

FROM GROWTH TO FORECAST: ANALYSING THE DYNAMICS OF SESAME PRODUCTION IN INDIA

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ABSTRACT

Sesame (*Sesamum indicum* L.) is an important oilseed crop in India and knowledge of its long-term production dynamics is relevant for agricultural planning. The present study aimed at analyzing the growth and instability of sesame area, production and productivity in India and predicting the future area and production based on the annual data from 1994-95 to 2023-24. The study period was subdivided into three 10-year sub-periods. The growth trends were estimated by compound annual growth rate (CAGR) analysis, the instability was determined by Cuddy-Della Valle instability index (CDVI) and the area and production were forecasted by Autoregressive Integrated Moving Average (ARIMA) models. During the entire study period, the production and productivity of sesame increased by 1.482% and 1.823% per year, respectively, while the area of sesame decreased by 0.336% per year. The overall CDVI values indicated low instability in area (8.999%), production (12.412%) and productivity (9.818%). Production had medium instability (17.559%) in Period I while area and productivity had low instability. The ARIMA (1,0,1) model had the lowest MAPE value for area (6.648%) and the ARIMA (0,1,1) model had the lowest MAPE value for production (10.817%). The point forecasts of sesame area and production of the selected models increased gradually over the forecast horizon. The results present quantitative evidence of the long-term growth, instability and forecast path of sesame production in India.

KEYWORDS: ARIMA; compound annual growth rate; Cuddy-Della Valle instability index; sesame; time-series forecasting; agricultural production.

1. INTRODUCTION

Sesame (*Sesamum indicum* L.), popularly called as “Til” in India, is one of the oldest oilseed crops grown for food and industrial uses and is sometimes referred to as the “Queen of Oilseeds”. It is known for its extraordinary drought resistance, low fertility soil tolerance and rich oil content that contains antioxidants and essential fatty acids. Sesame plays a pivotal role in India’s oilseed economy (1). It is adapted to tropical and subtropical areas (2). India is the largest producer of sesame with about 24% of the world's sesame area followed by Myanmar, Sudan, China and Uganda. Sesame is grown in India on about 17.5 lakh hectares with an annual production of about 770,000 tons, which is an average of 441 kg per hectare. China, however, has the highest productivity (3) in terms of yield. Low productivity in India has been linked to the use of marginal and sub-marginal land, low levels of input use and relatively low levels of improved production practice adoption (4). Maharashtra, Rajasthan, Madhya Pradesh, Gujarat, Uttar Pradesh, West Bengal, Tamil Nadu and Andhra Pradesh are the major sesame producing states in India.

In India, sesame production has been moderately decreasing in the last several years, mainly because of the unreliable climate and the lack of modern agricultural techniques (5). In response to these challenges and to decrease the reliance on edible oil imports, the Government of India has launched the National Mission on Edible Oils – Oilseeds (NEMO – Oilseeds) with a budget of Rs.10,103 crore up to 2030-31 (6). In this mission, sesame has been prioritized as a crop due to its export potential, health benefits and adaptability to rain-fed areas. To further support sesame farmers, several practical farming techniques are being promoted such as micro-irrigation, integrated pest management (IPM) and the use of modern equipment for sowing and harvesting. These interventions not only boost the efficiency of farming but also help in improving the yield. It is noteworthy that field trials with the sesame variety RT-351 have been conducted in Rajasthan with impressive results, leading to a 35-40% yield improvement over traditional varieties. These achievements demonstrate the potential for scaling up good practices and for having a significant impact on farmers (7).

2. Objectives

1. To identify the historical trends in area, production and yield of sesame in India.
2. To assess the variability in sesame cultivation using the Cuddy-Della Valle Instability Index (CDVI).
3. To forecast future sesame area and production in India using ARIMA modelling.

3. METHODOLOGY

The present study used a quantitative time-series analytical approach to analyze the past development, volatility and future course of sesame cultivation in India. The data on sesame area, production and productivity (yield) for the period 1994-95 to 2023-24 were analysed annually. The growth trends in area, production and productivity (8) were estimated by compound annual growth rate (CAGR) analysis and the Cuddy-Della Valle instability index (CDVI) was used to assess the instability after removing the underlying trend (9). Autoregressive Integrated Moving Average (ARIMA) models were used to predict the area and production of sesame for the forecast period (10,11).

