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Kommineni Jagadeesh
 Professor Jayashankar
 Telangana Agricultural
 University, Rajendranagar,
 Hyderabad -500030, India

Hathiram
 Professor Jayashankar
 Telangana Agricultural
 University, Rajendranagar,
 Hyderabad -500030, India

Varala Ramakrishna
 Professor Jayashankar
 Telangana Agricultural
 University, Rajendranagar,
 Hyderabad -500030, India

Growth, instability, and ARIMA-based projections of maize (*Zea mays* L.) production dynamics in India

Kommineni Jagadeesh¹, Hathiram², Varala Ramakrishna³

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ABSTRACT

Maize (*Zea mays* L.) is one of India's most important cereal crops, valued for its role in food, feed, and industrial use. This study analyzes long-term trends in maize area, production, and productivity in India from 1949–50 to 2024–25 using annual data, and forecasts these variables to 2035 using Autoregressive Integrated Moving Average (ARIMA) models. Compound growth rate (CGR), coefficient of variation (CV), and Cuddy–Della Valle instability index (CDVI) were used to quantify long-term trends and variability. The Augmented Dickey–Fuller (ADF) test confirmed non-stationarity in all three series, and second-order differencing ($d = 2$) was required to achieve stationarity. ARIMA(0,2,2) was identified as the best-fitting model (lowest AIC) for all three series. Forecasts indicate continued growth: area is projected to rise from 12,451 thousand ha in 2026 to 17,311 thousand ha by 2035; production from 45,412 to 80,478 thousand tonnes; and productivity from 3,686 to 4,620 kg/ha over the same period. These results indicate that, unlike declining-acreage crops such as pearl millet, maize cultivation in India is expanding on both the area and productivity fronts, driven by rising demand for feed, industrial starch, and ethanol production.

Keywords: Maize, ARIMA, Production dynamics, Compound growth rate, Cuddy–Della Valle instability index

1. Introduction

Maize (*Zea mays* L.) ranks as the third most important cereal crop in India after rice and wheat, and its role in the country's food, feed, and industrial economy has grown markedly over the past two decades. Traditionally valued as a staple food in tribal and rainfed regions, maize today is used predominantly as an input for the poultry and livestock feed industry, which alone accounts for roughly half to two-thirds of total domestic consumption, alongside a rapidly expanding share directed to starch manufacturing and fuel-ethanol production (Prusty, 2025; Warak, 2026) [1, 2]. Globally, maize is cultivated on more than 200 million hectares across over 170 countries and remains the world's most widely produced cereal by tonnage, with the United States and China together accounting for a majority of global output; India, by comparison, holds a much smaller share of world maize area and production, reflecting a productivity gap relative to leading maize-growing nations (ANGRAU, 2026; ICAR-IIMR, 2024) [3, 4].

Within India, however, maize has been the fastest-growing major cereal of the last decade. Cultivated area has expanded from roughly 3.3 million hectares in 1949–50 to more than 12 million hectares in 2024–25, while production has grown more than twenty-fold over the same period, driven jointly by area expansion and, more substantially, by productivity gains associated with the spread of single-cross hybrids and improved crop management (Yadav *et al.*, 2015) [5]. This growth has accelerated sharply since the mid-2010s: national industry assessments report that maize acreage rose by roughly 31% over the past decade while production increased by about 75%, pushing India's total maize output past 40 million tonnes (Nexdigm, 2025) [6]. A major driver of this recent surge is India's ethanol-blending programme. As the national target for ethanol blending in petrol has risen toward 20% (E20) and beyond, the share of maize diverted to grain-based distilleries has grown from under one million tonnes in 2022–23 to an estimated 12–17 million tonnes in 2024–25 now approaching a third of total maize production (Kumar, 2026; DTE Staff, 2025) [8, 7]. This has tightened supplies for the poultry and starch industries, which have historically been the dominant consumers of domestic maize, and has been linked to sharply rising feed costs and, in turn, to rising egg and poultry-meat prices (Business Today, 2026) [9]. At the same time, the ICAR–Indian Institute of Maize Research has set a roadmap targeting national maize production of 65–70 million tonnes by 2030, to be achieved through higher-starch hybrids and continued yield improvement (Nexdigm, 2025) [6].

