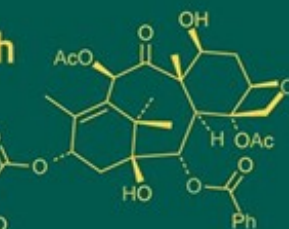
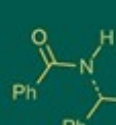
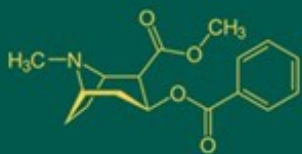


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Kommineni Jagadeesh

Professor Jayashankar
Telangana agricultural
University, Rajendranagar,
Hyderabad, Telangana, India

KB Eswari

Professor Jayashankar
Telangana agricultural
University, Rajendranagar,
Hyderabad, Telangana, India

**Rama Kanth Reddy
Patlolla**

Professor Jayashankar
Telangana agricultural
University, Rajendranagar,
Hyderabad, Telangana, India

Dharavath Hathiram

Professor Jayashankar
Telangana agricultural
University, Rajendranagar,
Hyderabad, Telangana, India

**Corresponding Author:
Kommineni Jagadeesh**

Professor Jayashankar
Telangana agricultural
University, Rajendranagar,
Hyderabad, Telangana,
India

Forecasting of pearl millet (*Pennisetum glaucum* L.) area, production and productivity in India using ARIMA approach

Kommineni Jagadeesh¹, KB Eswari², Rama Kanth Reddy Patlolla³, Dharavath Hathiram⁴

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ABSTRACT

Pearl millet is one of the most important climate-resilient cereal crops cultivated in the arid and semi-arid regions of India. Understanding long-term trends in its cultivation and production is essential for strategic planning and ensuring future food and nutritional security. The present study was undertaken to analyze the growth dynamics, instability, and future prospects of pearl millet cultivation in India using annual data on area, production, and productivity from 1949–50 to 2024–25. Compound growth rate (CGR), coefficient of variation (CV), and Cuddy–Della Valle instability index (CDVI) were employed to assess long-term trends and variability. Autoregressive Integrated Moving Average (ARIMA) models were used to forecast future trends up to 2035. The results revealed a negative growth rate in cultivated area (−0.64% per annum), indicating a gradual reduction in land allocated to pearl millet cultivation. However, production and productivity recorded positive growth rates of 1.66% and 2.31% per annum, respectively. Area exhibited relatively low instability (CDVI = 10.83), whereas production (20.20) and productivity (22.24) showed comparatively higher fluctuations. ARIMA(2,1,0), ARIMA(0,1,2) with drift, and ARIMA(1,1,2) with drift were identified as the best-fitting models for area, production, and productivity, respectively. Forecasts indicated a continued decline in cultivated area from 7008.66 thousand ha in 2026 to 6802.99 thousand ha by 2035. In contrast, production is projected to increase from 10.95 to 11.50 million tonnes, while productivity is expected to rise from 1527.75 to 1713.31 kg ha^{−1} during the same period. The findings demonstrate that productivity enhancement has been the primary driver of pearl millet production growth in India and will continue to play a crucial role in sustaining future production.

Keywords: Pearl millet, Growth rate, Instability analysis, ARIMA forecasting, Productivity, Food security

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.; $2n = 2x = 14$) is an important cereal crop cultivated predominantly in the arid and semi-arid regions of Asia and Africa, where it serves as a staple food for millions of people (Satyavathi *et al.*, 2021) [1]. Globally, millet cultivation covers 31.33 million ha, with Asia and Africa accounting for 11 million ha and 19.68 million ha, respectively (FAO 2025; <https://www.fao.org/faostat/en/#data/OCL>, Accessed 2025-01-02). India (13.5 million tons), Niger (3.35 million tons), and China (2.7 million tons) are the three major millet-producing countries in 2023 (FAO 2025). In India, Rajasthan has the largest area (4.35 million ha) and produces (4.67 million tons) (<https://www.indiastat.com/>). Its ability to perform well under high temperatures, low rainfall, poor soil fertility, and low-input conditions makes it one of the most climate-resilient cereals and a strategic crop for sustaining food production in fragile agro-ecologies. In recognition of the nutritional and ecological importance of millets, the United Nations General Assembly declared 2023 the International Year of Millets. Pearl millet is therefore increasingly viewed not only as a hardy dryland crop, but also as a valuable component of climate-resilient and nutrition-sensitive agriculture.

Pearl millet grains are highly nutritious, provide a good source of energy (363 kcal), protein (12.8%), vitamins and minerals particularly rich in iron (34–90 mg/kg), zinc (30–74 mg/kg), Ca (85–249 mg/kg), crude fiber (2.3g/100g), thus it is an important climate-resilient nutri-cereal for mitigating hidden hunger and provide nutritional security in Africa and Asia (Govindaraj *et al.*, 2020; Saleh *et al.*, 2013) [2, 3]. Beyond its nutritional significance, pearl millet plays a crucial role in sustaining livelihoods in marginal environments where cultivation of other cereals is often constrained by moisture stress and poor soil conditions. The crop serves as an important source of food, fodder, and income for millions of smallholder farmers and contributes substantially to the resilience of dryland farming systems. In recent years, increasing concerns regarding climate change, food security, and nutritional security have renewed global interest in millets. Recognition

of pearl millet as a climate-smart crop culminated in the declaration of 2018 as the National Year of Millets in India and the designation of 2023 as the International Year of Millets by the United Nations, highlighting its potential role in developing sustainable and resilient food systems. Consequently, understanding long-term trends in pearl millet cultivation and productivity has become increasingly important for policymakers, researchers, and development agencies.

