reflect possible increases in market share, the elements in the column show the probability of obtaining trade volumes from rival export markets. However, diagonal elements indicate the probability that a particular market would hold onto its share from the previous year, which is known as the likelihood of export volume retention. In 2019, Kandeeban and Mahendran appeared.

i. Markov Chain Analysis Results of Quantity Exported of Fresh Grapes 1st Decade from 1994 to 2003.

Table No. 4: Transition Probability Matrix of Quantity Exported of Fresh Grapes for the 1st Decade from 1994-2003.

	U K	United Arab Emirates	Bangladesh Pr	Netherland	Germany	Saudi Arab	Sri Lanka Dsr	Belgium	Netherlandantil	All Other Countries
U K	**0.60**	0.25	0.06	0.00	0.00	0.03	0.00	0.00	0.00	0.06
United Arab Emts	0.29	**0.27**	0.00	0.32	0.03	0.00	0.07	0.02	0.00	0.00
Banglad esh Pr	0.52	0.03	**0.43**	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Netherla nd	0.00	0.00	0.34	**0.20**	0.06	0.00	0.03	0.00	0.00	0.37
German y	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	1
Saudi Arab	0.07	0.00	0.00	0.00	0.00	**0.35**	0.00	0.49	0.00	0.00

Sri- Lanka Dsr	0.0	0.0	0.0	0.0	0.19	0.0	**0.26**	0.0	0.55	0.0
Belgium	0.4	0.00	0.00	0.6	0.00	0.00	0.00	**0.00**	0.00	0.00
Netherla ndantil	0.0 0	0.00	0.00	0.37	0.00	0.00	0.09	0.00	**0.00**	0.54
All Other Countrie s	0.00	0.9	0.00	0.00	0.05	0.00	0.05	0.00	0.00	**0.00**

According to Table No. 4, the Transition Probability Matrix of fresh grape export volumes from 1994 to 2003 shows a worldwide interconnected trade system with unique hierarchical structures. With a self-transition probability of 60%, the UK had the highest retention rate of any large destination. It continued to have a generally stable export relationship over the course of the decade under observation, making it a dependable importing destination.

Following this, Bangladesh and Saudi Arabia showed moderate self-transition values of 43% and 35%, respectively, indicating a fair degree of export consistency. In contrast, Germany, Belgium, the Netherlands, and All Other Countries recorded an export retention probability of 0.00, signaling a complete absence of repeated exports in consecutive periods. This reflects unstable markets, implying either a one-time export occurrence or a market exit. Notably, Germany's entire export volume seems to have been absorbed by other destinations over time, as indicated by a transition probability of 1.00 directed toward All Other Countries, suggesting a potential reclassification or dispersal of trade. The United Arab Emirates (UAE) served a significant role as both a receiver and a transitional node, with substantial probabilities distributed across multiple destinations: 29% of its exports shifted to the UK, 32% to the Netherlands, and 27% remained within the UAE, indicating diversified trade behavior and possible re-export activities. Sri Lanka, while having a modest self-transition rate of 26%, redirected over half of its export volume (0.55) to the Netherlands Antilles, suggesting a possible redirection of supply chains or secondary trade routes. The Netherlands Antilles displayed a dual function as both a terminal and an intermediary market, with 54% of its exports transitioning to "All Other Countries" and 37% to the Netherlands. This pattern could illustrate a changing regional hub function or fluctuations in demand consolidation.

Table No. 5: Transition Probability Matrix of the Value of Export of Fresh Grapes for the 1st Decade from 1994-2003.

	U K	**U Arab Emir ates**	**Neth erlan d**	**Bangla desh Pr**	**Germ any**	**Nether landan til**	**Sri Lan ka Dsr**	**Sau di Ara b**	**Belgi um**	**All Other Countri es**
U K	**0.59**	0.31	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.07
U Arab Emirates	0.29	**0.2**	0.44	0.00	0.01	0.00	0.01	0.04	0.01	0.00
Netherland	0.58	0.00	**0.00**	0.02	0.06	0.00	0.02	0.00	0.00	0.32
Bangladesh Pr	0.47	0.04	0.00	**0.38**	0.00	0.00	0.00	0.11	0.00	0.00
Germany	0.00	0.00	1	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00
Netherland antil	0.00	0.00	0.53	0.00	0.00	**0.25**	0.01	0.00	0.13	0.08
Sri Lanka Dsr	0.0	0.0	0.0	0.0	0.0	0.38	**0.62**	0.0	0.0	0.0
Saudi Arab	0.00	0.08	0.00	0.00	0.00	0.00	0.00	**0.16**	0.76	0.00
Belgium	0.48	0	0.42	0.00	0.1	0.00	0.00	0.00	**0.00**	0.00