Data Collection

Secondary data for sesame area, production and productivity were collected from the Area, Production and Yield (APY) database of the Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India (8) for the years 1994-95 to 2023-24. Data were broken down into three decadal sub-periods for comparison of growth and instability patterns: Period I (1994-95 to 2003-04), Period II (2004-05 to 2013-14) and Period III (2014-15 to 2023-24).

1. Growth Rate Analysis

Compound Annual Growth Rate (CAGR) Analysis

The compound annual growth rate (CAGR) was calculated to determine the annual growth rate of sesame area, production and productivity for each sub-period and overall study period. An exponential growth function was given by:

$$Y_t = Ae^{\beta t + \varepsilon_t}$$

where Y_t is the area, production or productivity of sesame in year t , A is the constant term, β is the estimated growth coefficient and t is the time variable. If the exponential function is taken to the natural log, it becomes:

$$\ln Y_t = \ln A + \beta t + \varepsilon_t$$

The ordinary least squares method was used to estimate the model after logarithmic transformation. The compound annual growth rate was:

$$CAGR = (e^{\beta} - 1) \times 100$$

where β is the estimated coefficient of the time variable.

2. Instability Index

Cuddy-Della Valle Instability Index (CDVI)

The Cuddy-Della Valle instability index (CDVI) was used to measure the instability in the area, production and productivity of sesame. The coefficient of variation (CV) was first calculated as:

$$CV = \frac{SD}{\bar{Y}} \times 100$$

where SD is the standard deviation and $\bar{Y}$ is the arithmetic mean of the respective time series. The Cuddy-Della Valle instability index was then calculated as:

$$CDVI = CV \sqrt{1 - R_{adj}^2}$$

Where R^2 is the adjusted coefficient of determination from the time-trend regression. The CDVI thus represents a measure of instability, once the trend component in the series (9) has been removed. CDVI values were considered low instability if the index was $< 15\%$, medium instability if it was $15\% - 30\%$ and high instability if it was $> 30\%$ (10).

3. ARIMA – Time Series Forecasting

The study used the Autoregressive Integrated Moving Average (ARIMA) approach based on the Box–Jenkins framework to predict the area and production of sesame in India. ARIMA models are widely used for modelling and forecasting of univariate time-series data which are composed of autoregressive, differencing and moving-average components (11).

An ARIMA model is represented as ARIMA (p, d, q), where p denotes the order of the autoregressive component, d denotes the order of differencing and q denotes the order of the moving-average component. The general model can be written in backshift notation as:

$$\phi(B)(1 - B)^d Y_t = c + \theta(B)\varepsilon_t$$

where B is the backshift operator, Y_t is the observed value of the series at time t , c is the constant term, $\phi(B)$ and $\theta(B)$ are the autoregressive and moving-average polynomials, respectively and ε_t is the random error term (11).

The model development was done using the Box–Jenkins approach. Prior to model identification, the time series were examined for stationarity. If the series was found to be non-stationary, then it was differenced to make it stationary. Next, the autocorrelation function (ACF) and the partial autocorrelation function (PACF) of the stationary series were analyzed to determine possible autoregressive (AR) and moving-average (MA) orders and to suggest candidate ARIMA models (12).

The sesame area and production were estimated separately by candidate ARIMA models. Model fit measures and residual diagnostics were used to assess the fitted models. The residual ACF and PACF were checked for the presence of any remaining serial correlation and satisfactory models would have approximately uncorrelated residuals and residuals that are consistent with a white-noise process (12).

The candidate ARIMA models were evaluated and the model with the minimum mean absolute percentage error (MAPE) with satisfactory residual diagnostics was considered for selection. MAPE was calculated as:

$$MAPE = \frac{100}{n} \sum_{t=1}^n \left| \frac{Y_t - \hat{Y}_t}{Y_t} \right|$$

where Y_t is the actual value at time t , $\hat{Y}_t$ is the fitted value and n is the number of observations used to calculate the error measure.

