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RESEARCH ARTICLE

Predicting area, production and productivity of gingelly in Tamil Nadu using linear and non-linear models

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Abstract

The objective of this study was to identify the most suitable linear and non-linear growth models for predicting the area, productivity, and production of gingelly in Tamil Nadu, as well as to project its future growth (until 2026 A.D.). The seasonal crop report of Tamil Nadu provided time series data regarding the area, productivity, and production of gingelly for a 58-year period spanning from 1965–1966 to 2022–2023. The study involved fitting multiple trend equations, including linear and non-linear growth models, to determine the best-fitting model for gingelly production in Tamil Nadu. For the forecasting up to 2026, the model that best suited the data was selected based on its highest coefficient of determination (R^2) and lowest Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) values. During the study period, the average gingelly area, production, and productivity in Tamil Nadu were recorded as 93892 ha, 37471 t, and 431 kg/ha, respectively. The cubic model's predictions for the future showed that area, productivity, and production will all rise significantly. By 2026 A.D., the predicted area is expected to be 28338.62 hectares, while production and productivity are projected to reach 15211.87 t and 581.22 kg/ha, respectively.

Keywords

linear model; non-linear model; R2 square, RMSE and MAPE

Introduction

India is blessed with a rich and varied agro-climatic environment that supports the cultivation of a wide range of oilseed crops. After the US, China, Brazil, and Argentina, India ranks as the world's fifth-largest vegetable oil economy in the world (1).

Gingelly (*Sesamum indicum* L.), commonly known as sesame, holds historical significance and economic importance and is extensively cultivated across Asia and Africa. A member of the Pedaliaceae family, gingelly is widely utilized in various industries, medicine, and nutrition across the globe. The seeds are commonly used as a garnish in baked goods, sweets, crackers, chips, vegetarian dishes, and Asian delicacies. Sesame oil, one of the one of the earliest known and utilized oils, has earned the tittle of "queen of oilseeds."

India is considered the center of origin for gingelly (2). Gingelly oil contains a variety of minor bioactive components, including antioxidants, vitamins, and minerals, along with approximately 20 percent protein and

80 to 90 percent unsaturated fatty acids. India is one of the largest producers, exporters, and consumers of gingelly worldwide. In terms of the total area used for sesame cultivation, Between 2023 and 2024, India allocated 1419.97 thousand ha to gingelly cultivation, yielding 689.31 thousand t, with an average productivity of 485 kg per hectare.The major gingelly-producing states include Gujarat, Uttar Pradesh, Andhra Pradesh, Rajasthan, Tamil Nadu, West Bengal, Maharashtra, Karnataka, Madhya Pradesh, and Orissa (3).

However, due to low yield and competition from other edible oil seeds, such as peanuts, sunflower, and soybean, it was unable to hold its position as the most important oilseed crop in the country.

This study aims to analyze the trends and prospects of gingelly cultivation in Tamil Nadu and India, focusing on production instability, cultivated area, and yield variations over the past three decades. Various statistical models, including time series models, growth curve models, and linear regression models, are used to address the components of the variance in production and change in the average production of gingelly simultaneously.

Globally, sesame is the oldest crop used for oil seeds. It is believed that the first human migrants from Africa introduced gingelly to India. Today, India exports gingelly seeds to several countries, including China, Netherlands, the USA, Hong Kong, Israel, Holland, UK, Germany, UAE , and Turkey.

Materials and Methods

Based on annual time-series secondary data obtained from the Tamil Nadu Seasonal Crop Report, the current study examined the area, production, and productivity of gingelly from 1965 to 2022. Data analysis was consucted using SPSS 16.0 software. Several trend analaysis models, including exponential, quadratic, and S-curve, and linear trend models, were used in this study (4-6).

For analytical purposes, the entire study period was arbitrarily divided into two sub-periods: Pre-liberalization (1965 to 1991) and post-liberalization (1992 to 2022). The compound growth rate (CGR) of gingelly was calculated separately for both periods to assess its growth performance and evaluate the impact of economic lineration on its cultivation.

