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Statistical analysis of growth trends in the production of mango in Dharwad and Kolar Districts of Karnataka

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Abstract
This study examines the long-term production trends of mango in Dharwad and Kolar districts of Karnataka using 44 years of secondary data (1980-2023). To capture the underlying patterns, linear, quadratic, cubic, exponential, and logarithmic regression models were applied, and their suitability was judged based on the coefficient of determination (R^2) and root mean square error (RMSE). The cubic model emerged as the most appropriate in both districts, explaining 79.84% of the variation in Dharwad with an RMSE of 14,184.28, and 68.41% in Kolar with an RMSE of 49,031.05. These findings suggest that mango production exhibited a non-linear trend, influenced by climatic factors, cultivation practices, and market conditions. Compound Annual Growth Rate (CAGR) analysis further confirmed positive growth, with Dharwad showing a significant annual increase of 5.15% and Kolar recording 1.68%. The relatively higher growth in Dharwad reflects better agro-climatic suitability and improved management, whereas Kolar's slower growth points to production constraints. Overall, the study highlights regional differences in mango cultivation and underscores the need for tailored strategies to enhance productivity, strengthen resilience, and support farmer incomes.

Keywords: Mango production, growth trends, Dharwad, Kolar, regression models, CAGR.

1. Introduction

In Horticulture, particularly in fruit crop cultivation, trend analysis provides critical insights into how the sector has evolved in response to shifting policies, market dynamics, technological advancements, and environmental conditions. It helps stakeholders understand whether the cultivation of specific crops is expanding, stagnating, or declining, which in turn supports planning for resource allocation, research investment, and infrastructure development (Ragini and Harshith, 2024) [6].

To conduct effective trend analysis, a variety of statistical tools and models are employed. These include descriptive statistics to summarize average values and variability, as well as time series plots to visualize patterns over time. For quantifying trends, regression-based models are frequently used. The linear regression model is the most basic, representing a constant rate of change. However, agricultural data often show more complex patterns, necessitating the use of nonlinear models, such as quadratic, cubic, exponential, and logarithmic regression models which are capable of capturing curvature, turning points, and other nonlinear behaviours in the data (Ramana Murthy and Hari Babu, 2018) [7].

Additionally, they are applied when changes in production occur at a rate proportional to their current size, often useful in cases of rapid technological adoption or area expansion. Similarly, they are employed when there is a sharp initial change followed by a tapering growth pattern, which is common in saturated markets or mature crop systems. These models help researchers identify subtle and varying growth dynamics that may not be evident through linear models alone.

Another widely used measure is the Compound Annual Growth Rate (CAGR), which calculates the average rate of growth per year over a specified time frame. CAGR is particularly helpful for summarizing long-term performance while smoothing out annual fluctuations, thereby offering a clearer picture of sustained growth or decline (Verma and Ahmed, 2023) [11].

In the Indian context, trend analysis has been extensively used to monitor the performance of various crops, including cereals, pulses, and horticultural produce. India ranks among the top fruit-producing countries globally, with crops such as mangoes, bananas, papayas, guavas, grapes, and citrus fruits contributing significantly to both domestic consumption and exports. Among these, mango, banana, and papaya are not only economically important but are also major sources of nutrition and employment for millions of farmers.

Karnataka, with its diverse agro-climatic zones, is a leading state in fruit cultivation. It produces a wide range of fruits and plays a vital role in the national horticulture sector. The state's horticultural success can be attributed to favourable soil and climate conditions, improved irrigation infrastructure, and government support through schemes like the National Horticulture Mission (NHM) and Rastriya Krishi Vikas Yojana (RKVY). However, despite this growth, fruit cultivation in Karnataka-like much of India, is increasingly exposed to the effects of climate variability.

Over the past two decades, both regions have experienced significant changes in the area and production of fruit crops, influenced by climatic events, market prices, water availability, and the adoption of improved practices. Applying various time-based trend models, including linear, quadratic, cubic, exponential, and logarithmic functions, allows for a comprehensive understanding of these changes. These models not only provide statistical estimates of growth but also help identify inflection points and transitions, such as periods of accelerated growth or decline across the historical timeline.