After model selection and diagnostic checking, the selected ARIMA models were used to generate forecasts of sesame area and production for the specified forecast horizon.

4. Results and Discussion

For the purposes of this study, Annual data on sesame area, production and productivity in India from 1994-95 to 2023-24 were analysed to understand the long-term trends and temporal variation. The analysis was carried out on the changes in the cultivated area, total production and productivity during the study period. The sesame area, production and productivity trends in India are shown in Fig. 1.

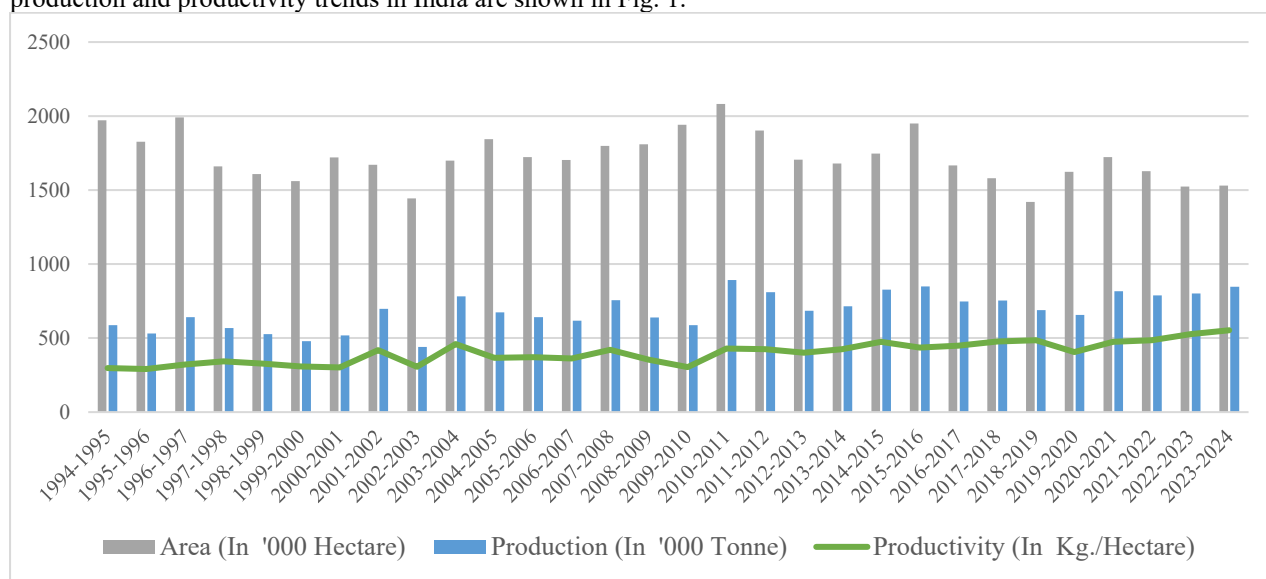


Figure 1. Trends in area, production and productivity of sesame in India, 1994–95 to 2023–24.

Trend in Area, Production and Yield of Sesame in India

The compound annual growth rates of sesame area, production and productivity in India for the three sub-periods and the study period are given in Table 1. In Period I (1994-95 to 2003-04), the area of sesame decreased by 2.265% annually while the production and productivity of sesame increased by 0.813% and 3.150% annually, respectively. So, the rise in productivity more than compensated for the fall in acreage and production rose marginally during this period. In Period II (2004-05 to 2013-14), area was virtually unchanged (+0.091%) and production and productivity grew by 1.686% and 1.594% annually, respectively. Sesame area decreased by 1.589% annually, production increased by almost nothing (0.157%) annually and productivity increased by 1.776% annually during Period III (2014–15 to 2023–24). During the entire study period (1994-95 to 2023-24), the area of sesame experienced a slight negative growth rate of -0.336% per year, while the production and productivity of sesame grew by 1.482% and 1.823% per year, respectively. The increase in production has been achieved despite a slight decrease in area, suggesting that productivity improvements have contributed to the overall increase over the study period (13). The long-term trend observed is in line with the findings of regional sesame studies which indicate that area, production and productivity growth can significantly differ between locations and periods (13).