To determine the compound annual growth rate, the following equation was fitted to the time- series data on area, yield, and production of the gingelly:

$$Y_t = a + bt \qquad \text{.........(Eqn.1)}$$

Where "Y_t" denotes the time series data of production, area, and yield for gingelly, "a" is the constant coefficient and "t" is the trend term. For a given absolute change in the value of the explanatory variable "t", the slope coefficient or "b" refers to the percentage change in Y_t for a one-unit change in t.

The CGR was calculated using following equation:

$$\text{CGR} = [\text{antilog b} - 1] \times 100 \qquad \text{.........(Eqn.2)}$$

The Ordinary Least Square (OLS) method was used to estimate equation 1. To determine the relevance of "b," the t-test was utilized. The equation posits that variations in agricultural productivity within a given year are contingent upon variations in the output from the year prior (7, 8).

The model used to estimate r is based on equation 1, where Y_t represents the observation (such as agricultural production, area, or productivity) at time t and r is the CGR.

$$Y_t = Y_0\,(1 + r)\,t \qquad \text{.........(Eqn.3)}$$

Typically, one assumes that the error-term exp (e) in equation 3 is multiplicative. This allows the model to be linearized using logarithmic transformation, yielding Eqn. (4):

$$(Y_t) = A + Bt + e \qquad \text{.........(Eqn.4)}$$

Where, A = ln (Y_0), and B = ln (1 + r).

After equation 4 is fitted to the data using the "least squares methods," the coefficient of determination R^2 was used to assess the model’s goodness of fit. Lastly, using equation 5, the CGR was calculated.

$$r\hat{} = \exp(B\hat{}) - 1 \qquad \text{.........(Eqn.5)}$$

The study incorporated linear, exponential, quadratic, and S-curve trend analysis models. For the secondary data, logistic and power models were also tested. Three accuracy metrics were used to choose the model that suited the data the best, they are R-Square, Adjusted R-Square, Mean Absolute Percentage Error (MAPE), and Root Mean Square Error (RMSE).

The correctness of fitted time series values is gauged by the Mean Absolute Percentage Error, or MAPE. Accuracy is expressed as a percentage. Because it depends on scale, the Root Mean Square Error (RMSE) is a metric for comparing predicting mistakes of various models for a specific dataset rather than across datasets. A well-fitted model with minimal forecasting errors is indicated by lower values for all of these metrics (9).

A metric that accounts for disproportionate error costs and enables a comparative baseline with naïve approaches was considered. By squaring the errors, the model assigns higher weights to large errors, ensuring a relative comparison between naïve and advanced forecasting methods.Large errors are assigned a significantly higher weight than small errors.

Using the best-fitted model, the study projected the area, productivity, and production of gingelly in Tamil Nadu from 2023 to 2026. The predictions were validated by comparing the model's outputs with actual historical data using techniques such as back-testing and cross-valida-tion. Performance metrics such as mean squared error (MSE) and MAPE were used to ensure the model's accuracy and reliability of the forecasts for gingelly area, productivity, and production in Tamil Nadu.

Results and Discussion

Trend analysis of area, production and productivity of gingelly in Tamil Nadu

Table 1 presents the estimated CAGRs for gingelly in Tamil Nadu across three distinct periods: 1965–1991 (pre-liberalization period), 1992–2022 (post-liberalization period), and 1965–2022 (overall period).

Table 1. Compound growth rates of area, production, and yield of gingelly in Tamil Nadu (percent per annum)

Year	Area	Production	Productivity
1965 to 1991 (Pre- liberalization period)	0.08^{NS}	0.62^{NS}	0.54*
1992 to 2022 (Post - liberalization period)	-3.73**	-3.25^{NS}	0.94**
1965 to 2022 (Overall period)	-2.08**	-1.09*	1.42**

******- significance at 1 percent level, *****- significance at 5 percent level, NS- Non-Significance.

The analysis reveals variations in gingelly's growth rates concerning area, productivity, and production. The area's CGR (0.08 percent) during the pre-liberalization was positive but not statistically significant indicating that growth was minimal and likely due to random fluctuations rather than consistent trends. During the post-liberalization era, the area growth rate was significantly negative at the 1 percent level. It was determined that during the post-liberalization era, gingelly area shrank. Gingelly production during the pre-liberalization era grew at 0.62 percent annual pace, which was encouraging but not statistically significant. However, post-liberalization era experienced a non-significantly declining growth rate of 3.25percent. At the one and five percent significance levels, the total area and production were declining at 2.08 percent and 1.09 percent respectively.

