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STABILITY ANALYSIS OF INDIA'S MANGO EXPORT MARKETS WITH DIFFERENT WEATHER CONDITIONS USING MACHINE LEARNING MODELS

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ABSTRACT:
This study examines the quantity and average value of food production, as well as the stability of mango export markets of India. To estimate yield, a novel approach Simpson's 1/3 rule model is presented at various variety levels. A new novel Machine learning (ML) model was used to estimated mango export of Indain market from 2026–2050, and also examined impact of climate change, how the export volume and mango production is increased in India. A standard econometric technique: Markov Chain, Compound Annual Growth Rate and Minimization of Mean Absolute Deviation analysis were compared with Machine learning -Empirical Mode Decomposition model to forecast India's fresh mango exports from 2026–2050. The findings suggest that mango production and export volume would increase if rising temperatures, water availability. The economic analysis indicates that global environmental changes positively impact mango production. Secondary data were collected from the India Meteorological Department (IMD), National Horticulture Board, APEDA - agriXchange, and Indiastat.

KEYWORDS: Markov Chain Analysis, ARIMA model, mango export across time, yield prediction, Simpson 1/3 rule model, Machine learning model.

INTRODUCTION

Due to the population explosion, there exists a gap between supply and demand. The agricultural sector is striving hard to provide food security for the existing and growing population around the world. According to the FAO, around 821 million people, or one in nine, are estimated to experience food insecurity. Over the last three decades, mango production has doubled worldwide. Asia remains the top producer of mangoes in both quantity and variety due to its favorable climate, accounting for 77% of total production, followed by the Americas (13%) and Africa (10%). In India, mango is considered the king of fruits, producing and catering to roughly 50% of the world's demand. India leads other competing countries in Asia, such as Pakistan, China, and Thailand. In the Americas, Mexico and Brazil are the largest producers of mangoes. In many developing countries, like India, the agricultural and trade sectors have contributed insignificantly to overall economic activity and both total output and employment.

Mango production in India ranged from 7.74 MT/ha in 2015–16 to 7.27 MT/ha in 2016–17, 8.09 MT/ha in 2017–18, and 12.75 MT/ha in 2019–20. Over the next ten years, it is estimated that 2309 acres of cultivable land will be dedicated to mango farming. Mango is one of the most significant fruit crops grown and exported from India. The UAE, Saudi Arabia, Qatar, Bahrain, the United Kingdom, Kuwait, Singapore, Malaysia, and Bangladesh collectively receive 97% of India's fresh mangoes. The area planted with mango trees has shown growth over the last ten years. In this paper, we introduced Simpson's 1/3 rule-based model to estimate mango yield and the Machine Learning-Empirical Mode Decomposition (EMD) method to forecast mango exports from 2024 to 2050. This shows that mango exports will increase globally by 3%–7%.

Thakor (2019) discussed that India exports mangoes to more than 33 countries worldwide. Mango exports increased from 37,109 M.T. in 2000-01 to 58,863 M.T. in 2010-11, with a value of Rs. 16,481 lakhs in 2010-11. The overall volume of fruit exports varies yearly due to seasonal conditions and the crop's unpredictable bearing pattern. The average mango trade over the last five years was approximately 53,500 tonnes. At the farm gate, the gross value of production (GVP) is estimated to be about $140 million annually. Despite being the world's top mango producer, India exports only a small portion of its total mango production, fluctuating between 0.19% and 0.66% from 2006-07 to 2015-16. The top six export destinations for Indian mangoes are the UAE (38.33%), Bangladesh (33.78%), the Netherlands (7.72%), the UK (4.02%), Saudi Arabia (2.92%), and Kuwait (2.02%). Bangladesh has been a reliable export market, maintaining an initial share of 82.32% over the period from 2006-07 to 2015-16. The UAE is the second most stable market, with a retention rate of 63.45%.

Although India produces more than 40% of the world's mangoes, its share of the global market is relatively small. In 2000, India's share was 3.96% in value and 5.97% in volume. By 2010, this had changed to 4.36% in volume and 3.11% in value. There is significant potential to increase mango exports from India. Thakor recommended improving advanced facilities in production zones and adding vapor heat treatment machines, irradiation units, and ripening chambers. Absolutely, more research is essential to bridge the gap. Understanding the challenges and opportunities in mango production and export can help develop better strategies and technologies. This can lead to improved yields, enhanced quality, and increased export potential.

N. Devi et al. (2019) explored the growth dimensions, instability, sources of growth, and variability in the export of mangoes and mango pulp to major importing countries. The study analyzed 30 years of secondary data on the volume and value of these exports from India to predict future trends. According to the findings, Kuwait and the UAE were the most reliable markets for fresh mangoes, while Saudi Arabia, the UAE, and the Netherlands were the most dependable for mango pulp. Bangladesh maintained a 34.48% export share with a moderate retention probability of 0.3448. In contrast, the UAE, Saudi Arabia, the UK, and Kuwait experienced declines in their shares by 3.45%, 10.34%, and 13.79%, respectively. This indicates that these countries were the most reliable importers of Indian mangoes, despite some nations importing less but still holding 33.33% of the total market.