Over the past seven decades, Indian agriculture has undergone substantial transformations driven by technological advancements, policy interventions, irrigation expansion, and changing cropping patterns. These changes have influenced the area under pearl millet cultivation, production levels, and productivity. While the cultivated area of pearl millet has generally declined, improvements in crop genetics and agronomic practices have resulted in significant yield gains. The analysis of historical trends and future forecasting provides valuable insights into the sustainability and future prospects of crop production systems. Among the forecasting models, the time-series forecasting particularly ARIMA models, have been widely used in agricultural research to predict future production trends and support evidence-based planning. Therefore, the present study was undertaken with the following objectives of assessing the long-term trends in area, production, and productivity of pearl millet in India and to estimate growth rates and instability in pearl millet cultivation. Thus study of forecasting the future trends in area, production, and productivity using ARIMA models can aid designing the strategies for enhancing the

consumption and integrating the nutrient crop like pearl millet into Indian diet.

Materials and Methods

Data source

The annual data on pearl millet area ('000 ha), production ('000 tonnes), and productivity (kg ha⁻¹) for India from 1949–50 to 2024–25 was downloaded from the Indiatat (<https://www.indiatat.com>). The dataset comprised 77 annual observations representing more than seven decades of pearl millet cultivation in India.

Estimation of compound growth rate

The compound growth rate was estimated using a semi-logarithmic regression model:

$$\ln(Y) = a + bt$$

where Y represents area, production, or productivity; *a* is the intercept; *b* is the regression coefficient; and *t* is time.

The compound growth rate was calculated as:

$$\text{CGR}(\%) = [\exp(b) - 1] \times 100$$

Instability analysis

The coefficient of variation (CV) was computed as:

$$\text{CV}(\%) = (\text{Standard deviation}/\text{Mean}) \times 100$$

To account for trend effects, instability was estimated using the Cuddy–Della Valle Index (CDVI):

$$\text{CDVI} = \text{CV} \times \sqrt{1 - R^2}$$

where *R*² is the coefficient of determination obtained from trend regression.

Time-series forecasting

Time-series forecasting was performed using Autoregressive Integrated Moving Average (ARIMA) models following the methodology proposed by (Box *et al.*, 1976) [4]. Stationarity of the series was examined using the Augmented Dickey–Fuller (ADF) test (Dickey *et al.*, 1979) [5]. The best-fitting models were selected based on the lowest Akaike Information Criterion (AIC) (Akaike, 1974) [6]. Further, the model adequacy was evaluated using residual diagnostics and the Ljung–Box test (Burns, 2002) [7]. Forecasts were generated for the period 2026–2035.

Results and discussion

Long-term trends in pearl millet cultivation

The historical data revealed substantial changes in pearl millet cultivation over the study period. The area under pearl millet cultivation declined from 9.30 million ha during 1949–50 to approximately 7.36 million ha during 2024–25. Despite this decline in cultivated area, production increased from 2.80 million tonnes to more than 11 million tonnes during the same period. The Productivity exhibited remarkable improvement, increasing from 306 kg ha⁻¹ in 1949–50 to more than 1500 kg ha⁻¹ in recent years. These observations indicate that productivity enhancement has been the principal factor contributing to increased pearl millet production in India.

The decline in cultivated area may be attributed to changing cropping patterns, expansion of irrigated agriculture, urbanization, and increasing preference for alternative commercial crops in several regions of the country. Similar declines in millet acreage have been reported in

India due to agricultural intensification and diversification towards crops offering higher economic returns (Sandeep *et al.*, 2025) [8]. Nevertheless, pearl millet continues to remain an important crop in rainfed and drought-prone regions because of its resilience under adverse environmental conditions, including drought, high temperature, and poor soil fertility (Govindaraj *et al.*, 2020; Yadav *et al.*, 2012) [2, 9].

The substantial increase in production despite declining cultivated area reflects the success of crop improvement programs and technological interventions implemented during the last several decades. The widespread adoption of hybrids, improved agronomic practices, and enhanced input use efficiency have significantly contributed to productivity enhancement in pearl millet production systems (Kumar *et al.*, 2018; Yadav *et al.*, 2013) [10, 11].

Growth rate analysis

The compound growth rate analysis revealed contrasting trends among the studied variables (Table 1). The area under pearl millet cultivation recorded a negative growth rate of -0.64% per annum, indicating a gradual reduction in cultivated area over time. In contrast, production and productivity exhibited positive growth rates of 1.66% and 2.31% per annum, respectively. The higher growth rate observed for productivity compared with production suggests that improvements in yield have been the primary contributor to increased production. The positive growth observed for production and productivity highlights the increasing efficiency of pearl millet production systems in India. Similar trends have been documented in other cereal crops where technological progress and genetic improvement have been the major factors contributing towards increase in production trends (Pingali, 2012) [12]. The results therefore suggest that future increases in pearl millet production are likely to depend more on productivity enhancement rather than expansion of cultivated area. But considering impact of climate change and need for nutritional rich crops like millet, expansion of area of pearl millet is also much essential which together can contribute its enhanced production.