In terms of gingelly productivity, there was a notable positive growth rate of 0.54 percent during the pre-liberalization era and an improved rate of 0.94 percent in the post-liberalization period. At a 1 percent significance level, gingelly productivity for the entire period was determined to be positive at 1.42 percent.

These finding suggest a notable decrease in gingelly production and area over the time, but a notable rise in productivity. This suggests that although the amount of gingelly cultivated decreased, output efficiency increased.

In the current study, 58 years of data on gingelly area, productivity, and production in Tamil Nadu were taken into consideration. The secondary data was fitted to both linear and non-linear growth models, including the linear, logarithmic, inverse, quadratic, cubic, power, and exponential models. Tables 1, 2, and 3 presents the findings for gingelly productivity, area, and production in Tamil Nadu, respectively, derived from fitting all linear and non-linear models.

Table 2. Linear and non-linear models of gingelly area in Tamil Nadu

Model	Parameter				Selection Criteria		
	Constant	A	B	C	R^2	RMSE	MAPE
Linear	142099.46**	-1634.13**	-	-	62.9	62.3	21003.98
Logarithmic	168420.33**	-23953.81**	-	-	38.3	37.2	27094.17
Inverse	88076.19**	72605.56*	-	-	9.60	8.00	32793.64
Quadratic	119064.61**	669.35	-39.04**	-	71.0	69.9	18587.06
Cubic	108320.43**	2765.55	-127.11*	0.99	72.1	70.5	18222.83
Power	217927.98**	-0.30**	-	-	38.6	37.5	31510.39
Exponential	158702.05**	-0.021**	-	-	65.3	64.7	23975.62
Logistic	0.000063**	1.02**	-	-	65.3	64.7	23975.62

******,***** indicate significance at 1% and 5% levels of probability respectively.

Table 3. Linear and non-linear models of gingelly production in Tamil Nadu

Model	Parameter				Selection Criteria		
	Constant	A	B	C	R^2	RMSE	MAPE
Linear	44075.02**	-223.86*	-	-	8.3	6.7	12419.02
Logarithmic	44241.15**	-2175.89	-	-	22.0	5.0	12826.45
Inverse	37166.19**	3808.43	-	-	2.0	16.0	12960.01
Quadratic	31893.55**	994.29**	-20.65**	-	24.2	21.5	11290.35
Cubic	31269.05	1116.13	-25.77	0.06	24.3	20.1	11288.34
Power	51107.97**	-0.14	-	-	3.5	1.8	13635.18
Exponential	46054.41**	-0.01**	-	-	7.7	6.1	13257.67
Logistic	0.00002**	1.011**	-	-	7.7	6.1	13257.67

******,***** indicate significance at 1% and 5% levels of probability respectively.

Table 2 indicates that the cubic model exhibited a higher R^2 value (0.72) compared to other linear and non-linear growth models for the gingelly area. Additionally, the cubic model showed lower values for RMSE (70.5) and MAPE (18222.83), establishing it as the most suitable model for forecasting the gingelly area in Tamil Nadu.

Table 3 showed that the cubic model had the highest R^2 (0.24), the lowest MAPE (11288.34), and the lowest RMSE (20.1) for gingelly production in Tamil Nadu. As a result, the cubic function was selected for forecasting gingelly production in Tamil Nadu.

Table 4 further supports this choice, revealing that the cubic model yielded the lowest RMSE (3950.68) and the highest R^2 value (0.70) among all model tested. Hence, the cubic model was selected to predict gingelly productivity in Tamil Nadu.