Mendelsohn et al. (2001) discussed how economies can manage climate sensitivities through available technology and better adoption adjustments. In contrast, developing economies are more climate-sensitive and rely on labor-intensive technologies. Kurukulasuriya et al. (2008) examined the impact of climate change on agriculture, noting that additional warming due to high greenhouse gas emissions would benefit temperate zones while tropical regions would suffer. Agricultural productivity and yield can be adversely affected by various climate factors, including temperature variability, changes in sowing and harvesting dates, rainfall patterns, land suitability, and water availability. These changes can create problems for agriculture, impacting crops, insects, livestock health, weeds, diseases, and soil erosion. For instance, increasing extreme weather events have affected mango production in Cambodia, Pakistan, China, and the Philippines.

In an experiment, the mean leaf size of trees grown at 30/25°C (day/night temperature) was 300% greater than that of trees grown at 20/15°C (Whiley et al., 1989). However, another group of scientists did not observe any significant effect of temperature on leaf size for leaves developed within the mean daily temperature range of 20-28°C (Dambreville et al., 2013). Drought and flooding negatively affect the vegetative development of mango trees by reducing tree growth. Rising temperatures, however, could positively impact mango fruit growth. In Australia, the estimated duration of mango fruit development decreased by 12-16 days (7-8%) due to a 1.5°C increase in winter temperatures over the last 45 years (T. Olesen, 2011). Higher temperatures may benefit fruit quality by inducing stress that helps synthesize secondary compounds, which can increase nutritional value. However, high temperatures also cause physiological changes within the mango fruit.

Kavita Balyan et al. (2022) discussed the increasing integration of global markets and suggested several changes in the export of fresh mangoes. The acceptance of consignments by importing nations, which have established legally validated systems for the safe import of food commodities, ultimately determines the exporters' income. The Indian system has struggled with tolerance control in foreign markets to address these shifts. Time series data from 1987 to 2020 were evaluated to visualize the necessity of distinguishing and quantifying the quantity and value direction of fresh mango exports. The analysis indicated that area growth, rather than productivity, primarily drives the domestic mango supply. High importer SPS (Sanitary and Phytosanitary) criteria have increased the cost of complying with safe export regulations, making it challenging for Indian exporters to meet these standards.\

In this article, the compound annual growth rate was predicted using the Cuddy Della Valle Index (I) approach. Subsequently, the growth rate of value was used to forecast premium commodities, which are highly sought after in international markets. As a result, several nations have raised their food safety standards in response to customer preferences, brand image protection, and stringent food legislation (Aarthi et al., 2012). Technological, institutional, and policy changes are responsible for the instability of mango exports. Upgrading storage, export, and quality facilities in this area is essential.

Asia has had an average yearly temperature increase of 0.5°C over the previous few decades. While Lobell et al. (2008) confirmed that by 2050, yield in central and south Asia could fall by 30% due to climate change, the IPCC, 2007a, said that agricultural crop yields could decline as a result of global warming. The World Bank's assessment of the Ministry of Agriculture states that although India is the world's greatest producer of fruits and vegetables, its export performance is poor because of high transportation costs, a disjointed supply chain, inadequate logistics, and lower quality standards. India continues to export 0.5% of the world's fruits and 1.7% of the world's veggies. Since multinational corporations will dominate the domestic market and import high-quality goods at competitive prices from other countries, this manuscript will help fill the gap and compete domestically in the future. The inability to compete internationally in the export of fresh mango is a global necessity.

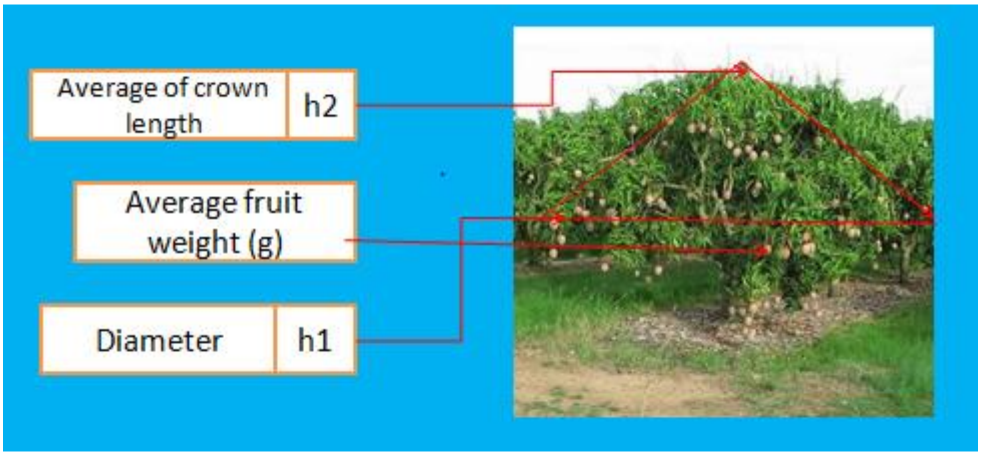
The study is divided into five sections: Section 2 covers the methodology; Section 3 covers the forecasting analysis; Section 4 covers the results and discussion; and Section 5 provides a conclusion.

2. METHODOLOGY

This section examines the export of mangoes from India, using time series secondary data on area, production, value, and predictivity from 1987–1988 to 2023–2024. Through the National Horticultural Board, APEDA-agriXchange, and IMD, the necessary data was obtained. The present study employed Markov chain analysis and yield estimation to investigate the composition of agricultural exports.