This dual pressurizing demand from feed, starch, and biofuel users on one side, and land, water, and yield constraints on the other makes reliable forecasting of maize area, production, and productivity essential for input planning, price stabilization, trade policy, and the design of the ethanol-blending roadmap itself. Long-term time-series data provide a natural basis for such forecasting, and Autoregressive Integrated Moving Average (ARIMA) models, following the classical methodology of Box *et al.* (1976) [10], have been widely

Corresponding Author:
Kommineni Jagadeesh
 Professor Jayashankar
 Telangana Agricultural
 University, Rajendranagar,
 Hyderabad -500030, India

and successfully applied to Indian cereal production series precisely because they capture historical trend and autocorrelation structure without requiring exogenous explanatory variables. ARIMA-based forecasts have previously been developed for Indian maize yield at the national level (Verma, 2018) [11], for maize area and production using ARIMA models refined with a genetic-algorithm optimization approach (Rathod *et al.*, 2017) [12], for maize production forecasting using classical Box–Jenkins ARIMA (Sharma *et al.*, 2018) [13], and, more recently, for state-level maize yield forecasting in Bihar and Karnataka (Girijawathi *et al.*, 2026) [14]. These studies consistently find that low-order ARIMA specifications, selected on minimum AIC and validated through Ljung–Box residual diagnostics, provide an adequate and parsimonious description of Indian maize time series, reinforcing the appropriateness of the same framework for the present analysis.

Maize offers an instructive contrast: rather than contracting, its cultivated area has been expanding for two decades, and this expansion, layered on top of substantial productivity growth, is now itself a partial cause of demand-side strain within the domestic maize economy. Applying the identical CGR–CV–CDVI–ARIMA framework to maize therefore serves two purposes. First, it provides evidence-based decadal forecasts of area, production, and productivity through 2035, of direct relevance to poultry-feed, starch, and ethanol-industry planning as well as to policymakers monitoring the sustainability of the ethanol-blending programme's reliance on maize as feedstock. Second, it enables a direct, methodologically consistent comparison between a declining-acreage dryland cereal (pearl millet) and an expanding-acreage, demand-driven commercial cereal (maize), illustrating how instability and growth-rate diagnostics differ across crops experiencing structurally different market pressures. The specific objectives of this study are therefore to: (i) quantify long-term growth rates and instability in maize area, production, and productivity in India from 1949–50 to 2024–25; (ii) identify the best-fitting ARIMA model for each series based on stationarity testing and minimum AIC; and (iii) generate ten-year-ahead forecasts (2026–2035) to inform planning around India's rapidly evolving maize demand landscape.

2. Materials and methods

2.1 Data source

Annual data on maize area ('000 ha), production ('000 tonnes), and productivity (kg/ha) for India, covering the period 1949–50 to 2024–25 (76 observations), were compiled from the Indiastat database (total across Kharif, Rabi, and Summer seasons).

2.2 Compound growth rate

The compound growth rate (CGR) was estimated from a semi-logarithmic trend regression: $\ln(Y) = a + bt$, where Y is area, production, or productivity and t is time. $\text{CGR}(\%) = [\exp(b) - 1] \times 100$.

2.3 Instability analysis

The coefficient of variation (CV) was calculated as (standard deviation / mean) $\times 100$. To remove the effect of the underlying trend, the Cuddy–Della Valle instability index (CDVI) was computed as CDVI

$= \text{CV} \times \sqrt{1 - R^2}$, where R^2 is from the linear trend regression.

2.4 Time-series forecasting

ARIMA models were fitted following the Box–Jenkins methodology. Stationarity was assessed with the Augmented Dickey–Fuller (ADF) test; series found non-stationary were differenced until stationary. Candidate models were compared by Akaike Information Criterion (AIC), and residual adequacy was checked using the Ljung–Box test for autocorrelation. Forecasts were generated for 2026–2035 with 95% confidence intervals.

3. Results and discussion

3.1 Long-term trends

Maize area increased from about 3.30 million ha in 1949–50 to 12.09 million ha in 2024–25. Production rose from 2.00 million tonnes to 43.41 million tonnes over the same period, while productivity increased from 627 kg/ha to 3,590 kg/ha more than a five-fold gain. Unlike pearl millet, where area has contracted, maize area has expanded markedly, especially since the early 2000s, reflecting diversification toward maize as a commercial and industrial crop.

3.2 Growth rate and instability

Table 1. Growth rate and instability parameters of maize in India, 1949–50 to 2024–25.