Table 1. Growth rate and instability parameters of pearl millet in India.

Variable	CAGR (%)	CV (%)	CDVI
Area	-0.64	17.21	10.83
Production	1.66	40.34	20.20
Productivity	2.31	55.49	22.24

Note: CAGR, compound annual growth rate; CV, coefficient of variation; CDVI, Cuddy–Della Valle instability index. Negative CAGR values indicate a declining trend over the study period

Instability analysis

The coefficient of variation and Cuddy–Della Valle Index indicated differing levels of variability among the studied variables. Area exhibited the lowest instability (CDVI = 10.83), indicating relatively stable land allocation despite the long-term declining trend. Production and productivity showed higher instability, with CDVI values of 20.20 and 22.24, respectively.

The comparatively lower instability in area suggests that farmers continue to maintain pearl millet cultivation in drought-prone and resource-poor regions where alternative crop options are limited. However, the greater instability observed in production and productivity indicates a stronger influence of environmental and management factors on crop performance. Pearl millet is predominantly cultivated under rainfed conditions, making it highly susceptible to fluctuations in rainfall distribution, drought stress, and seasonal climatic variability. Consequently, yield variation directly affects production levels from year to year.

The higher instability observed for productivity compared with area further suggests that technological interventions, adoption of improved cultivars, changes in agronomic practices, and variability in input use have contributed to fluctuations in crop performance over time. Similar observations have been reported in earlier studies on pearl millet and other rainfed cereals, where productivity exhibited greater variability than cultivated area due to the combined effects of climatic uncertainty and technological change.

Despite the observed variability, the positive growth rates recorded for production and productivity indicate that technological advancements and genetic improvement have successfully offset the adverse effects of climatic fluctuations (Sinha *et al.*, 2021) [13]. Therefore, sustained investment in climate-resilient cultivars, improved crop management practices, and enhanced irrigation infrastructure will be essential for reducing production instability and ensuring future food and nutritional security.

ARIMA model selection and diagnostics

The Augmented Dickey–Fuller (ADF) test indicated non-stationarity in the original time series for area and productivity, necessitating first-order differencing to achieve stationarity before model fitting. Similar observations have been reported in long-term agricultural time series, where trends associated with technological progress and structural changes often result in non-stationary behaviour. Based on the minimum Akaike Information Criterion (AIC), ARIMA(2,1,0) was identified

as the most suitable model for area, whereas ARIMA(0,1,2) with drift and ARIMA(1,1,2) with drift were selected for production and productivity, respectively (Table 2).

The relatively low AIC values obtained for the selected models indicate their superior ability to explain the temporal variability in the data while maintaining model parsimony. The inclusion of a drift component in the production and productivity models suggests the presence of an underlying long-term positive trend in these variables, reflecting sustained improvements in pearl millet production systems over time. Such positive trends are likely associated with technological advancements, genetic improvement, enhanced crop management practices, and increasing adoption of improved cultivars.

Residual diagnostics further confirmed the adequacy of the selected models. The Ljung–Box test yielded non-significant p -values ($p > 0.05$) for all models, indicating the absence of residual autocorrelation and suggesting that the models successfully captured the temporal dependence present in the data. Moreover, the residuals exhibited characteristics of white noise, implying that no systematic information remained unexplained after model fitting.

The satisfactory performance of the selected ARIMA models demonstrates their suitability for forecasting pearl millet area, production, and productivity. Similar studies have reported the effectiveness of ARIMA models in forecasting agricultural production and productivity due to their ability to capture historical trends and temporal dependencies in time-series data (Box & Jenkins, 1976; Paul & Sinha, 2016) [4]. Therefore, the selected models were subsequently used to generate forecasts of pearl millet area, production, and productivity for the period 2026–2035.

Table 2. Best-fitting ARIMA models for pearl millet variables.

Variable	Model	AIC
Area	ARIMA(2,1,0)	1235.96
Production	ARIMA(0,1,2) with drift	1313.74
Productivity	ARIMA(1,1,2) with drift	934.23

Note: AIC - Akaike Information Criterion

Forecasting of pearl millet area

The ARIMA (2,1,0) model predicted a gradual decline in pearl millet area over the forecast period. The cultivated area is expected to decrease from 7008.66 thousand ha in 2026 to 6802.99 thousand ha by 2035. The projected decline reflects the continuation of historical trends associated with crop diversification and changing land-use patterns. Despite the reduction in cultivated area, pearl millet is expected to maintain its importance in dryland agricultural systems due to its resilience under adverse climatic conditions. Further, the widening confidence intervals associated with long-term forecasts indicate increasing uncertainty with forecast horizon, a common characteristic of time-series projections. Nevertheless, the overall forecast trajectory consistently suggests a gradual decline in area rather than abrupt changes in cultivation patterns, indicating relative stability in future land allocation decisions.