2.1. Simpson's 1/3 rule based yield estimation

Individual mango tree yield is calculated by modified Simpson's 1/3 rule with integrated fruit weight and entire tree height:



$$Yield\ per\ tree = \frac{h}{100}\int_{h_1}^{h_2}[(r.\log_1 + r.\log_n) + 2(r.\log_2 + r.\log_4 + r.\log_5 + ---) + 2(\mathrm{r.log}_3 + r.\log_6 + \cdots)]\mathrm{dh}$$

where h_1 is tree stem height(feet) and h_2 is crown length (feet) that is greater than h_1, h is maximum weight of single fruit, r.log1 is first picking average fruit weight, r.logn is last picking average fruit weight and $\log_{2,3,\ldots\ldots}$ is remaining picking fruit weight.

Compound Annual Growth Rate Analysis

Growth rate in export of mango products to differenttrade destinations by India for a period of 30 years

$$Y_t = AB^t V_t \qquad (1)$$

Where, Y_t = Area / production / productivity or othervariable under consideration in the year t,

A = Intercept indicating Y in the base period(t = 0), B = 1 + g, T = time period, V_t = Random disturbance term.

Equation (1) is converted into the logarithmicform as follows to make it in a linear form:

$$In\ \mathrm{Y_t} = In\ \mathrm{A} + \mathrm{t^*In\ B} + \mathrm{In\ V_t} \qquad (2)$$

This is of the following form

$$Q_t = a + bt + U_t \qquad (3)$$

where $Q_t = In\,Y_t$, $\mathrm{a = In\ A, b = In\ B, U_t} = In\ \mathrm{V_t}$. The values of 'a' and 'b' were estimated by usingOrdinary Least Squares estimation technique.Later, the original 'A' and 'B' parameters inequation (6) were obtained by takingantilogarithms of 'a' and 'b' values as;A = Antilog (a), B = Antilog (b).

3. FORCASTING ANALYSIS

This part covers the examination of compound annual growth rate, export quantity estimation, and instability. The Machine Learning model is used to assess the relationship between the amount of fresh mango output exported and the climate. The fresh mango export prediction for 2024–2050 is provided.

3.1. Markov Chain Analysis

Markov chain analysis was employed to analyze thestructural change in any system whose progress through time can be measured in terms of single outcome variable (Mahadevaiah et.al 2005). In the present study, the dynamic nature of tradepatterns (i.e the gains and losses) in export of Indian mangoin major importing countries was examined using the Markov chain model. Markov chain analysis involves developing atransitional probability matrix 'P', whose elements, Pij indicatethe probability of exports switching from country 'i' to country'j' over

time. The diagonal element Pij where i=j, measures the probability of a country retaining its market share or in otherwords, the loyalty of an importing country to a particular country's exports.
The average exports to a certain nation were previously thought to be a random variable that solely depended on the nation's historical exports, which are displayed algebraically as follows:

$$E_{jt} = \sum_{i=1}^{n} \left(E_{(it-1)} * P_{ij} + e_{jt} \right) \qquad (4)$$

Where, Ejtis exports from India to the jth countryin the year t; Eit-1 is exports of ith country during the year t = 1; Pijis probability that exports will shift from ith country to jth country; ejtis error term which is statistically independent of Eit-1 and N is number of importing countries. The transitional probabilities Pij, which can be arranged in a (c × n) matrix, have the following properties,

$$\sum_{i=1}^{n} \left(P_{ij} \right) = 1 \quad and \quad 0 \le P_{ij} \le 1 \qquad (5)$$

Thus, the expected export share of each country during period 't' was obtained by multiplying the exports to these countries in the previous period (t – 1) with the transitional probability matrix. The probability matrix has taken as input data form the period 1987-88 to 2022-23. Thus, transitional probability matrix (T) was estimated using linear programming framework by a method referred to as minimization of mean absolute deviation (MMAD);

$$Min \qquad \mathrm{OP}^* + I\ e \qquad (6)$$

Subject to

$$XP^* + V = Y$$

$$GP^* = 1$$

$$P^* \ge 0$$

where P^* is a vector of the probabilities P_{ij}, O is a null vector, 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.
Prediction of quantity of mango export is made by using the Transitional Probability Matrix

$$B_t = B_0 * T$$

$$B_{i+1} = B_{t+i-1} * T \qquad (7)$$

where $B_0 =$ Quantity exported in Base years, $B_{i+1} =$ Quantity exported in next year (prediction), $T =$ Transitional probability matrix.

3.2. Forcasting export quantity of mango through Machine learning(ML) model approach

According to Anonymous (2021), India has a lot of room to develop its mango crop because the country's appetite for the fruit is increasing yearly. Production and consumption are adjusted by the process, time, and location efficacies, which aid in the formulation of effective marketing strategies. Pardhi et al. (2018) investigated the ARIMA model to predict mango production and the log linear model to estimate growth trends. In the current study, the Machine learning approach is used to anticipate the export of fresh mangos from India using simple exponential smoothing with respect of weather parameters.