In summary, this study seeks to examine the long-term trends in the production of the mango crop in Dharwad and Kolar districts, Karnataka using a suite of statistical models, including linear, polynomial, exponential, logarithmic functions, and CAGR. Furthermore, it aims to explore the impact of weather variables on fruit yield and to develop predictive models using machine learning tools. The combined use of classical statistical and modern computational approaches is expected to generate actionable insights for improving agricultural resilience and promoting sustainable fruit cultivation in the region.

2. Materials and Methods

Description of the study area

Dharwad

Dharwad lies at an altitude of around 750 meters above sea level. The district has a tropical climate with moderate to heavy rainfall during the monsoon season and is classified as Aw in the Koppen-Geiger climate system. It is located at 15.4589° N latitude and 75.0078° E longitude, and falls under the Northern Transition Zone of Karnataka. Major crops grown include cotton, groundnut, sugarcane, various pulses, and fruit crops such as banana, guava, and papaya.

Kolar

Kolar is located at an elevation of about 849 meters above sea level. It has a tropical climate with moderate rainfall and dry spells, and is categorized as Aw under the Koppen-Geiger classification. Geographically, it lies at 13.1367° N latitude and 78.1290° E longitude, and comes under the Eastern Dry Zone of Karnataka. The district is well known for its fruit cultivation, especially mango, sapota, grapes, and also supports sericulture and vegetable farming.

Nature and sources of data

Crop Data

The data on the production of mango has been collected for the period of 44 years from 1980 to 2023. The secondary data on the yield of the mango crop will be collected from the following sources

- Directorate of Economics and Statistics (DES), Bangalore
- Department of Horticulture, Bangalore

Simple Linear Regression

It models the relationship between a single independent variable(x) and a dependent variable (y). This method is used for predicting a dependent variable based on an independent variable. The equation for the simple linear regression is given by,

$$Y=\beta_0 + \beta_1 X + \varepsilon,$$

where Y is a dependent variable (production), β_0 is the intercept, $\beta_1$is the regression coefficient of Y on X, X is an independent variable (time) and ε is the error term.

Polynomial Regression

This model is a form of Linear Regression where the relationship between the independent variable and the dependent variable is modelled as an n^{th}-degree polynomial. This model is used for capturing nonlinear relationships using polynomial terms. The model for the polynomial regression is given by

$$Y= \beta_0 + \beta_1 X + \beta_2 X^2 + \cdots + \beta_n X^n + \varepsilon,$$

where Y is the dependent variable (production), β_0 is an intercept, $\beta_1, \beta_2, \ldots, \beta_n$ are the regression coefficients, X is an independent random variable (time)**.**

Exponential Regression

It models the relationship where the rate of change of the dependent variable is proportional to its current value. It is used in growth processes, such as population growth or radioactive decay. The equation is given by

$$Y= \beta_0 e^{-\beta_1 X + \varepsilon},$$

where Y is a dependent variable (production), X is an independent variable (time), β_0 is an intercept, ε is an error term.

Logarithmic Regression

Logarithmic models are a type of non-linear regression used to describe relationships where the rate of change in the dependent variable decreases (or increases) rapidly at first and then levels off. These models are particularly useful when the data follows a pattern where the response variable changes quickly at low levels of the predictor variable but slows down as the predictor increases. The basic form of a logarithmic model is

$$Y = a + b \ln(X) + \varepsilon,$$

where Y is the dependent variable (yield), X is the independent variable (time), a is the intercept, b is the coefficient that represents the rate of change, ln(X) is the natural logarithm of X and ε is the error term.

Compound Annual Growth Rate (CAGR)

The Compound Annual Growth Rate (CAGR) represents the average annual rate at which a value grows over some time, assuming the growth is steady and compounded each year. An exponential growth model reflects a constant percentage increase over time. CAGR simplifies irregular growth patterns into a single, consistent rate. It is commonly used to evaluate long-term trends in fields like finance, agriculture, and economics.

$$Y_t = a\, b^t e^u,$$

where Y_t is the dependent variable (yield), a is the intercept term, b is (1+ r) where r is the compound growth rate, t is time and u is an error term.