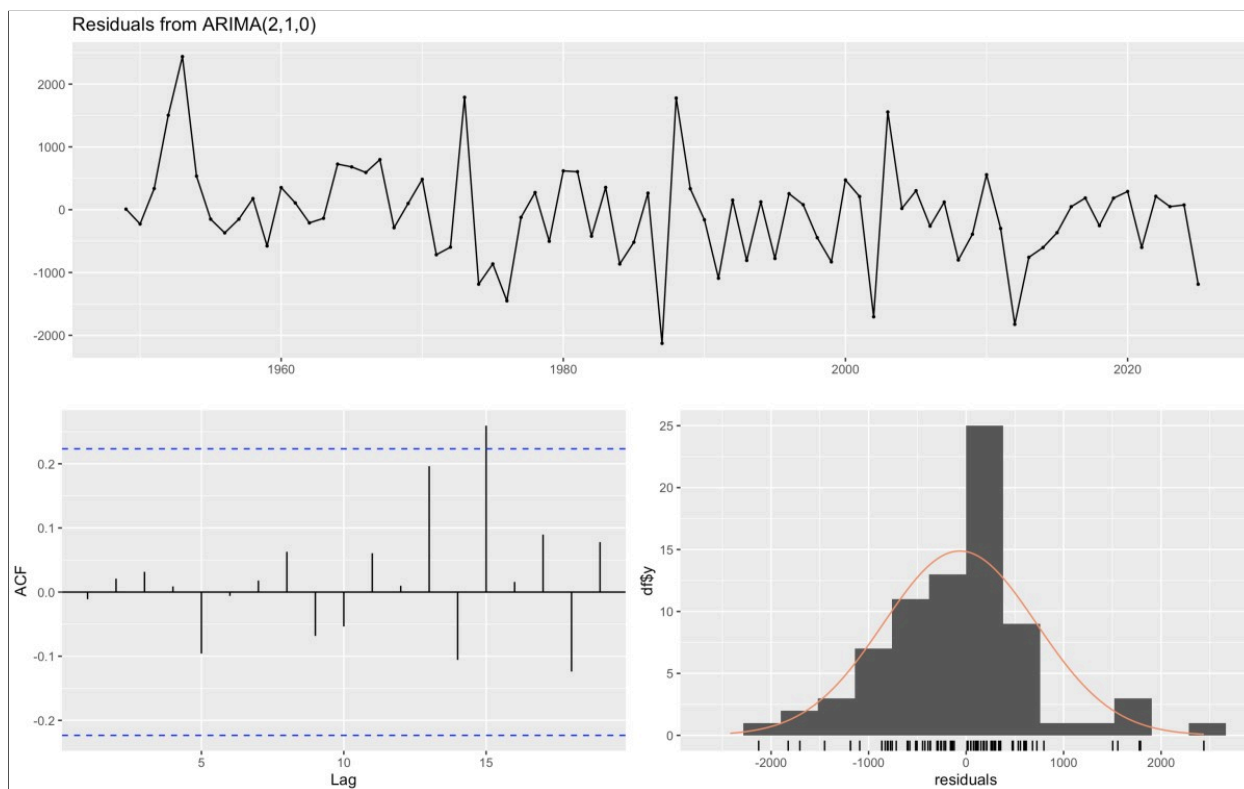


Figure 1. Residual diagnostic plots for the ARIMA(2,1,0) model fitted to pearl millet area data, showing residual time series, autocorrelation function (ACF), and residual distribution.