The following ML algorithms are implemented:

Step (i): Find the modal components of the first order. The positive and negative pair export quantity $(-1)^n y(t) w_i(t)$ is added to the domestic price $x(t)$ to form the international price $x(t) + (-1)^n y(t) w_i(t)$, where n is the coefficient and n∈{1, 2}, $w_i(t)$ is the production of ith year, $y(t)$ is export quantity of current year and weather parameters sequence that follows the standard normal distribution added for the ith time, and $i = 1, 2, \cdots p$. The new export quantity is obtain:

$$y(t+1)=x(t)+(-1)^n y(t)w_i(t)=MFC_i(t)+r_1+\beta_1 \textbf{ Temperature}_{t-1}+\cdots\cdots+\beta_p\textbf{Temperature}_{t-p}$$
$$+\alpha_1\textbf{Rainfall}_{t-1}+\ldots\ldots+\alpha_p\textbf{Rainfall}_{t-p}+\lambda_1\textbf{Wind speed}_{t-1}+\cdots\cdots\cdots+\lambda_p\textbf{Wind speed}_{t-p}$$
$$+\eta_1\textbf{Wind direction}_{t-1}+\cdots+\eta_p\textbf{Wind direction}_{t-p}+\gamma_1\textbf{Relative Humidity}_{t-1}+\cdots\cdots \quad (8)$$
$$+\gamma_p\textbf{Relative Humidity}_{t-p}$$

where $\beta_i,\alpha_i,\lambda_i,\eta_i,\gamma_i$ are coefficients and $MFC_i(t)$ is supply quantity of other countries. Then, multiple first-order components $MFC_1(t)$ are obtained, and the final first-order component $\bar{M}\bar{F}\bar{C}_i$ is obtained by calculating the average value of all $MFC_1(t)$,

$$MFC_i(t)=\frac{1}{N}\sum_{i=1}^{N}\bar{M}\bar{F}\bar{C}_i(t) \qquad (9)$$

The component $r_1(t)$ is new arriving export quantity which is obtained by formula (8) and (9):

$$r_1=x(t)+(-1)^n y(t)w_i(t)-\frac{1}{N}\sum_{i=1}^{N}\bar{M}\bar{F}\bar{C}_i(t)+\beta_1 \textbf{ Temperature}_{t-1}+\cdots\cdots+\beta_p\textbf{Temperature}_{t-p}$$
$$+\alpha_1\textbf{Rainfall}_{t-1}+\ldots\ldots+\alpha_p\textbf{Rainfall}_{t-p}+\lambda_1\textbf{Wind speed}_{t-1}+\cdots\cdots\cdots+\lambda_p\textbf{Wind speed}_{t-p}$$
$$+\eta_1\textbf{Wind direction}_{t-1}+\cdots+\eta_p\textbf{Wind direction}_{t-p}+\gamma_1\textbf{Relative Humidity}_{t-1}+\cdots\cdots \quad (10)$$
$$+\gamma_p\textbf{Relative Humidity}_{t-p}$$

Step (ii): Find the second order modal components. The positive and negative pair export quantity $(-1)^n y(t)w_i(t)$ is added to the arriving export quantity $r_1(t)$ to form the new price distribution $r_1(t)+(-1)^n y(t)w_i(t)$, and then decompose it N times again:

$$r_1(t)+(-1)^n y(t)w_i(t)=MFC_2(t)+r_2+\beta_1 \textbf{ Temperature}_{t-1}+\cdots\cdots+\beta_p\textbf{Temperature}_{t-p}$$
$$+\alpha_1\textbf{Rainfall}_{t-1}+\ldots\ldots+\alpha_p\textbf{Rainfall}_{t-p}+\lambda_1\textbf{Wind speed}_{t-1}+\cdots\cdots\cdots+\lambda_p\textbf{Wind speed}_{t-p}$$
$$+\eta_1\textbf{Wind direction}_{t-1}+\cdots+\eta_p\textbf{Wind direction}_{t-p}+\gamma_1\textbf{Relative Humidity}_{t-1}+\cdots\cdots \quad (11)$$
$$+\gamma_p\textbf{Relative Humidity}_{t-p}$$

After that, the second-order component $\bar{M}\bar{F}\bar{C}_2(t)$ is obtained by averaging all $MFC_2(t)$.
Finally, the second order residual component $\bar{M}\bar{F}\bar{C}_2(t)$ is obtained:

$$r_2(t)=r_1(t)+(-1)^n y(t)w_i(t)-\bar{M}\bar{F}\bar{C}_2(t)\beta_1 \textbf{ Temperature}_{t-1}+\cdots\cdots+\beta_p\textbf{Temperature}_{t-p}$$
$$+\alpha_1\textbf{Rainfall}_{t-1}+\ldots\ldots+\alpha_p\textbf{Rainfall}_{t-p}+\lambda_1\textbf{Wind speed}_{t-1}+\cdots\cdots\cdots+\lambda_p\textbf{Wind speed}_{t-p}$$
$$+\eta_1\textbf{Wind direction}_{t-1}+\cdots+\eta_p\textbf{Wind direction}_{t-p}+\gamma_1\textbf{Relative Humidity}_{t-1}+\cdots\cdots \quad (12)$$
$$+\gamma_p\textbf{Relative Humidity}_{t-p}$$