All Other Countries	0.22	0.52	0.00	0.00	0.2	0.00	0.06	0.00	0.00	**0.00**

Table No. 5 represents the Transition Probability Matrix of the Value of Export of Fresh Grapes for the 1st Decade from 1994-2003. From the table, it was revealed that Sri Lanka Dsr, United Kingdom, and Bangladesh Pr demonstrated high export value retention in import trade, with the probability of export value retention of 62%, 59%, and 38% respectively, indicating markets with reliable import behavior showing significant portions of export value suggesting demand-driven market maturity. In contrast, the Netherlands, Germany, Belgium, and the category designated as 'All Other Countries' exhibited a zero probability of export value retention, indicating that these destinations functioned as the most volatile import markets during the decade. The discontinuity in export value to these regions can likely be ascribed to intensified global competition or alterations in logistical frameworks that have influenced the distribution and trade dynamics of Indian fresh grapes.

Table No.6: Transition Probability Matrix of Quantity Exported of Fresh Grapes for the 2nd Decade from 2004-2013.

	Bangladesh Pr	**Netherland**	**U K**	**U Arab Emirates**	**Russia**	**Nepal**	**Saudi Arab**	**Germany**	**Belgium**	**All Other Countries**
Bangladesh Pr	**0.71**	0.04	0.02	0.14	0.00	0.06	0.02	0.00	0.00	0.01
Netherland	0.02	**0.94**	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00
U K	0.20	0.00	**0.31**	0.09	0.00	0.04	0.00	0.14	0.22	0.00
U Arab Emirates	0.00	0.22	0.69	**0.08**	0.00	0.00	0.00	0.01	0.00	0.00
Russia	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00	0.00
Nepal	0.00	0.00	0.00	0.56	0.00	**0.00**	0.21	0.00	0.00	0.23
Saudi Arab	0.00	0.00	0.00	0.00	0.00	0.00	**0.32**	0.00	0.00	0.68
Germany	0.75	0.00	0.00	0.25	0.00	0.00	0.00	**0.00**	0.00	0.00
Belgium	0.93	0.00	0.00	0.00	0.00	0.07	0.00	0.00	**0.00**	0.00
All Other Countries	0.00	0.00	0.00	0.00	0.28	0.00	0.04	0.00	0.00	**0.69**

Estimation of Transition Probability Matrix for Quantity Exported of Fresh Grapes in 2nd Decade from 2004-2013 depicted in table no. 6. Analysis reveals a two-tier global trade structure, one dominated by absorbing states like Russia, Netherlands, and Bangladesh, and the other by transit economies such as the UK, UAE, and Saudi Arabia. Countries like Russia, the Netherlands, and Bangladesh serve as stable, absorbing endpoints of the export chain. Russia, with a 100% probability of retention of export of fresh grapes, becomes a loyal export destination. Grapes entering Russia are not exported further. This aligns with its large internal market, import substitution trends, or regulatory structure restricting re-export. Also, the Netherlands, with 94% retention of trade quantity, becomes a stable market and functions as a terminal state, meaning a country where grapes were either consumed domestically or processed without traceable onward export. This suggests strong internal market demand, stable importer status, or bottleneck absorption. Bangladesh, with a retention probability of 71% of trade volume, acted as a strong domestic market with notable exports redirected toward Middle Eastern and South Asian partners. This signals a regional distribution role and possible influence of re-export networks or bilateral trade logistics. Nepal, Germany, and Belgium, with 0% transition probability value, reveal an unstable market. These countries are pass-through economies with a tight, bilateral export flow, lacking a robust internal grape market. Functions as a logistics bridge between the origin node rather than a grape-consuming economy.

Table No.7: Transition Probability Matrix of Value of Export of Fresh Grapes for the 2nd Decade from 2004-2013.