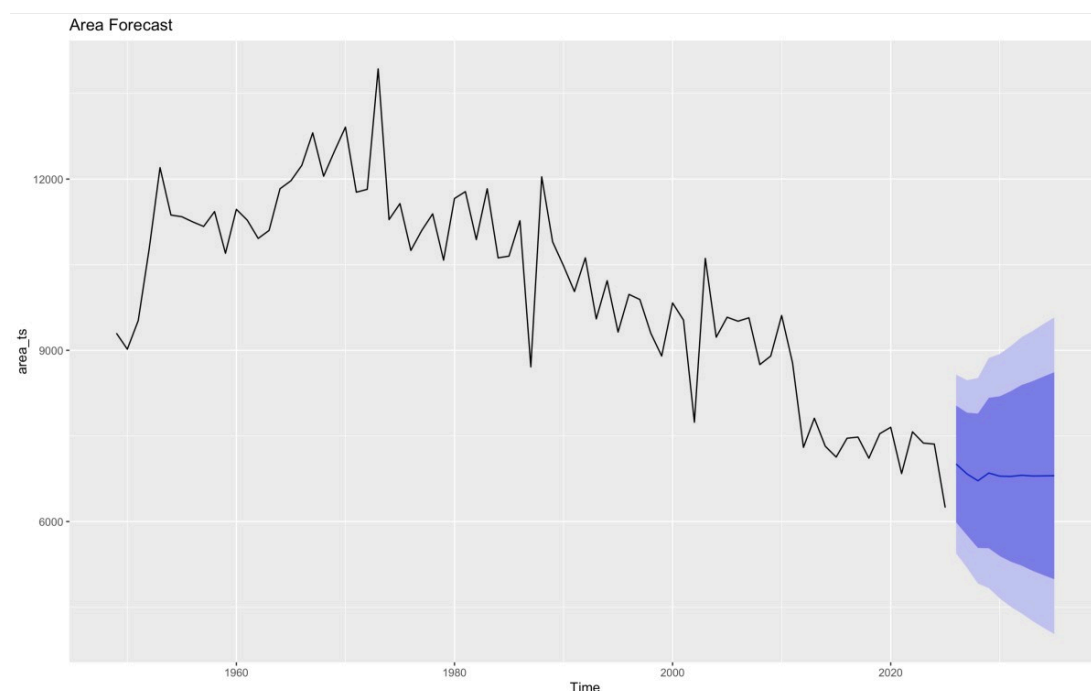


Figure 2. Historical trend and ARIMA(2,1,0)-based forecast of pearl millet cultivated area in India (1949–2035).

Forecasting of pearl millet production

Production forecasts generated using the ARIMA (0,1,2) model with drift indicated a gradual increase from 10.95 million tonnes in 2026 to 11.50 million tonnes by 2035. The positive drift parameter suggests sustained long-term growth in production. The projected increase in production despite declining cultivated area highlights the importance of productivity gains in supporting future production growth. Several

factors may contribute to the projected increase in production, including the continued adoption of improved hybrids and varieties, enhanced seed systems, better nutrient and water management practices, and advancements in crop breeding. Furthermore, increasing recognition of pearl millet as a climate-resilient and nutrient-dense cereal, coupled with national and international initiatives promoting millet cultivation, may further support production growth in the coming years.

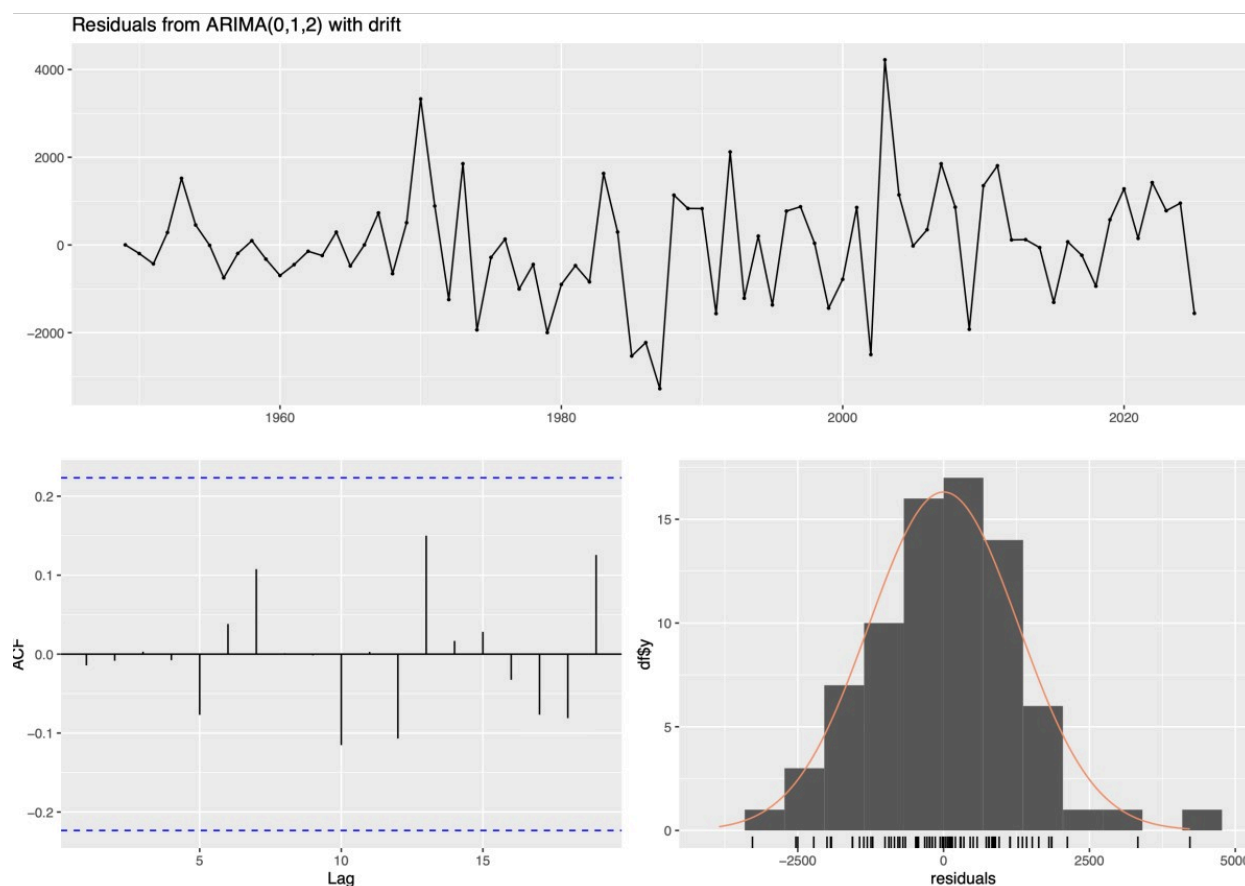


Figure 3. Residual diagnostic plots for the ARIMA(2,1,0) model fitted to pearl millet production data, showing residual time series, autocorrelation function (ACF), and residual distribution.