Step (iii): Repeat the operation of step (ii) until the remaining export quantity can no longer be decomposed. Assuming that D mean $MFC_i(t)$ components are obtained when the residual price cannot be decomposed again, then the residual sequence R(t) is obtained finally:

$$R(t)=x(t)+(-1)^n y(t)w_i(t)-\sum_{i=1}^{D}\bar{M}\bar{F}\bar{C}_i(t)+\beta_1 \textbf{ Temperature}_{t-1}+\cdots\cdots+\beta_p\textbf{Temperature}_{t-p}$$
$$+\alpha_1\textbf{Rainfall}_{t-1}+\ldots\ldots+\alpha_p\textbf{Rainfall}_{t-p}+\lambda_1\textbf{Wind speed}_{t-1}+\cdots\cdots\cdots+\lambda_p\textbf{Wind speed}_{t-p}$$
$$+\eta_1\textbf{Wind direction}_{t-1}+\cdots+\eta_p\textbf{Wind direction}_{t-p}+\gamma_1\textbf{Relative Humidity}_{t-1}+\cdots\cdots \quad (13)$$
$$+\gamma_p\textbf{Relative Humidity}_{t-p}$$

Therefore, the decision export quantity can be indicated as below:

$$x(t)=\sum_{i=1}^{D}\bar{M}\bar{F}\bar{C}_i(t)+R(t)-(-1)^n y(t)w_i(t)+\beta_1\ \mathbf{Temperature}_{t-1}+\cdots\cdots+\beta_p\mathbf{Temperature}_{t-p}$$
$$+\alpha_1\mathbf{Rainfall}_{t-1}+\ldots\ldots+\alpha_p\mathbf{Rainfall}_{t-p}+\lambda_1\mathbf{Wind\ speed}_{t-1}+\cdots\cdots\cdots+\lambda_p\mathbf{Wind\ speed}_{t-p}$$
$$+\eta_1\mathbf{Wind\ direction}_{t-1}+\cdots+\eta_p\mathbf{Wind\ direction}_{t-p}+\gamma_1\mathbf{Relative\ Humidity}_{t-1}+\cdots\cdots \quad (14)$$
$$+\gamma_p\mathbf{Relative\ Humidity}_{t-p}$$

Numerous performance evaluation indices have been suggested to quantify the predictive performance of prediction models. On the other hand, the temperature prediction indicates both the actual and expected values at various years. The weather parameter correlation is used to compute the correlation between the predicted value and the real value of the model, thereby indirectly explaining the model's ability to extract characteristic information from the data and verifying the superiority of the model proposed in this paper in terms of fresh mango export quantity.

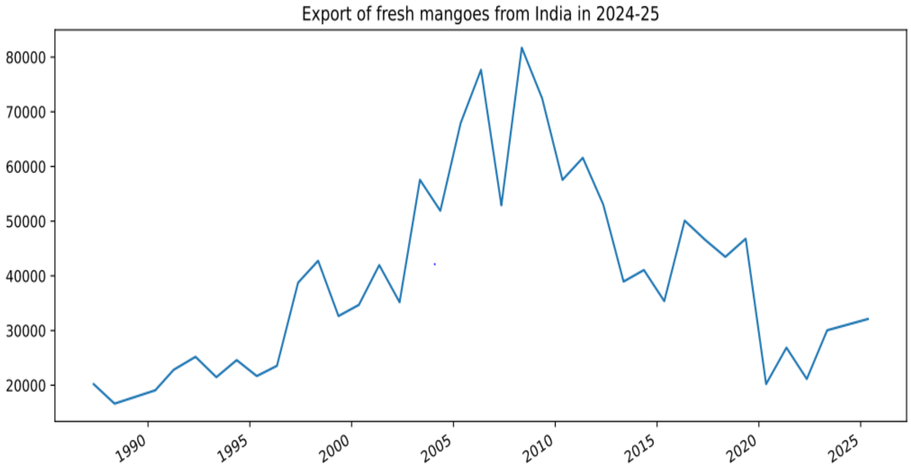


Fig.1.The export quantity of fresh mango from India in 2025-2026

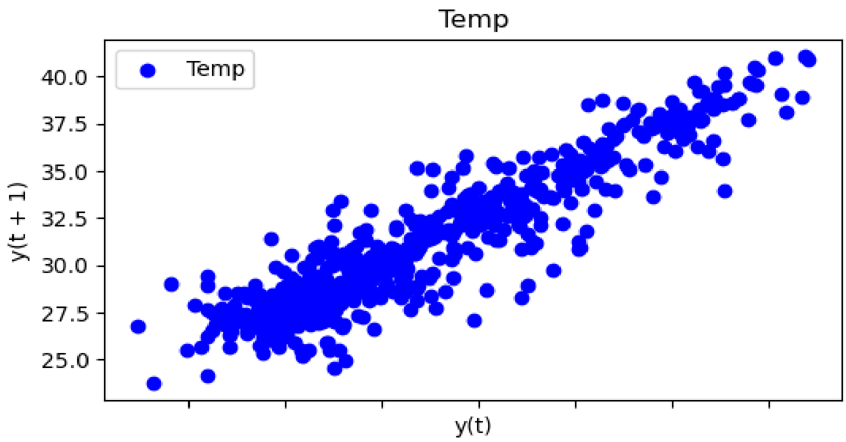


Fig.2. The current year $y(t)$ and weather parameters sequence that follows the standard normal distribution added for the ith time that is $y(t+1)$

4. RESULTS AND DISCUSSION

4.1. Growth and Instability in Mango Products from India: World Scenario

Figure 1 illustrates that fresh mango exports during 2025–2026 are influenced by rising ambient temperatures, projected to increase by 1.5–3 °C (Figure 2). Figure 3 shows that country-wise production and production shares (%) are expected to rise in 2026–2027. As presented in Figure 4, mango plantations covering 46,671 thousand acres generate approximately 18.77 million tons annually. India remains the world's leading mango producer, accounting for 40.2% of global production. Figure 5 highlights that, under forecasted weather parameters and rising temperatures, China and Thailand may expand exports to Gulf countries. These two nations are already among the largest producers, with annual outputs of 4.7 million and 3.4 million tons, respectively. Other countries including Mexico, Brazil, Egypt, and Pakistan are collectively contribute about 19.9 million tons, with an average productivity of 3.2 tons/ha (Table 1).