Table 1. Compound annual growth rates (%) of sesame area, production and productivity in India.

S. No.	Particulars	Area	Production	Productivity
1	Period I	-2.265	0.813	3.150
2	Period II	0.091	1.686	1.594
3	Period III	-1.589	0.157	1.776
4	Overall period	-0.336	1.482	1.823

Instability in Area, Production and Yield of Sesame in India

Table 2 gives the Cuddy-Della Valle instability index of sesame area, production and productivity in India during the three sub-periods and the study period. In Period I (1994-95 to 2003-04), area had low instability (7.196%), production had medium instability (17.559%) and productivity had low instability (13.186%). The CDVI for area, production and productivity in Period II (2004-05 to 2013-14) were 7.036%, 12.379% and 9.573%, respectively, which are considered low. The instability of area, production and productivity were also low in Period III (2014–

15 to 2023-24) with CDVI values of 7.395%, 8.416% and 6.937%, respectively. The CDVI values for area, production and productivity were 8.999%, 12.412% and 9.818%, respectively, for the overall study period, which were all low. The results thus show that production decreased and productivity instability increased from Period I to Period III and area instability was in the low instability category for all three sub-periods. The CDVI values for production and productivity in the latter period are relatively lower, suggesting more stability in the national-level time series than in Period I (14).

Table 2. Cuddy-Della Valle instability index (%) of sesame area, production and productivity in India.

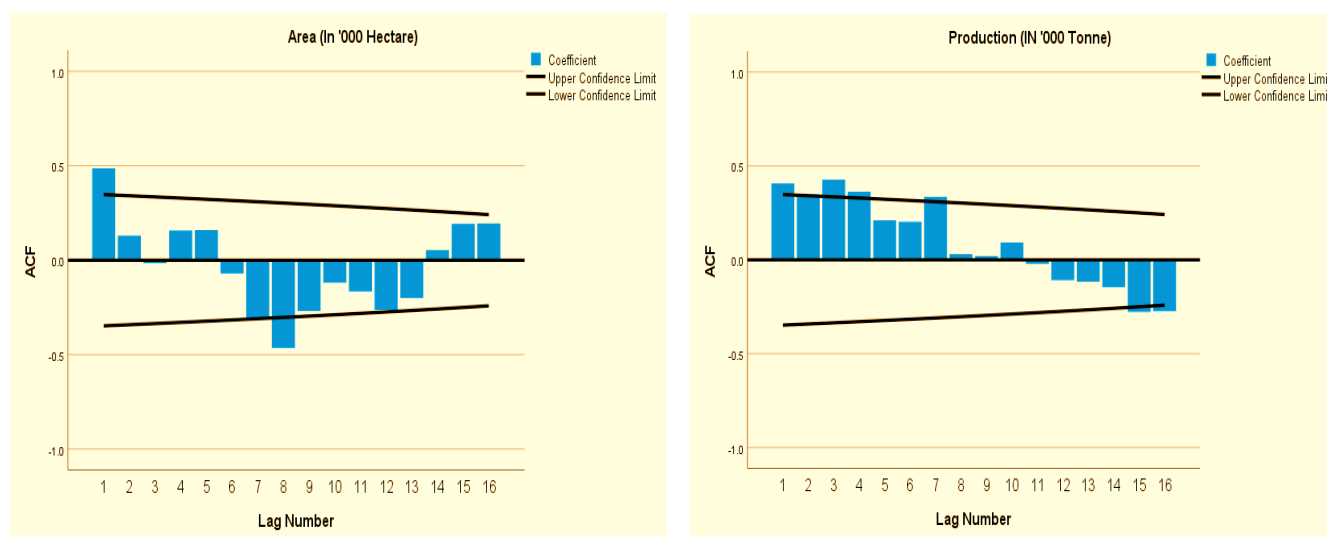
S. No.	Particulars	Area	Production	Productivity
1	Period I	7.196	17.559	13.186
2	Period II	7.036	12.379	9.573
3	Period III	7.395	8.416	6.937
4	Overall period	8.999	12.412	9.818