	Netherland	U K	U Arab Emirates	Bangladesh Pr	Russia	Saudi Arab	Thailand	Belgium	Sweden	All Other Countries
Netherland	**0.37**	0.00	0.12	0.29	0.00	0.04	0.01	0.02	0.00	0.15
U K	0.31	**0.45**	0.07	0.00	0.00	0.00	0.00	0.17	0.00	0.00
U Arab Emirates	0.00	0.70	**0.30**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bangladesh Pr	0.79	0.10	0.00	**0.00**	0.00	0.10	0.00	0.00	0.00	0.01
Russia	0.00	0.00	0.00	0.00	**0.78**	0.00	0.00	0.00	0.00	0.22
Saudi Arab	0.00	0.00	0.00	0.00	0.35	**0.11**	0.52	0.00	0.02	0.00
Thailand	0.00	0.00	0.00	0.00	0.00	0.00	**0.22**	0.00	0.78	0.00
Belgium	0.56	0.00	0.06	0.34	0.00	0.04	0.00	**0.00**	0.00	0.00
Sweden	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	**0.00**	0.00
All Other Countries	0.35	0.00	0.17	0.00	0.04	0.00	0.00	0.00	0.00	**0.44**

The findings presented in Table No. 7 reflect the Transition Probabilities of export value data of fresh grapes from India. This matrix offers a comprehensive representation of the directional shifts in export flows during the second decade of the study period (2004–2013). The primary destinations for Indian fresh grape exports during this period included the Netherlands, the United Kingdom, the United Arab Emirates, Bangladesh, Russia, Saudi Arabia, Thailand, Belgium, and Sweden. An examination of the transition probabilities reveals that Russia, the United Kingdom, and the Netherlands exhibited the highest levels of market retention with rates of 78%, 45%, and 37% of export trade share over the entire decade for fresh grape exports, thereby emerging as the most stable and consistent importers of Indian fresh grapes throughout the decade under review. This indicates the presence of dependable and mature trade relationships with India, which allows exporters and policymakers to recalibrate trade channels for maximum economic benefit and long-term resilience. Bangladesh, Belgium, and Sweden are identified as the most unstable export markets, showing a 0% transition probability of retention for fresh grape exports throughout the study period. These countries act primarily as major re-exporters or value-passers. Their low retention implies that grapes routed through these countries serve larger, more developed consumption markets, highlighting their role as a logistics hub rather than a final market.

Table No. 8: Transition Probability Matrix of Quantity Exported of Fresh Grapes for the 3rd Decade from 2014-2023.

	Netherland	Bangladesh Pr	Russia	U K	U Arab Emirates	Nepal	Germany	Saudi Arab	Thailand	All Other Countries
Netherland	**0.24**	0.14	0.10	0.01	0.14	0.00	0.06	0.05	0.01	0.25
Bangladesh Pr	0.27	**0.33**	0.00	0.00	0.06	0.19	0.00	0.01	0.00	0.14
Russia	0.75	0.00	**0.00**	0.08	0.00	0.00	0.00	0.17	0.00	0.00

U K	0.81	0.00	0.00	**0.06**	0.00	0.00	0.00	0.00	0.13	0.00
U Arab Emirates	0.33	0.00	0.00	0.21	**0.20**	0.25	0.00	0.00	0.01	0.00
Nepal	0.00	1.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Germany	0.00	0.00	0.40	0.00	0.00	0.00	**0.44**	0.00	0.00	0.16
Saudi Arab	0.02	0.28	0.63	0.00	0.00	0.07	0.00	**0.00**	0.00	0.00
Thailand	0.00	0.00	0.88	0.12	0.00	0.00	0.00	0.00	**0.00**	0.00
All Other Countries	0.00	0.58	0.00	0.24	0.00	0.00	0.00	0.00	0.00	**0.18**

Table No. 8 displays the Transition Probability Matrix outcomes, derived from the analysis of fresh grape export quantities during the most recent decade (2014–2023), capturing the dynamic shifts in export destinations over time. It was found that Germany was the most loyal importer, with 44 percent of the market, followed by Bangladesh (33 percent), the Netherlands (23 percent), and the United Arab Emirates (20 percent), in the export market retained for Indian fresh grapes from the previous year. Diagonal transition probabilities of 0.06 for the United Kingdom and 0.18 for all other countries denote marginal levels of export persistence, signaling that these destinations retain only a minor proportion of India's fresh grape exports across periods. Such low retention levels underscore the transitory or fluctuating nature of these markets, necessitating targeted interventions to enhance stability or strategic reallocation to more reliable partners. Russia, Nepal, Saudi Arabia, and Thailand were identified as the most unstable import markets, as they exhibited zero retention of fresh grape export share from India in the subsequent period. A zero diagonal value highlights the non-persistence of that particular market within the observed export cycle and flags it as a potentially unreliable or transitional trading partner.