Variable	CAGR (%)	CV (%)	CDVI
Area	1.34	31.00	9.12
Production	3.50	82.23	17.35
Productivity	2.13	49.95	11.50

All three variables recorded positive compound growth rates, in contrast to pearl millet where area growth was negative. Production showed the highest CAGR (3.50% per annum), driven jointly by area expansion (1.34%) and productivity gains (2.13%). Area also showed the lowest instability (CDVI = 9.12), indicating a relatively steady long-term expansion once the underlying trend is accounted for, while production exhibited the highest instability (CDVI = 17.35), reflecting sensitivity to weather and market conditions in individual years.

3.3 Stationarity and ARIMA model selection

The ADF test indicated that the original series for area, production, and productivity were all non-stationary ($p > 0.05$ in each case), and required second-order differencing ($d = 2$) to achieve stationarity a stronger degree of differencing than reported for pearl millet ($d = 1$), consistent with the more pronounced curvature (accelerating growth) in the maize series, especially in the last two decades. Based on the minimum AIC, ARIMA(0,2,2) was selected as the best-fitting model for all three variables (Table 2).

In all three cases, the Ljung–Box test returned non-significant p -values ($p > 0.05$), indicating that model residuals are free of autocorrelation and approximate white noise — confirming that the fitted ARIMA(0,2,2) models adequately capture the temporal structure of the data.

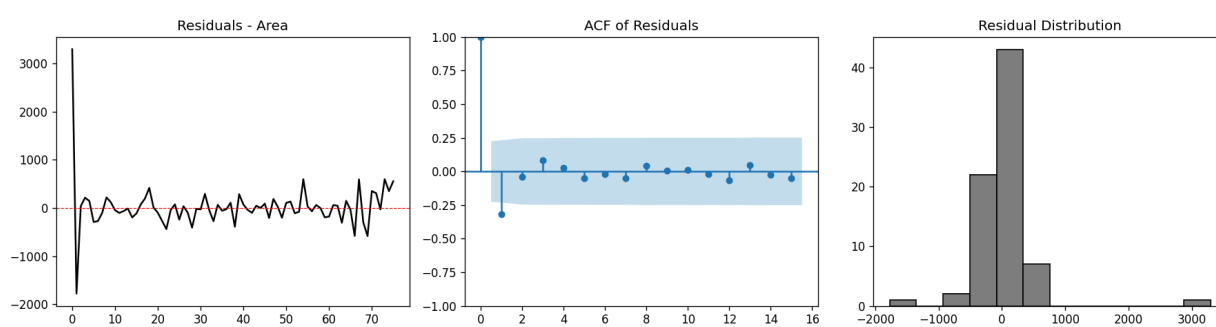


Figure 1. Residual diagnostics (residual series, ACF, distribution) for the ARIMA(0,2,2) model fitted to maize area.

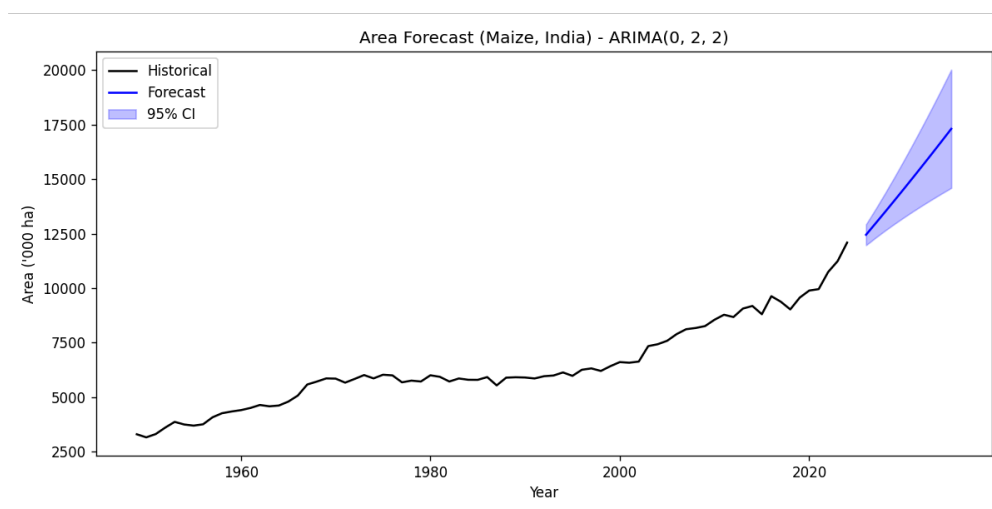


Figure 2. Historical trend and ARIMA(0,2,2)-based forecast of maize cultivated area in India (1949–2035).