ARIMA model outcomes

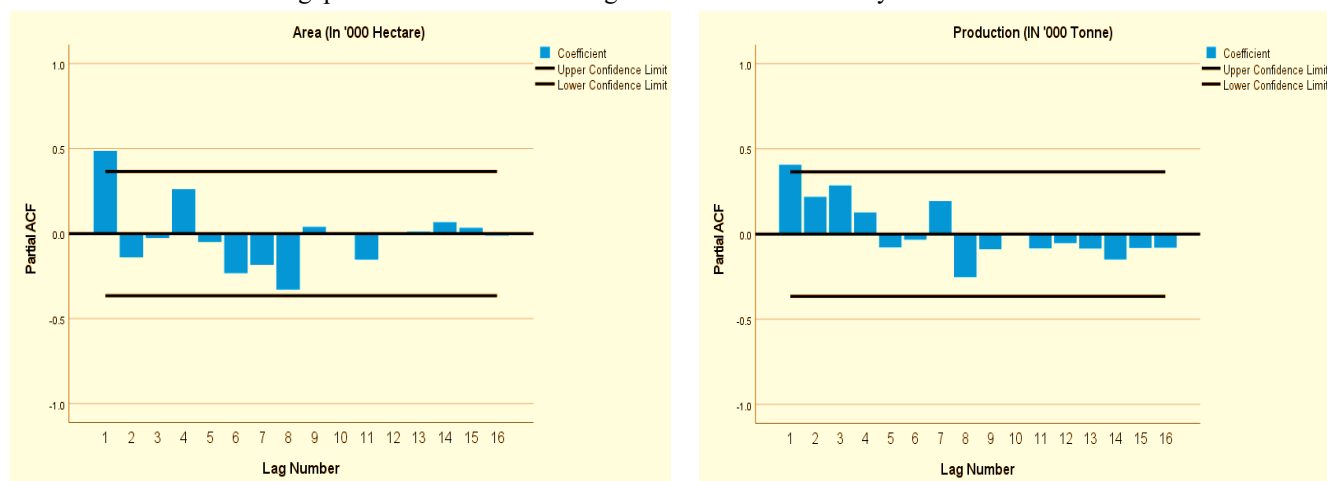
To identify the autoregressive and moving-average orders (11) for the ARIMA model, the ACF and PACF plots of the sesame area and production series were examined to assess the serial dependence in the series. The ACF plots of area and production exhibited significant autocorrelation at several low lags, suggesting persistence in the series and the PACF plots of area and production gave information about the autoregressive dependence at the different lags. The error measure and residual diagnostics were used to compare the candidate models with different combinations of autoregressive, differencing and moving-average orders, as the orders of a mixed ARIMA model are not uniquely determined by the ACF and PACF patterns. Figures 2 and 3 show the ACF and PACF plots for model identification.

Figure 2. Autocorrelation function (ACF) plots of sesame area and production.

Figure 3. Partial autocorrelation function (PACF) plots of sesame area and production.



Five candidate ARIMA models were tested for sesame area. ARIMA (1,0,1) had the lowest MAPE of 6.648% and was chosen for forecasting provided the residual diagnostics were satisfactory. The other candidate models



recorded MAPE values of 6.913% for ARIMA (1,0,0), 7.065% for ARIMA (1,1,1), 7.559% for ARIMA (0,1,1) and 7.709% for ARIMA (1,1,0) (Table 4).

Five ARIMA models were also tested for sesame production. Based on the satisfactory residual diagnostics, ARIMA (0,1,1) was chosen for forecasting with the lowest MAPE of 10.817%. The corresponding MAPE values were 13.740% for ARIMA (1,0,0), 11.126% for ARIMA (1,1,1), 12.111% for ARIMA (1,0,1) and 13.572% for ARIMA (1,1,0) (Table 3).

Table 3. MAPE (%) of candidate ARIMA models for sesame production.