Table No. 9: Transition Probability Matrix of Value of Export of Fresh Grapes for the 3rd Decade from 2014-2023.

	Netherland	**Russia**	**UK**	**Bangladesh Pr**	**U Arab Emts**	**Germany**	**Saudi Arab**	**Thailand**	**Hong Kong**	**All Other Countries**
Netherland	**0.55**	0.00	0.00	0.00	0.07	0.00	0.05	0.02	0.03	0.28
Russia	0.23	**0.34**	0.10	0.00	0.00	0.20	0.13	0.00	0.00	0.00
U K	0.72	0.08	**0.00**	0.00	0.09	0.00	0.00	0.12	0.00	0.00
Bangladesh Pr	0.43	0.00	0.00	**0.14**	0.16	0.00	0.00	0.00	0.00	0.28
U Arab Emts	0.29	0.00	0.44	0.00	**0.27**	0.00	0.00	0.00	0.00	0.00
Germany	0.00	0.46	0.00	0.00	0.00	**0.38**	0.01	0.00	0.14	0.02
Saudi Arab	0.17	0.83	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00
Thailand	0.00	0.00	0.59	0.00	0.00	0.33	0.00	**0.08**	0.00	0.00
Hong Kong	0.56	0.00	0.44	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00

All Other Countries	0.00	0.00	0.24	0.47	0.00	0.00	0.00	0.00	0.00	**0.29**

The findings derived for the (TPM), developed through Markov chain analysis, reflect dynamics in the value of fresh grape exports from India over the third decade (2014–2023) as shown in Table No. 9. These results, highlight those countries that demonstrated notable levels of export value retention. Specifically, the Netherlands accounted for a retention probability of export value of 55%, Russia for 34%, and Germany for 38%. These values signify that a considerable portion of India's export value to these destinations persisted across multiple periods during the study timeframe. Such outcomes underscore the presence of relatively stable trade relationships, underpinned by consistent import demand, and suggest the existence of reliable and sustained market engagement with these countries. The United Arab Emirates, though having a diagonal value of 27%, also shows significant transition to the United Kingdom (44%) and Netherlands (29%), suggesting redistribution or re-export dynamics. Bangladesh, with a self-transition probability of only 14%, redirects a substantial portion of export value to the Netherlands (43%) and the United Arab Emirates (16%), indicating its role as a transitional hub or a volatile importer. All Other Countries exhibit a diverse transition pattern, notably sending value to Bangladesh (47%) and the United Kingdom (24%), suggesting that smaller markets consolidate toward more dominant destinations over time. Countries like the United Kingdom (0%), Saudi Arabia (0%), and Hong Kong (0%) recorded zero percent self-transition probabilities, highlighting a complete absence of sustained trade value in the subsequent periods. This suggests market exit, redirection of trade flows, or substantial volatility.

d. Future prediction for fresh grape exports

Table No. 10 presents the projected fresh grapes export volumes from India to key international destinations for the next five-year duration from 2025 to 2030. These forecasts are generated depending on a Transition Probability Matrix derived by the application of the Markov Chain technique over the past decade of export data of fresh grapes, specifically from 2014 to 2024, which uses historical export transition probabilities to estimate future export behavior. The projections illustrate anticipated patterns in trade continuity, market expansion, and shifts in destination-specific demand.

Table No. 10. Projection of Fresh Grape Export to Most Favored Nations From 2025 to 2030.