3. Results and Discussion

The trend analysis of mango production in Dharwad district revealed that the cubic model provided the best fit among the models tested, with an R^2 value of 0.7984 and the lowest RMSE of 14,184.28 (Table 1). This indicates that the production trend followed a non-linear trajectory, with the cubic function effectively capturing fluctuations in output over time. In the Kolar district, the cubic model also proved to be the most suitable, achieving an R^2 of 0.6841 and an RMSE of 49,031.05 (Table 2). Although the explanatory power of the model was slightly lower than that observed in Dharwad, it still outperformed linear, quadratic, logarithmic, and exponential models, highlighting the complex but structured pattern of mango production in the district.

Table 1: Comparison of statistical models for trend analysis of the production of mango in Dharwad district of Karnataka

Models	Model Parameters	Mango Production (in Metric Tons)		
		Parameter Estimator	R^2	RMSE
Linear	(β_0)	-4325983.6**	0.7710	49429.33
	(β_1)	2185.78**		
Quadratic	(β_0)	115384304.7#	0.7906	14454.93
	(β_1)	-117439.6#		
	(β_2)	29.88#		
Cubic	(β_0)	82.89*	0.7984	14184.28
	(β_1)	55298.55#		
	(β_2)	-56.31#		
	(β_3)	0.0143#		
Exponential	(β_0)	-90.01**	0.7648	52553.23
	(β_1)	0.0503**		
Logarithmic	(β_0)	-33191348.7**	0.7713	49428.1
	(β_1)	4372772.48**		

Note: **-Significant at 1 per cent
*- Significant at 5 per cent
#- Significant at 6 per cent

Table 2: Comparison of statistical models for trend analysis of the production of mango in the Kolar district of Karnataka

Models	Model Parameters	Production (Metric Tons)		
		β	R^2	RMSE
Linear	(β_0)	-10118275.6**	0.5795	56574.67
	(β_1)	5229.8**		
Quadratic	(β_0)	-787702868.9*	0.6823	49174.4
	(β_1)	782262.9**		
	(β_2)	-194.1*		
Cubic	(β_0)	-596.8**	0.6841	49031.05
	(β_1)	-398160.01**		
	(β_2)	395.5**		
	(β_3)	-0.098**		
Exponential	(β_0)	-20.5	0.516	60677.84
	(β_1)	0.017**		
Logarithmic	(β_0)	-79312830.1**	0.581	56481.7
	(β_1)	10479588.03**		

Note: **-Significant at 1 per cent
*- Significant at 5 per cent

The growth dynamics were further substantiated by the Compound Annual Growth Rate (CAGR) estimates. In Dharwad, mango production exhibited a significantly high CAGR of 5.15%, reflecting a strong and consistent increase over the years. Conversely, in Kolar, the CAGR was 1.68%, indicating a more modest but still positive growth in production (Table 3). The higher growth rate in Dharwad suggests more favourable conditions for mango cultivation, which could be attributed to agro-climatic suitability, wider adoption of improved crop management practices, and better market opportunities. In contrast, the relatively lower growth rate in Kolar may be linked to production constraints such as climatic variability, limited resource availability, or competing crop choices that restrict expansion.

Overall, these findings suggest that while both districts have recorded positive growth in mango production, Dharwad has demonstrated a stronger upward trajectory compared to Kolar. The results align with earlier studies reporting non-linear growth patterns in fruit crop production in India (Angamuthu, 2021; Uddin *et al.*, 2016; Varalakshmi *et al.*, 2022) [1, 8, 10], emphasizing the role of regional disparities in shaping production outcomes. The evidence suggests a need for targeted interventions in Kolar to enhance productivity and growth, including improved irrigation facilities, access to quality planting materials, and strengthened market linkages. In Dharwad, sustaining the existing momentum will be crucial for maintaining long-term production gains.