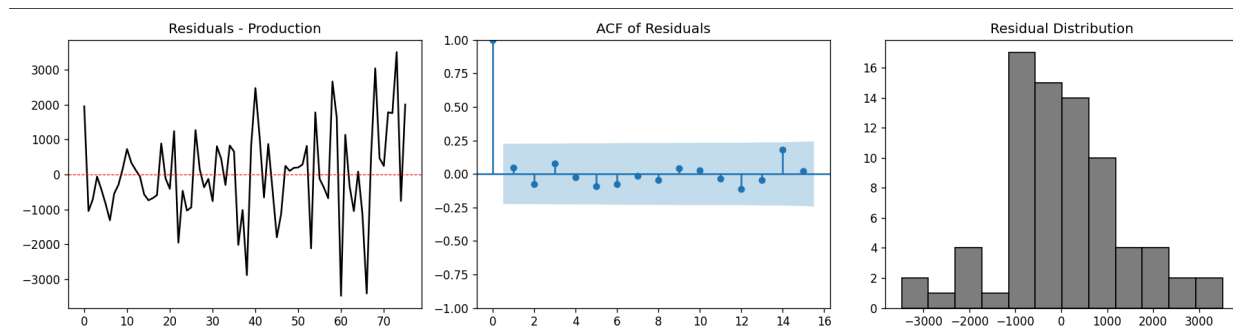


Figure 3. Residual diagnostics for the ARIMA(0,2,2) model fitted to maize production.

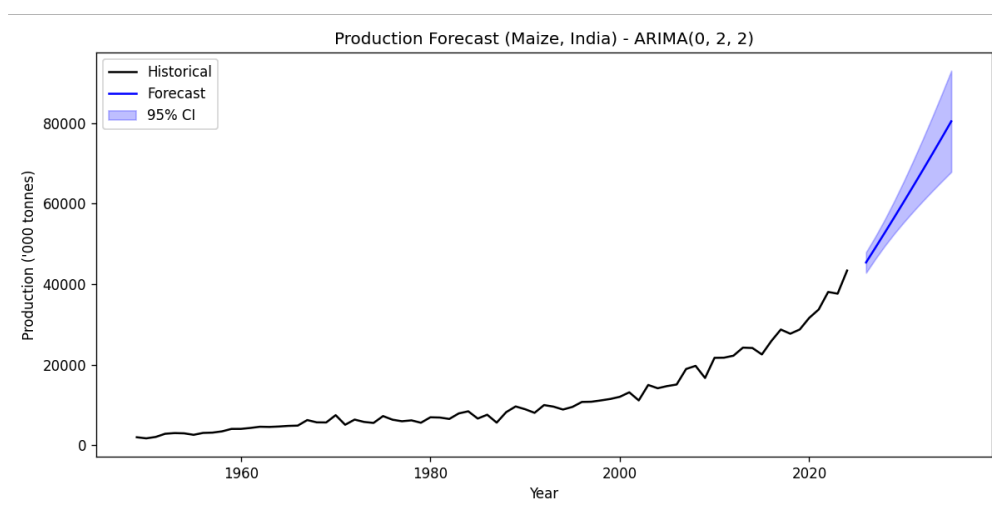


Figure 4. Historical trend and ARIMA(0,2,2)-based forecast of maize production in India (1949–2035).

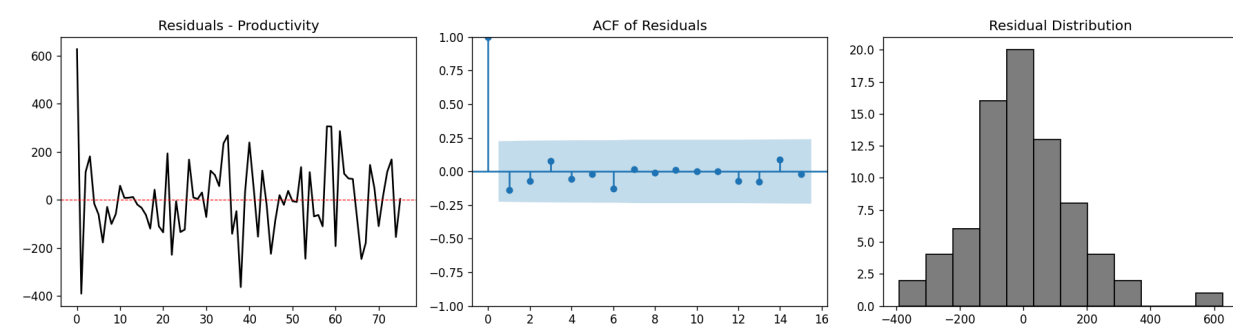


Figure 5. Residual diagnostics for the ARIMA(0,2,2) model fitted to maize productivity.