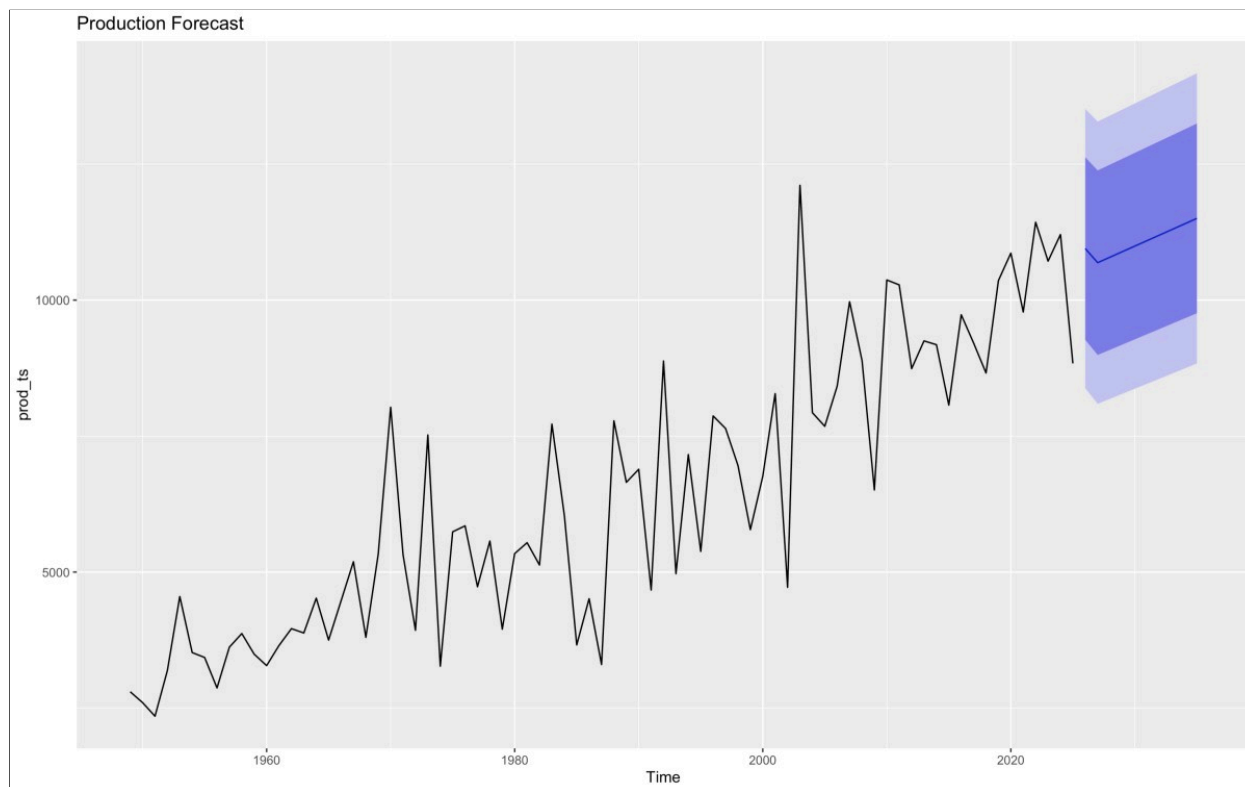


Figure 4. Historical trend and ARIMA(0,1,2)-based forecast of pearl millet production in India (1949–2035).

Forecasting of pearl millet productivity

The ARIMA (1,1,2) model with drift predicted a steady increase in productivity from 1527.75 kg ha⁻¹ in 2026 to 1713.31 kg ha⁻¹ in 2035. The projected increase reflects ongoing technological progress and

continued genetic improvement of pearl millet cultivars. The forecast suggests that future gains in pearl millet production will be driven primarily by productivity enhancement rather than expansion of cultivated area. This trend is particularly important in the context of increasing land-use competition and climate change. Further, Therefore,

continued productivity enhancement through genetic improvement and technological innovation will be crucial for strengthening food, nutritional, and livelihood security in vulnerable dryland regions.