Table 3: Growth rate of production of mango based on CAGR (%) in Dharwad and Kolar districts of Karnataka

	District	Mango
CAGR (%)	Dharwad	5.15**
	Kolar	1.68**

Note: **- Significant at 1 per cent

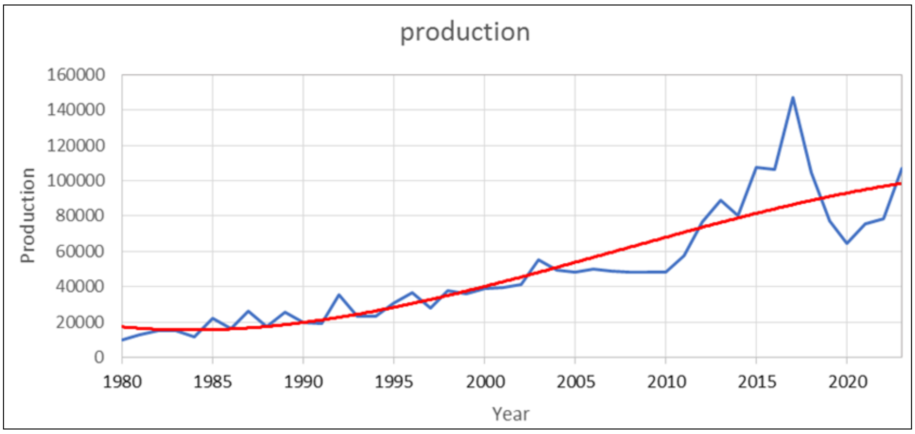

Fig 1: Plot of best fit model (Cubic model) for the production of Mango crop in the Dharwad district of Karnataka

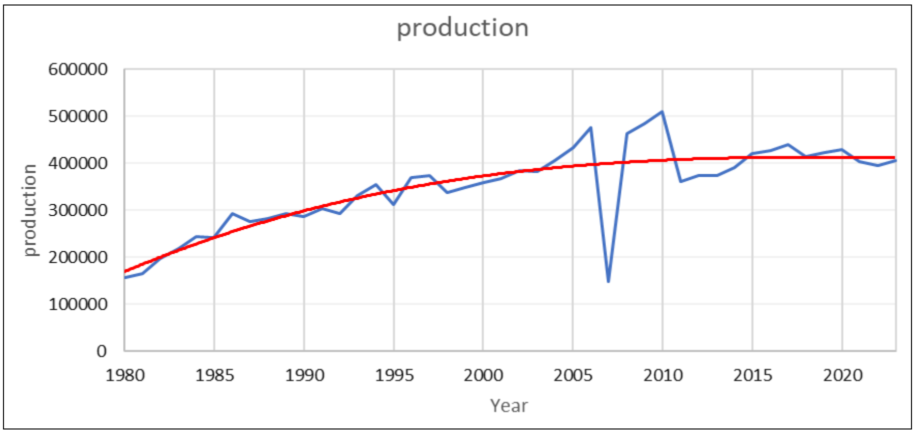

Fig 2: Plot of best fit model (Cubic model) for the production of Mango crop in the Kolar district of Karnataka

Conclusion

The study examined the long-term changes in mango production in the Dharwad and Kolar districts to understand how it has evolved over the years. By applying various statistical models to the historical data, it was observed that mango production has followed a consistently increasing trend. Among the models used, one captured the variations and growth pattern more effectively, showing a gradual and steady rise in production over time.

Further, the Compound Annual Growth Rate (CAGR) analysis supported this trend, revealing that mango production in Dharwad and Kolar has grown at an average annual rate of 5.15 and 1.68 percent. This indicates a healthy and stable improvement in output over the years.

These findings suggest that mango cultivation in the districts has strengthened over time, likely due to better farming practices, favourable weather, increased awareness among growers, and horticultural schemes. The upward trend in production reflects the crop’s growing importance in the region’s horticultural landscape and signals a positive future for mango farmers in Dharwad and Kolar.

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