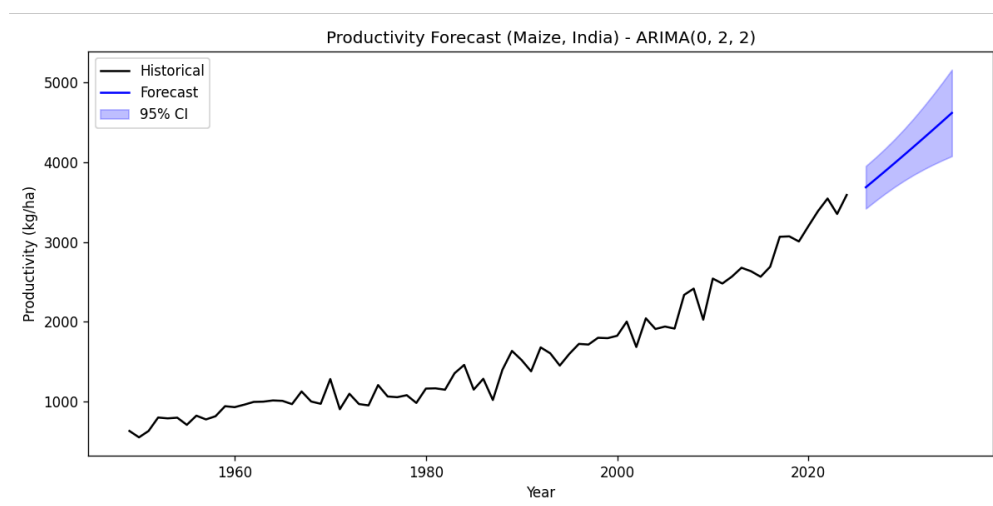


Figure 6. Historical trend and ARIMA(0,2,2)-based forecast of maize productivity in India (1949–2035).

3.4 Ten-year forecast (2026–2035)

The ARIMA(0,2,2) models project continued growth across all three variables over the next decade. Cultivated area is expected to increase from 12,451 thousand ha in 2026 to 17,311 thousand ha by 2035. Production is projected to rise from 45,412 to 80,478 thousand

tonnes, and productivity from 3,686 to 4,620 kg/ha, over the same period (Table 3). The confidence intervals widen with forecast horizon, as expected, reflecting increasing uncertainty in longer-range projections; the recent acceleration in area (post-2015) is the main driver of the relatively steep projected trajectory, and forecasters should treat the outer years (2032–2035) with appropriate caution.

Table 2. Best-fitting ARIMA models for maize variables.

Variable	Model	AIC	Ljung-Box <i>p</i> -value
Area	ARIMA(0,2,2)	1032.26	0.502
Production	ARIMA(0,2,2)	1281.20	0.987
Productivity	ARIMA(0,2,2)	950.61	0.943

Table 3. Forecasted area, production, and productivity of maize in India, 2026–2035.

Year	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
2026	12,451.37	45,411.76	3,685.99
2027	12,969.8	49,127.39	3,785.92
2028	13,493.62	52,888.17	3,886.8
2029	14,022.83	56,694.11	3,988.62
2030	14,557.43	60,545.19	4,091.4
2031	15,097.41	64,441.43	4,195.12
2032	15,642.78	68,382.82	4,299.79
2033	16,193.54	72,369.36	4,405.41
2034	16,749.68	76,401.06	4,511.98
2035	17,311.22	80,477.91	4,619.5

The results of this study extend, and in several respects invert, the pattern reported by Jagadeesh *et al.* (2026) [15] for pearl millet using an identical CGR–CV–CDVI–ARIMA framework. Where pearl millet area contracted at –0.64% per annum over 1949–50 to 2024–25 even as production and productivity rose, maize area, production, and productivity all grew simultaneously over the same broad period, with production (CAGR = 3.50% per annum) growing faster than either area (1.34%) or productivity (2.13%) alone. This joint expansion reflects maize's dual identity in India: a food grain in some regions but, increasingly, an industrial input whose area response follows commercial derived demand from the feed, starch, and since the early 2020s ethanol sectors, rather than the largely inelastic, food-security-driven acreage seen in a subsistence dryland cereal like pearl millet.