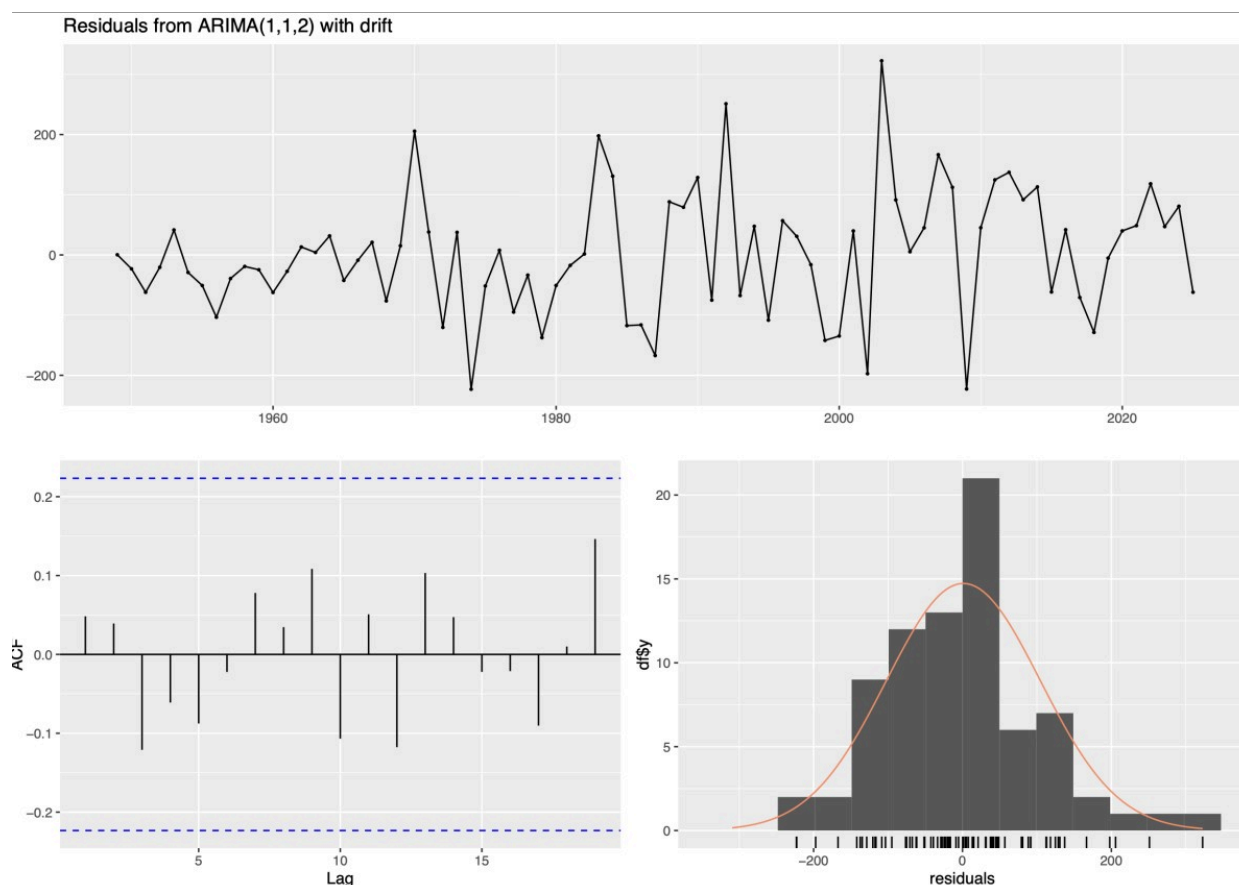


Figure 5. Residual diagnostic plots for the ARIMA(2,1,0) model fitted to pearl millet productivity data, showing residual time series, autocorrelation function (ACF), and residual distribution.