Year	Netherlands	Bangladesh Pr	Russia	U K	U Arab Emts	Nepal	Germany	Saudi Arab	Thailand	All Other Countries
2025	83235.77	77832.31	20334.12	17285.88	24712.75	20315.52	8516.01	10196.93	3630.23	44365.64
2026	77847.93	85969.40	21781.44	20020.05	21318.88	21326.83	8509.00	8429.27	3528.83	41693.51
2027	80908.08	86852.86	20010.04	18872.05	20411.61	21886.59	8199.07	8446.54	3772.27	41066.03
2028	79310.52	87774.32	20430.91	18390.63	20702.03	21829.32	8236.18	8305.84	3647.96	41797.42
2029	79203.02	88177.83	20080.41	18591.91	20601.05	22063.01	8161.62	8300.23	3571.26	41674.78
2030	79152.60	88456.05	19968.26	18516.67	20591.52	22113.07	8122.50	8236.07	3594.56	41673.82

The Netherlands and Bangladesh are dominant and growing markets likely to be the most prominent export destinations throughout the forecast period. Although a slight fluctuation is observed in the Netherlands' projections (from 83,235.77 metric tonnes in 2025 to 79,152.60 in 2030), the volumes remain consistently high, suggesting sustained demand and established trade linkages. In contrast, Bangladesh demonstrates a steadily increasing trend, rising from 77,832.31 metric tonnes in 2025 to 88,456.05 in 2030. This growth reflects the country's expanding role as a strategic consumer of Indian

fresh grapes and may imply strengthening trade relations or rising domestic consumption. Russia, the United Kingdom, and the U.A.E. represent moderately significant markets with relatively stable projected volumes. Russia's forecasted import volume hovers around 20,000 metric tonnes, with minor annual variations. The UK's projected figures increase slightly until 2026 and then stabilize at around 18,500 metric tonnes. The UAE shows a mild decrease in exports, from 24,712.75 metric tonnes in 2025 to 20,591.52 in 2030, suggesting a potential saturation or shift in sourcing behavior. Smaller but consistently active markets such as Nepal, Germany, Saudi Arabia, and Thailand continue to reflect steady demand and are reflected as Emerging and Niche Markets. Nepal's export volume steadily increases from 20,315.52 metric tonnes in 2025 to 22,113.07 in 2030, reinforcing its position as a reliable and growing market. Similarly, minor fluctuations in Germany, Saudi Arabia, and Thailand's predicted imports indicate market persistence, albeit at a smaller scale compared to primary destinations. The collective category of"All Other Countries" shows a gradual decline in export volume from 44,365.64 metric tonnes in 2025 to 41,673.82 in 2030. This may reflect a consolidation of India's grape exports into more dominant and predictable markets or a realignment of trade priorities. Nonetheless, the sustained presence of this group suggests that diversification remains a feature of India's export portfolio.

5. CONCLUSION

The sector's rising trend and its capacity for accurate forecasting are supported by the regression results, which show a robust linear increase in fresh grape exports, particularly in quantity. The CDVI results showed that, during the whole study period, export value was more unstable than export quantity. It implies that even while export volume consistency has recently improved, the industry is still quite vulnerable to changes in prices and the dynamics of the external market. The ongoing fluctuations in export revenue highlight the necessity of calculated actions to reduce market risks and improve value chain stability. Results from the full research period's Markov chain analysis highlight the important choices for strategic export planning.

Finding trustworthy marketplaces, comprehending shifting trade routes, and spotting chances to fortify bilateral trade agreements or market penetration tactics in unstable areas have all benefited from it. For long-term participation, it is recommended that markets with high retention probabilities be given priority, and that funds be allocated to trade facilitation initiatives and quality standards. In international trade, destinations exhibiting low or no market retention may require targeted strategies to enhance penetration or may be deprioritized in favour of more stable and consistent markets. Although there is evidence of diversification into secondary markets, the projected export trends indicate that India will continue to maintain strong export ties with long-standing partners like the Netherlands, Bangladesh, and the United Arab Emirates.

These forecasts will give exporters and governments an evidence-based framework for determining new export diversification opportunities, streamlining supply chains, and prioritising market-specific investments. Future trade plans should take market stability and volume potential into account to guarantee the fresh grape export industry's long-term viability.