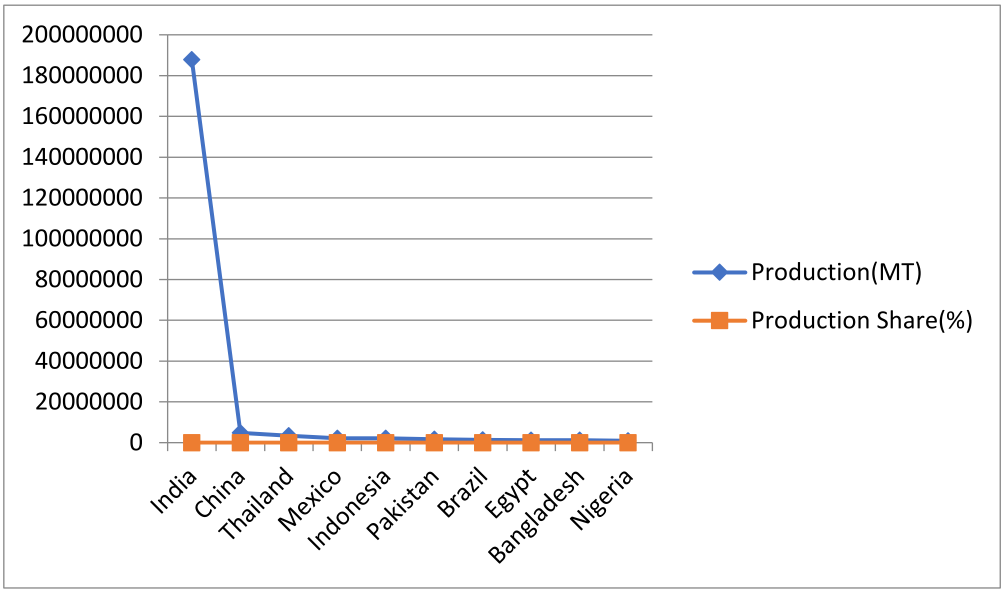


Fig.3.Country wise production and production share(%)

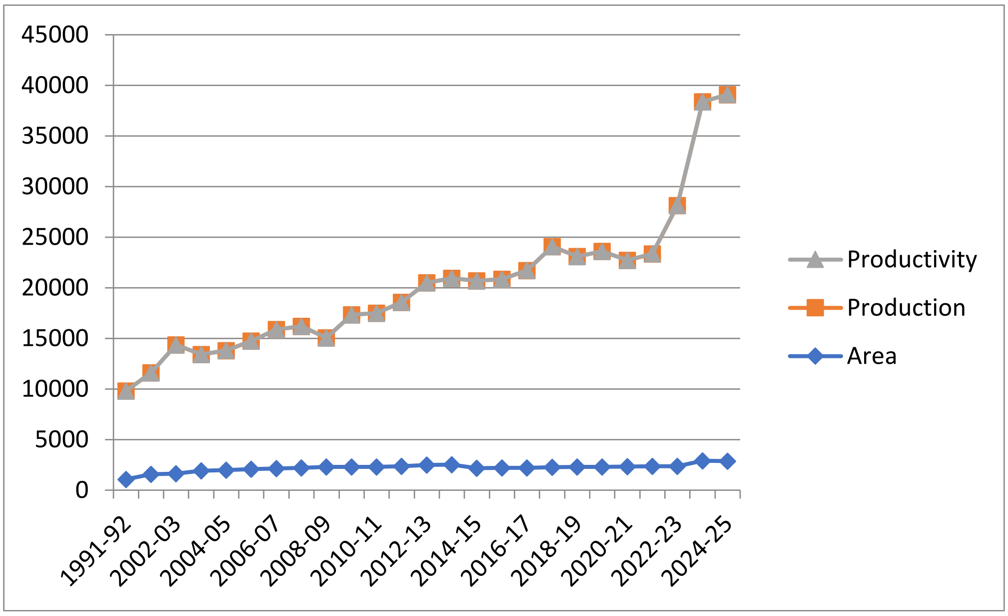


Fig.4. Area, production and productivity analysis of export fresh mango with different weather conditions

The rise in the US dollar, largely due to oversupply, is a key factor influencing these outcomes. It is also noteworthy that the UAE—historically one of India's major maritime product markets—has experienced a decline in relative market share. Based on equations (8)–(14), forecasts indicate that India's mango exports to the UAE will decline from 198,500 MT in 2016–17 to 49,700 MT in 2026–27 in value terms, and from 1,781.7 crores to 382 crores in quantity exported. This decline is primarily attributed to reduced shrimp exports to the UAE, driven by falling local shrimp production and weakening consumer demand.