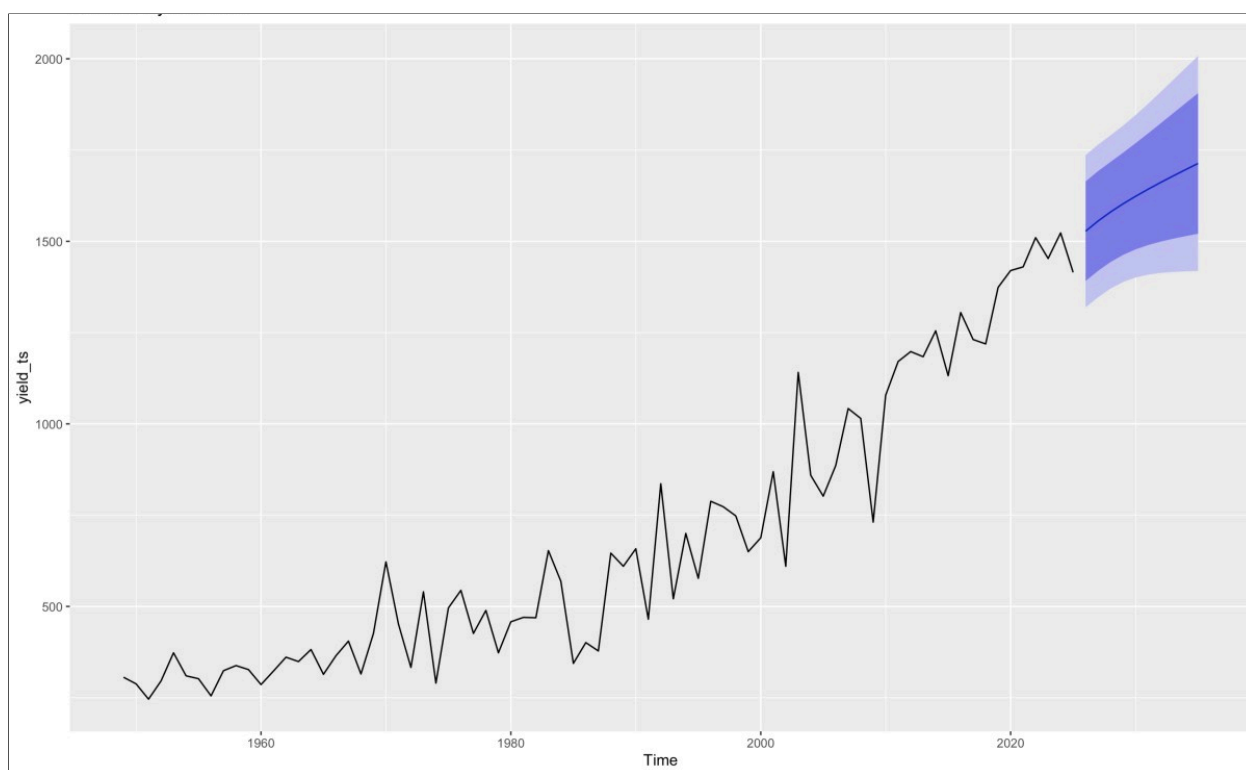


Figure 6. Historical trend and ARIMA(1,1,2)-based forecast of pearl millet productivity in India (1949–2035).

Table 3. Forecasted area, production and productivity of pearl millet in India.

Year	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg ha ⁻¹)
2026	7008.66	10947.82	1527.75
2027	6833.73	10687.57	1555.80
2028	6714.93	10789.40	1580.51
2029	6850.42	10891.23	1602.81
2030	6795.01	10993.07	1623.38
2031	6790.61	11094.90	1642.72
2032	6810.87	11196.73	1661.16
2033	6798.42	11298.56	1678.96
2034	6800.60	11400.39	1696.30
2035	6802.99	11502.22	1713.31

Conclusion

The present study demonstrated significant changes in pearl millet cultivation in India over the last seven decades. Although the area under cultivation declined at an annual rate of 0.64%, production and productivity increased substantially, with growth rates of 1.66% and 2.31% per annum, respectively. Instability analysis indicated relatively stable cultivated area but greater fluctuations in production and productivity. ARIMA forecasting suggested that the declining trend in area is likely to continue; however, production and productivity are expected to increase steadily up to 2035. These findings highlight the crucial role of technological advancements and genetic improvement in sustaining pearl millet production under changing agricultural and climatic conditions. Continued investment in breeding programs, climate-resilient cultivars, and improved crop management practices will be essential for ensuring future food and nutritional security in India. Further several efforts towards policies promoting millet cultivation can aid in increasing pearl millet area along with production and productivity.

References

1. Satyavathi CT, Ambawat S, Khandelwal V, Srivastava RK. Pearl Millet: A Climate-Resilient Nutricereal for Mitigating Hidden Hunger and Provide Nutritional Security. *Frontiers in Plant Science*. 2021;12(September):1–18.
2. Govindaraj M, Rai KN, Kanatti A, Upadhyaya HD, Shivade H, Rao AS. Exploring the genetic variability and diversity of pearl millet core collection germplasm for grain nutritional traits improvement. *Scientific Reports*. 2020;10(1):21177.
3. Saleh ASM, Zhang Q, Chen J, Shen Q. Millet grains: Nutritional quality, processing, and potential health benefits. *Comprehensive Reviews in Food Science and Food Safety*. 2013;12(3):281–295.
4. Box G, Jenkins GM. *Analysis: Forecasting and control*. San Francisco; 1976:10.
5. Dickey DA, Fuller WA. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*. 1979;74(366a):427–431.
6. Akaike H. A new look at the statistical model identification. *IEEE Transactions on Automatic Control*. 1974;19(6):716–723.
7. Burns P. Robustness of the Ljung-Box test and its rank equivalent. Available at SSRN 443560. 2002.
8. Sandeep K, Sharma A, Yashwant S, Parmar S. Millets in India: Evaluating the Current Scenario, Emerging Trends, Export Dynamics and Future Prospects. *Journal of Indian Society of Agricultural Statistics*. 2025;79(1):19–28.
9. Yadav OP, Rai KN, Gupta SK. Pearl Millet: Genetic Improvement in Tolerance to Abiotic Stresses. *Improving Crop Productivity in Sustainable Agriculture*. 2012:261–288.
10. Kumar A, Tomer V, Kaur A, Kumar V, Gupta K. Millets: A solution to agrarian and nutritional challenges. *Agriculture and Food Security*. 2018;7(1):1–15.
11. Yadav OP, Rai KN. Genetic Improvement of Pearl Millet in India. *Agricultural Research*. 2013;2(4):275–292.
12. Pingali PL. Green revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences of the United States of America*. 2012;109(31):12302–12308.
13. Sinha P, Singh VK, Bohra A, Kumar A, Reif JC, Varshney RK. Genomics and breeding innovations for enhancing genetic gain for climate resilience and nutrition traits. *Theoretical and Applied Genetics*. 2021;134(6):1829–1843.
14. Govindaraj M, Rai KN, Kanatti A, Upadhyaya HD. Exploring the genetic variability and diversity of pearl millet core collection germplasm for grain nutritional traits improvement. *Scientific Reports*. 2020;(0123456789):1–13.

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