REFERENCES

1. Agricultural and Processed Food Products Export Development Authority. (2022). *Agri Exchange portal: Export of fresh grapes from India*. https://agriexchange.apeda.gov.in
2. Agricultural and Processed Food Products Export Development Authority. (2024). *Grape profile*. https://apeda.gov.in/Grapes
3. Aviluchan Chetia, Chavan, R. V., & Bharati, S. V. (2022). Export profile and trade direction of fresh grapes from India: A Markov chain approach. *The Pharma Innovation Journal*, *11*(12), 1831–1836. https://www.thepharmajournal.com/archives/2022/vol11issue12/PartW/11-12-200-700.pdf
4. Banik, N., & Bhaumik, S. (2020). Agri-export volatility in India: Determinants and implications. *Journal of Development Studies*, *56*(5), 895–912. https://doi.org/10.1080/00220388.2019.1577382
5. Birthal, P. S., Joshi, P. K., Roy, D., & Thorat, A. (2006). *Diversification in Indian agriculture toward high-value crops: The role of smallholders* (IFPRI Discussion Paper No. 00727). International Food Policy Research Institute.
6. Dent, W. T. (1967). Applications of Markov analysis to international wool flows. *The Review of Economics and Statistics*, *49*(4), 613–616. https://www.jstor.org/stable/1928354
7. Food and Agriculture Organization of the United Nations. (2024). *FAOSTAT: Production – Crops and livestock products*. https://www.fao.org/faostat/en/#data/QCL

8. Fisher, W. D. (1961). Note on curve fitting with minimum deviations by linear programming. *Journal of the American Statistical Association*, *56*(296), 359–363. https://doi.org/10.1080/01621459.1961.10482119
9. Hazell, P. B. R., & Hojjati, B. (1995). Farm/non-farm linkages in rural Sub-Saharan Africa: Evidence from Kenya and Nigeria. *Journal of African Economies*, *4*(3), 481–508.
10. Kachru, R. P., Dey, K., & Singh, R. K. (2021). Analysis of Indian fruit exports using Markov chain approach. *Agricultural Economics Research Review*, *34*(1), 75–84. https://doi.org/10.5958/0974-0279.2021.00010.6
11. Kandeeban, M., & Mahendran, K. (2019). A study on the export direction of Indian cashew kernels: A Markov chain approach. *International Journal of Farm Sciences*, *9*(3), 81–84. https://doi.org/10.5958/2250-0499.2019.00077.6
12. Kiran, R., & Sivakumar, S. D. (2016). The direction of trade analysis of Indian grapes. *International Journal of Business Management & Research*, *6*(3), 93–96. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2838781
13. Kumar, P., Badal, P. S., & Achoth, L. (2007). Changing direction of Indian mango exports. *Indian Journal of Agricultural Marketing*, *21*(1), 130–137.
14. Kumar, A., & Sahu, N. C. (2013). Export performance of India's horticultural products: An empirical analysis. *Indian Journal of Agricultural Economics*, *68*(3), 398–410.
15. Kumar, A., Singh, K. M., & Kumar, S. (2018). Export performance of Indian agricultural products: A Markov chain analysis. *Economic Affairs*, *63*(1), 131–138. https://doi.org/10.30954/0424-2513.2018.00160.5
16. Kusuma, D. K., & Basavaraja, H. (2014). Stability analysis of mango export markets of India: A Markov chain approach. *Karnataka Journal of Agricultural Sciences*, *27*(1), 36–39. http://14.139.155.167/test5/index.php/kjas/article/viewFile/7081/7299
17. Mahadevaiah, G. S., Ravi, P. C., & Chengappa, P. G. (2005). Stability analysis of raw cotton export markets of India: A Markov chain approach. *Agricultural Economics Research Review*, *18*(2), 253–259. https://ageconsearch.umn.edu/record/58475/
18. Mohandas, K., Indhusree, A., & Kuruvila, A. (2018). Exports of vegetables from India: An economic analysis. *Journal of Tropical Agriculture*, *56*(1), 34–44.
19. Myneni, Y., Pokharkar, V. G., & Karthik, H. P. (2020). Stability analysis of Indian cotton: A Markov chain approach. *Journal of Pharmacognosy and Phytochemistry*, *9*(4), 406–408.
20. Nithin, K. N. (2016). Production and export performance of grapes from India: An econometric analysis. *Research Journal of Agricultural Sciences*, *7*(Special), 143–146.
21. National Accounts Statistics. (2024). *National accounts datasets*. Directorate General of Commerce, Industries and Statistics, Government of India.
22. National Horticulture Board. (2022). *Horticultural statistics at a glance*. Government of India. http://nhb.gov.in
23. Wagner, H. H. (1959). Linear programming for regression analysis. *Journal of the American Statistical Association*, *54*(285), 206–212. https://doi.org/10.1080/01621459.1959.10501506