India's mango exports were projected at 100,020 tonnes in 2004. Between 2017 and 2018, exports increased by nearly 20%. As shown in Table 2, China accounted for 11.8% of global mango exports during 2004–2006, with productivity 8.5% higher than India. However, in terms of value, the European Union dominated, accounting for 27.37% of purchases. In 2018–19 and 2019–20, India overtook China as the world's top mango exporter, with 46,510.27 MT and 49,658.67 MT, respectively. The total value, however, remained essentially constant at 400,649.55 lakhs across the two years. The UAE has now emerged as the largest importer, accounting for 34.81% of India's mango exports by value. This projection is supported by machine learning models, with ACF and PACF values and residuals showing increases of approximately 0.3% and 0.7% (Figures 7 and 8).

4.2. Forecasting weather parameters

Based on area, production, and productivity data, forecasts were generated using a Machine Learning–Empirical Mode Decomposition (EMD) model, as presented in Table 3.

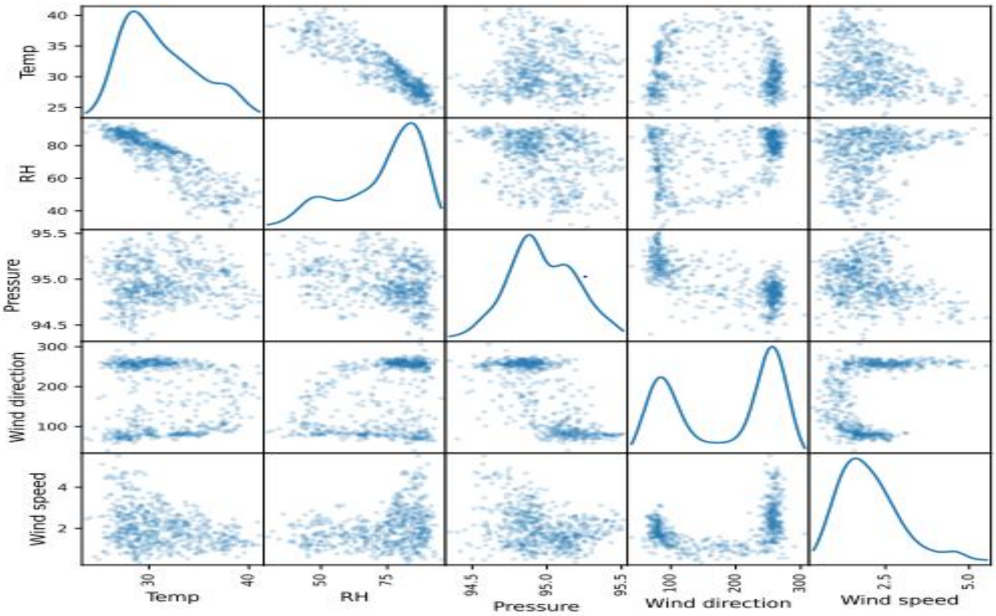


Fig.5.Export fresh mango with different weather conditions

The EMD-based machine learning approach was applied to key climatic variables—temperature, wind speed, wind direction, and relative humidity—for India during the period 2026–2050 (Figure 5). The model outputs indicate stable forecasting performance, with residuals remaining within the normal range. Furthermore, the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) values also fall within acceptable limits, confirming the robustness of the model.

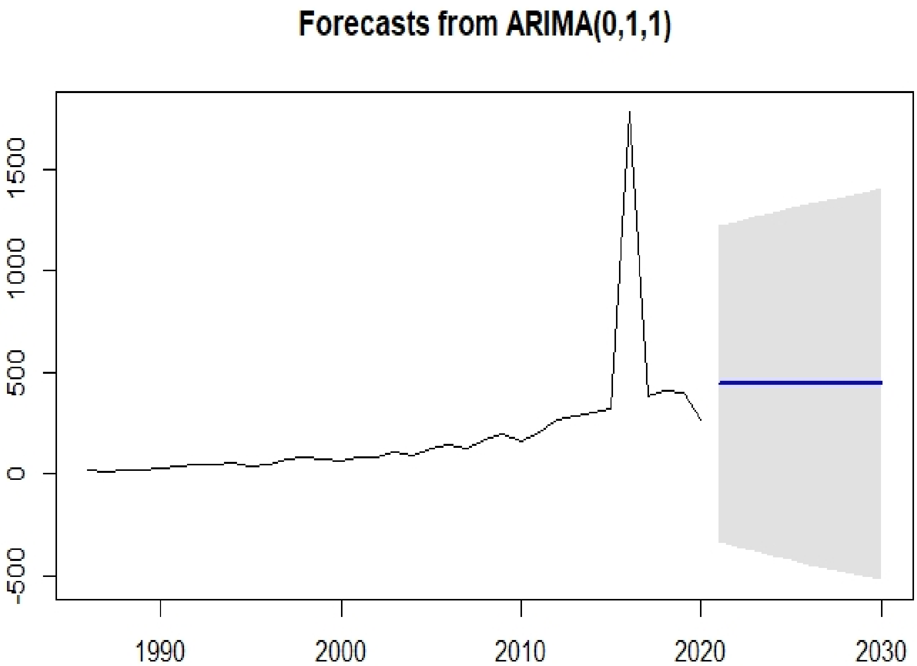


Fig.7. Residuals analysis of export fresh mango

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.982[a]	.964	.960	1.35464
2	.981[b]	.963	.959	1.36227
3	.980[c]	.961	.959	1.37337
4	.979[d]	.959	.957	1.39728

a. Predictors: (Constant), RD, Tmin, RH, RF, Tmax

b. Predictors: (Constant), RD, Tmin, RH, Tmax

c. Predictors: (Constant), RD, Tmin, RH

d. Predictors: (Constant), RD, RH

Fig.8. Showing the respance of R, R2 and Adjusted R2.