Table 4. Linear and non-linear models of gingelly productivity in Tamil Nadu

Model	Parameter				Selection Criteria		
	Constant	A	B	C	R^2	RMSE	MAPE
Linear	255.73**	5.95**	-	-	70.0	69.4	4257.69
Logarithmic	138.64**	94.02**	-	-	49.5	48.6	7152.44
Inverse	454.86**	-295.74*	-	-	13.4	11.8	12276.03
Quadratic	277.77**	3.74	0.04	-	70.6	69.5	4170.09
Cubic	321.23**	-4.74	0.39	-0.01	72.1	70.6	3950.68
Power	208.33**	0.22**	-	-	52.6	51.8	6427.26
Exponential	276.55**	0.01**	-	-	71.8	71.3	4216.74
Logistic	0.01**	0.99**	-	-	71.8	71.3	4216.74

**,* indicate significance at 1% and 5% levels of probability respectively.

These findings align with previous studies, which have also identified the cubic model as the preferred method for forecasting parameters such as coarse rice prices and productivity in Bangladesh (10, 11).

Forecasting of gingelly area, production and productivity in Tamil Nadu using best fitted model

The area, production, and productivity of gingelly in Tamil Nadu were projected for 2026 AD using the best-fitted linear and non-linear model, with the findings presented in Table 5.

Table 5. Forecasted values of gingelly area, production, and productivity in Tamil Nadu by cubic model

Year	Forecasted area (Hectares)	Forecasted production (Tonnes)	Forecasted productivity (Kg/ha)
2023	33394.81	19310.55	585.18
2024	31603.40	17974.92	584.53
2025	29916.02	16608.57	583.22
2026	28338.62	15211.87	581.22

The area of gingelly in Tamil Nadu was forecasted using the best-identified model, the cubic model, and the result is tabulated in Table 5. By 2026 AD, the projected gingelly area in Tamil Nadu is expected to be 28338.62 ha, showing a decline compared to the average area over the study period.

Given that the cubic model exhibited the highest R^2 values and the lowest MAPE, it was determined to be the most suitable model for forecasting gingelly production in Tamil Nadu by 2026 AD. Based on Table 5, the forecasted production using the cubic model is 15211.87 t.

The cubic model, owing to its lowest MAPE values and highest R^2, was also used to anticipate gingelly's productivity in Tamil Nadu. 583.22 kg/ha is the productivity predicted by the cubic model for 2026 AD. Table 5 presents the findings of the projections, which indicated a growing tendency by 2025 AD from the study period average.

Conclusion

The study identified annual variations in the area, production, and productivity of gingelly in Tamil Nadu . Prior to liberalization, gingelly's yearly growth rate was positive; following liberalization, the growth area became negative for area and production, while productivity continued to rise. Despite the decline in the cultivated area and overall production, an improvement in productivity was observed.

To address this decline, it is imperative to increase the cultivated area and yield of gingelly crops in Tamil Nadu. This can be achieved through the development of high-yielding varieties (HYV), adoption of advanced agricultural technologies, and enhanced farmer awareness programs. The increase in gingelly productivity, cultivated area, and overall production can be attributed to population growth and the rising demand for gingelly in Tamil Nadu.

The cubic model was determined to be the best-fitting model out of all the linear and nonlinear models for the area, production, and productivity of gingelly in Tamil Nadu, based on its lowest RMSE, MAPE value, and highest R^2 value. During the study period, the average area, production, and productivity of gingelly in Tamil Nadu were recorded as 93892 ha, 37,471 t, and 431 kg/ha, respectively.

According to the cubic model's predictions, the forecasted decline in both area and productivity reflects potential challenges like land degradation, reduced efficiency, or changing agricultural practices. While the area under cultivation decreases, the slight drop in productivity may be influenced by factors such as climate conditions or a shift towards less productive farming methods.

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Authors' contributions

SB participated in designing the study, conducted statistical analysis, developed experimental protocol, and drafted the initial draft of manuscript. MI, PS, KPS, PP, AS and RGS participated in the revision of the manuscript.

Compliance with ethical standards

Conflict of interest: There is no conflict of interest between the authors.

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