Model	MAPE (%)
ARIMA (1,0,0)	13.740
ARIMA (1,1,1)	11.126
ARIMA (0,1,1)	10.817
ARIMA (1,0,1)	12.111
ARIMA (1,1,0)	13.572

Figures 4 and 5 show the residual ACF and PACF plots for the selected area and production models. There was no obvious systematic autocorrelation in the residual plots and the residual autocorrelations were all within the plotted confidence limits at the inspected lags. This means that the chosen models were able to pick up the overall serial dependence of the respective series.

Figure 4. Residual autocorrelation function (ACF) and partial autocorrelation function (PACF) plots of the selected ARIMA (1,0,1) model for sesame area.

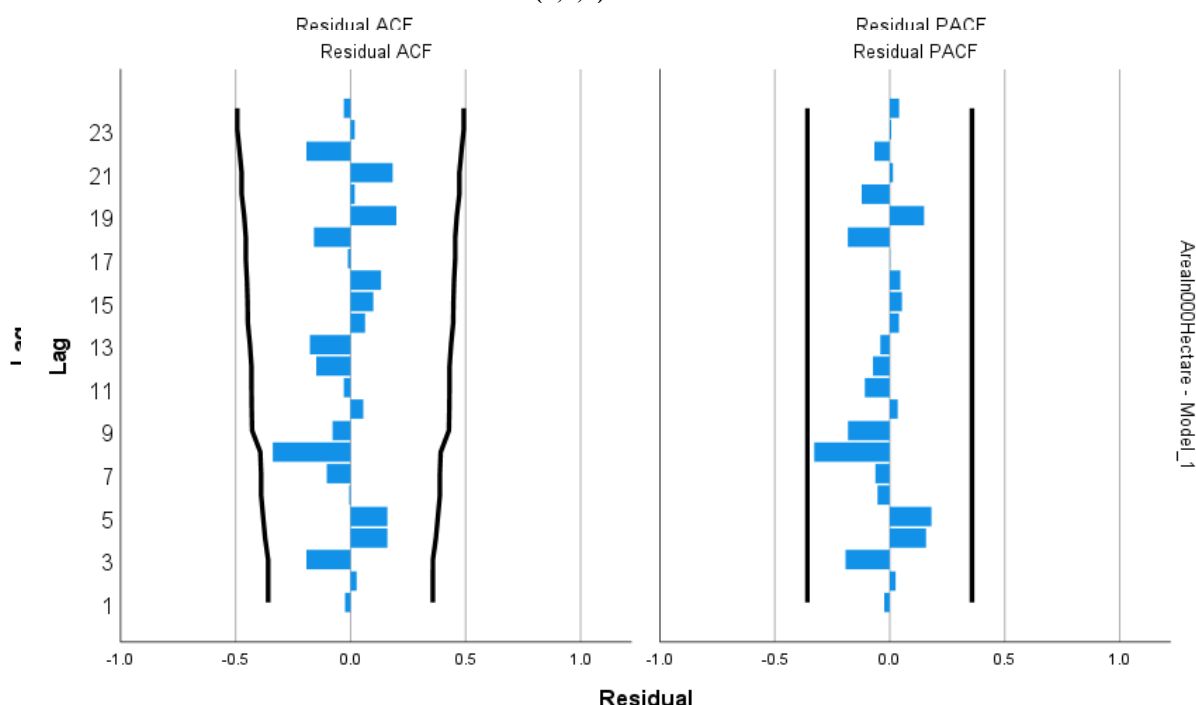


Figure 5. Residual autocorrelation function (ACF) and partial autocorrelation function (PACF) plots of the selected ARIMA (0,1,1) model for sesame production.

Forecast Error Assessment

The mean absolute percentage error (MAPE) was used to compare the candidate ARIMA models for sesame area and production. The corresponding MAPE values are presented in Tables 3 and 5, respectively.

Forecasting of Sesame Area and Production Using Candidate ARIMA Models

Tables 5 and 6 show the point forecasts of the sesame area and production, respectively, produced by the candidate ARIMA models.

The point forecasts for the sesame area in India for the candidate ARIMA models are shown in Table 5. The ARIMA (1,0,1) model had the smallest MAPE (6.648%) among the models tested and was chosen for the sesame area forecasting (Table 4). The selected model predicted a point forecast of 1,633 thousand hectares for 2025, 1,691 thousand hectares for 2026 and 1,714 thousand hectares for 2027, showing a gradual increase in the forecasted area for the forecast horizon.