5. CONCLUSION

China, Thailand, and Pakistan together account for 34.81% of the total value of global mango exports. Mangoes from India exert a significantly greater influence on the international fresh mango market compared to other countries. To forecast yield across different varieties, the Simpson's 1/3 rule was applied. Based on this model, production is estimated at 28,826.11 MT in 2024–2025, under climatic conditions where the maximum mean temperature ranges from 29.0 to 35.4 °C, the minimum mean temperature from 18.9 to 23.9 °C, rainfall between 37.0 mm and 186.0 mm, and average relative humidity between 32% and 63%.

A machine learning technique was further developed to estimate mango exports from India for the period 2026–2050. The model suggests that rising temperatures may drive global mango exports upward by approximately 5–7%. The most reliable export markets for Indian mangoes are the United Arab Emirates, the United Kingdom, Qatar, Oman, and Kuwait, with respective growth prospects of 0.90, 0.87, 0.88, and 0.90 percentage points. Saudi Arabia, Bangladesh, Nepal, and the UAE are projected to remain among the most frequent importers of Indian mangoes. Collectively, exports of all mango varieties are expected to generate Rs. 271.84 crores (USD 36.23 million). The forecasting model's validation metrics confirm robustness, with ACF and PACF values of approximately 0.3 and 0.7, respectively, and residuals remaining within the predicted range.

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Table .1: Major producing countries of mango in the world

S.No.	**Country**	**Production(MT)**	**Production Share(%)**
1.	India	187790000	23.47
2.	China	4771038	10.23
3.	Thailand	3432129	7.36
4.	Mexico	2197313	4.71
5.	Indonesia	2184399	4.68
6.	Pakistan	1606091	3.44
7.	Brazil	1417149	3.04
8.	Egypt	1277008	2.73
9.	Bangladesh	1161685	2.49
10	Nigeria	917617	1.96
World total		46615462	64.11

Table .2 Showing the area production and productivity of mango in India

ear	**Area**	**Production**	**Productivity**
1991-92	1077.6	8715.8	8.08
2001-02	1575.8	10020.2	6.35
2002-03	1623.4	12733.2	7.84
2003-04	1906.7	11490.0	6.02
2004-05	1970.4	11829.7	6.00
2005-06	2080.7	12663.1	6.08
2006-07	2154.0	13734.0	6.37
2007-08	2201.0	13997.0	6.35
2008-09	2309.0	12750.0	5.52
2009-10	2312.3	15026.7	6.49
2010-11	2297.0	15188.0	6.61
2011-12	2378.1	16196.4	6.81
2012-13	2500.0	18002.4	7.20
2013-14	2516.0	18431.0	7.32
2014-15	2163.0	18527.0	8.56
2015-16	2209.0	18643.0	8.43
2016-17	2212.0	19506.0	8.81
2017-18	2258.0	21822.0	9.66
2018-19	2293.0	20798.0	9.07
2019-20	2309.0	21285.0	9.21
2020-21	2317.0	20386.0	8.79
2021-22	2350.0	21011.0	8.94
2022-2023	2390.0	22963.7	9.60
2023-24	2908.6	35474.4	12.19
2024-25	2883.9	36208.6	12.55

Table 3: Showing the export quanatiyt of fresh mango from India

Year	**Export of fresh mangoes(MT) from India**

2025-26	33402.09
2026-27	33323.63
2027-28	32611.09
2028-29	36151.52
2029-30	34356.47
2030-31	35837.67
2031-32	37116.54
2032-33	35812.61
2033-34	37865.19
2034-35	37459.68
2035-36	37414.83
2036-37	38758.13
2037-38	37887.35
2038-39	38690.24
2039-40	39007.9
2040-41	38532.22
2041-42	39416.6
2042-43	39105.27
2043-44	39204.97
2044-45	39686.01
2045-46	39295.91
2046-47	39699.05
2047-48	39736.84
2048-49	39582.9
2049-50	39948.77

ACKNOWLEDGEMENTS

We extend our thanks to our Chairman Sri Shanmugha College of Engineering and Technology for supporting us to carry out this manuscript.

Authors' contributions R.Ravi Kumar carried out the average value of food production, as well as the stability of mango export markets of India, participated in the sequence alignment and drafted the manuscript. T.Aasaithambi carried out Simpson’s 1/3 rule model is presented at various variety levels. . S.Senthilkumar carried out economic analysis indicates that global environmental changes positively impact mango production. S.Manimala carried out Machine learning (ML) model was used to estimated mango export of Indain market from 2026–2050. M. Venkatachalam carried out the standard econometric technique: Markov Chain, Compound Annual Growth Rate and Minimization of Mean Absolute Deviation. K.Sugnaya developed MATLAB code for global environmental changes positively impact mango production and secondary data were collected from the India Meteorological Department (IMD), sequence alignment and drafted. All authors read and approved the final manuscript.