The instability results reinforce this distinction. Using the conventional CDVI classification bands (very low: 0–5; low: 5–15; medium: 15–30; high: 30–50) reported in Indian crop-instability literature (Prasad *et al.*, 2024; Rana *et al.*, 2021) [16], maize area (CDVI = 9.12)

and productivity (11.50) fall in the low-instability range, while production (17.35) falls in the medium range. This mirrors a broader pattern documented across Indian field crops for instance in state-level wheat and spice-crop CGR/CDVI studies (Prakash, 2024; Vala *et al.*, 2024) [17, 18] where production instability typically exceeds instability in area or yield individually, because production variance compounds year-to-year fluctuation from both components rather than reflecting either source alone. That maize area instability remains low despite two decades of aggressive expansion suggests the expansion has been a fairly steady structural shift driven by persistent, strengthening demand, rather than a series of erratic reactions to individual seasons' prices or weather.

The selection of ARIMA(0,2,2) for all three maize series, with second-order differencing required to achieve stationarity, is itself informative. The pearl millet study needed only first-order differencing for its series; the additional order of differencing found here reflects the more pronounced curvature an accelerating, rather than merely linear,

trend visible in the maize series since approximately 2015, consistent with the acreage and production growth rates reported in recent industry assessments (Nexdigm, 2025) [6]. This has a direct consequence for the forecasts: a $d = 2$ ARIMA model extrapolates the recent rate of change in the trend, not merely the trend's recent level, so the resulting ten-year forecast (area rising to 17.3 million ha, production to 80.5 million tonnes by 2035) is best read as a continuation of the post-2015 acceleration rather than a return to the flatter, decades-averaged growth rate of 1.34% per annum reported in Table 1. This is a well-documented property of low-order linear ARIMA models applied over long horizons in the presence of structural change: such models perform well under stable trend conditions but can over- or under-shoot when a series contains an unmodelled structural break such as the sudden emergence of ethanol demand as a driver of maize acreage around 2021–22 (Asghar *et al.*, 2012) [19]. The widening 95% confidence intervals by 2032–2035 already signal this growing uncertainty, and the outer forecast years should be read as an upper-bound trajectory contingent on continued strong demand growth, rather than a point prediction carrying the same confidence as the 2026–2028 estimates.

The forecasts also carry a policy-relevant tension with no counterpart in the pearl millet study: unlike a food-security crop whose production growth is unambiguously beneficial, maize's growth is currently outpacing the capacity of its two long-standing end uses poultry feed and starch to absorb it without price conflict, because a rapidly growing third use (ethanol) draws on the same grain pool (Business Today, 2026; DTE Staff, 2025) [9, 20]. Whether the projected area and production growth eases or intensifies that tension will depend on whether yield gains, via higher-starch, higher-yielding hybrids under the ICAR-IIMR 2030 roadmap, keep pace with combined feed, food, and biofuel demand, or whether area expansion continues to be the primary lever which would raise land-use competition with other kharif crops in the same agro-ecologies. This is compounded by climate risk: maize yield is known to be sensitive to heat stress during flowering, with controlled studies estimating yield losses of roughly 1% per °C-day above 30 °C under favorable conditions and up to 1.7% under drought stress (Lobell *et al.*, 2011) [21], and Indian crop-simulation studies project yield declines under most mid-century warming scenarios absent continued genetic and management adaptation (Aggarwal, 2003; IFPRI, 2009) [22, 23]. The ARIMA forecasts presented here, being purely statistical extrapolations of historical trend, do not explicitly incorporate such climate-driven yield risk and should therefore be read as a business-as-usual trajectory rather than a climate-adjusted projection. As with the pearl millet study, continued investment in stress-tolerant hybrids and monitoring of the evolving balance between feed, food, and industrial maize demand will be necessary for the productivity gains implicit in this forecast to be realized in practice.

4. Conclusion

Between 1949–50 and 2024–25, maize cultivation in India expanded on all fronts area, production, and productivity in marked contrast to pearl millet, whose area has contracted over the same period. ARIMA (0,2,2) models, selected on minimum AIC and validated by non-significant Ljung–Box statistics, project this expansion to continue through 2035, with area reaching roughly 17.3 million ha, production 80.5 million tonnes, and productivity 4,620 kg/ha. These trends reflect the crop's growing importance for feed, industrial, and biofuel demand, and underscore the need for continued investment in hybrid seed systems, irrigation, and market infrastructure to sustain this growth trajectory.

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