Table 4. MAPE (%) of candidate ARIMA models for sesame area.

Model	MAPE (%)
ARIMA (1,0,0)	6.913
ARIMA (1,1,1)	7.065

ARIMA (0,1,1)	7.559
ARIMA (1,0,1)	6.648
ARIMA (1,1,0)	7.709

Table 5. Point forecasts of sesame area under candidate ARIMA models in India, 2025–2027.

Forecasted Area (in '000 Hectare)			
Model	2024-2025	2025-2026	2026-2027
ARIMA (1,0,0)	1621	1670	1696
ARIMA (1,1,1)	1561	1574	1579
ARIMA (0,1,1)	1526	1513	1499
ARIMA (1,0,1)	1633	1691	1714
ARIMA (1,1,0)	1513	1499	1484

Table 6 shows the point forecasts for the sesame production in India for the candidate ARIMA models. The results indicated that the ARIMA (0,1,1) model had the lowest MAPE of 10.817% (Table 5) and was chosen for forecasting sesame production. The chosen model predicted the point forecast of 818 thousand tonnes in 2025, 826 thousand tonnes in 2026 and 835 thousand tonnes in 2027, which shows an increase in the sesame production forecast over the forecast period.

Table 6. Point forecasts of sesame production under candidate ARIMA models in India, 2025–2027.

Forecasted Production (in '000 Tonnes)			
Model	2024-2025	2025-2026	2026-2027
ARIMA (1,0,0)	756	717	700
ARIMA (1,1,1)	835	846	856
ARIMA (0,1,1)	818	826	835
ARIMA (1,0,1)	778	773	768
ARIMA (1,1,0)	839	857	862

5. CONCLUSION

The study analysed the growth and instability of sesame area, production and productivity in India and predicted sesame area and production based on annual data from 1994-95 to 2023-24. The sesame area decreased marginally by 0.336% per year, while production and productivity grew by 1.482% and 1.823% per year, respectively, during the entire study period. Low instability was observed in sesame area, production and productivity during the overall study period as per the Cuddy-Della Valle instability index. Production was medium unstable at 17.559%, area was low unstable at 7.196% and productivity was low unstable at 13.186% during Period I. Production and productivity instability dropped to low during the following sub-periods. The ARIMA (1,0,1) model was chosen for sesame area and the ARIMA (0,1,1) model was chosen for sesame production with the lowest reported MAPE values, which resulted in gradual increases in the corresponding point forecasts over the forecast horizon. The results highlight the ongoing importance of productivity improvement and agricultural interventions to support sesame production in India. But the study does not directly estimate the causal effects of individual policies, technologies, climatic conditions or other factors on the changes in sesame area, production and productivity.

6. LIMITATIONS

The study has some limitations that need to be taken into account when analyzing the results. First, it relies on secondary annual time-series data from 1994-95 to 2023-24 and hence on the coverage, consistency and accuracy of the underlying official statistics. Second, the growth and instability analyses are descriptive of the past and do not provide any causal explanation of the impact of climatic conditions, government policies, technological change, input use, labour availability or market factors on the changes in sesame area, production and productivity. Third, the ARIMA models are univariate forecasting models and thus mainly depend on the past behaviour of the series to be forecasted without explicitly using any external explanatory variables. Lastly, the forecasts are model-based estimates for the forecast horizon considered and could deviate from future actual values in case of structural changes or unexpected shocks.

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Authors' contributions

NR performed the study, analyzed the data and wrote the manuscript. BP participated in the design of the study, supervision and revision of the manuscript. MD and VS participated in data analysis, interpretation and revision. KM helped design and supervise the study. VMI provided methodological guidance, supervision and critical revision. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests.

Ethical issues: None.

Declaration of generative AI and AI-assisted technologies in the writing process

The AI was used only for grammar checking and for the clarity and readability of the manuscript. The authors have used the tool and reviewed and edited the content and are responsible for the final content of the manuscript.

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