

International Journal of Statistics and Applied Mathematics

ISSN: 2456-1452

NAAS Rating (2026): 4.49

Maths 2026; 11(4): 125-134

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<https://www.mathsjournal.com>

Received: 15-01-2026

Accepted: 17-02-2026

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Comparative evaluation of growth models for pulse crop performance in Telangana state

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DOI: <https://www.doi.org/10.22271/math.2026.v11.i4b.2308>

Abstract

Pulses are an important component of sustainable agriculture due to their high protein content, low input requirements, and ability to improve soil fertility through biological nitrogen fixation. Globally, the area under pulses increased from 64.14 million hectares in the triennium ending 1970 to 93.54 million hectares in 2019, accompanied by substantial gains in production and productivity. The present study examines long-term trends in area, production, and productivity of major pulse crops in three districts of Telangana state Adilabad, Mahbubnagar, and Nizamabad using a 30-year time-series dataset covering the period from 1993 to 2022.

Multiple growth models, including linear, quadratic, exponential, monomolecular, and Generalized Additive Models (GAM), were fitted to the data to capture temporal dynamics. Model performance was assessed using diagnostic criteria such as coefficient of determination (R^2), Mean Absolute Percentage Error (MAPE), and Root Mean Squared Error (RMSE). The results consistently indicate that the Generalized Additive Model provides the best fit across districts and variables, demonstrating superior explanatory power and lower prediction errors compared to other models. The study highlights the effectiveness of GAM in modelling nonlinear trends in pulse crop cultivation and offers useful insights for forecasting and policy planning in pulse production within Telangana state.

Keywords: Pulse crops, Generalized Additive Model (GAM), Trend analysis, Area, production and productivity, Time-series analysis, Telangana

1. Introduction

Pulses occupy a central position in the agricultural and nutritional systems of the Indian subcontinent, complementing cereals as a primary food source. Commonly consumed in the form of *dal*, pulses are rich in high-quality protein, essential amino acids, dietary fibre, vitamins, and minerals, making them indispensable for ensuring nutritional security, particularly among vegetarian populations. Owing to their affordability and nutritional value, pulses are often referred to as the “protein source of the poor” (Guntukula and Goyari, 2022) [5].

Beyond their dietary importance, pulse crops contribute significantly to the sustainability of agricultural systems. As leguminous crops, they enhance soil fertility through biological nitrogen fixation, improve soil structure, and reduce dependence on synthetic fertilizers. Pulses are frequently incorporated into crop rotations, intercropping, and mixed cropping systems, thereby supporting resource conservation and long-term farm productivity. Recognizing their agronomic and economic significance, pulse cultivation in India has received considerable policy support over the years (Pasala and Rudra, 2017). Consequently, the area under pulses expanded from 19.09 million hectares in 1950-51 to 31.1 million hectares in 2021-22, accompanied by an increase in production from 8.41 to 27.3 million tonnes and a notable improvement in productivity (Guntukula, 2018) [4].

Among the various pulse crops grown in India, Bengal gram (*Cicer arietinum* L.) holds a dominant position, accounting for nearly half of the total pulse output. India is the leading producer of Bengal gram globally, contributing more than 60 percent of world production.

In Telangana, the crop is predominantly cultivated during the rabi season. Red gram (*Cajanus cajan*), another major pulse crop, ranks second in importance and is mainly grown during the kharif season (Kalamkar *et al*, 2002)^[6]. Apart from its use as *dal*, red gram also provides fodder and green vegetables, often being cultivated as an intercrop. Given the economic and nutritional relevance of these crops, analysing their long-term performance using appropriate statistical models is essential for informed planning and policy formulation.

2. Material and Methods

Data Source

The present research investigation comprising of secondary time-series data on area, production, and productivity of Bengal gram and red gram for a period of 30 years (1993-2022). District-wise data for Adilabad, Mahbubnagar, and Nizamabad districts of Telangana state were collected from the Statistical Abstracts of Telangana, the Directorate of Economics and Statistics (DES), and the Indiatat database. These data were utilized to examine long-term growth behaviour and to identify suitable models for trend analysis and forecasting.

Description of Growth Models

To analyse temporal variations, both linear and nonlinear growth models were fitted to the data using five different methods.

A. Linear Growth Model

The linear model assumes a constant rate of change over time and is expressed as:

Where,

Y_t denotes area, production, or productivity at time t ; β_0 is the intercept; β_1 represents the linear growth rate; and ε_t is the random error term (Gautam and Sisodia, 2018)^[3].

B. Quadratic Growth Model

The quadratic model accounts for curvature in the trend and is defined as:

$$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \varepsilon_t$$

Where,

β_2 captures acceleration or deceleration in growth over time period (Satish *et al*, 2022)^[14].

C. Exponential Growth Model

The exponential model is suitable for describing proportional growth and is specified as:

$$Y_t = \alpha e^{\beta t} + \varepsilon_t$$

Where,

α is the scale parameter, β is the exponential growth rate, and e is the base of the natural logarithm (Shah *et al*, 2014)^[12].

D. Monomolecular Growth Model

The monomolecular model describes growth approaching an asymptote and is given by:

$$Y_t = \alpha(1 - \beta e^{-\gamma t}) + \varepsilon_t$$

Where,

α Represents the asymptotic maximum level, and β and γ are model parameters (Kumar *et al*, 2012)^[8].

E. Generalized Additive Model (GAM)

To capture complex nonlinear patterns, a Generalized Additive Model was employed. The GAM is expressed as:

$$Y_t = \alpha + f(t) + \varepsilon_t$$

Where,

α is the intercept and $f(t)$ is a smooth nonparametric function of time estimated using spline-based techniques (Khan *et al*, 2013)^[7]. Model estimation was carried out using a backfitting algorithm that iteratively estimates the smooth and parametric components.

Model Estimation and Diagnostic Criteria

Nonlinear models were estimated using nonlinear least squares via the `nlsLM` function from the `minpack.lm` package in R. Model performance was evaluated using the following diagnostic measures:

Coefficient of Determination

$$R^2 = 1 - \frac{\sum(Y_t - \hat{Y}_t)^2}{\sum(Y_t - \bar{Y})^2}$$

Mean Absolute Percentage Error (MAPE)

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

Root Mean Squared Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (Y_t - \hat{Y}_t)^2}{n}}$$

Where, Y_t = Observed value, $\hat{Y}_t$ = Predicted value and n = Number of observations. The model exhibiting the highest R^2 and the lowest MAPE and RMSE values was considered the most appropriate (Malhi and Kiran, 2015)^[9].

Residual Diagnostics

Residual independence was assessed using the Runs test, while normality of residuals was examined through the Shapiro-Wilk test. All statistical analyses were performed using R statistical software.

3. Results and Discussion

The performance of different growth models was evaluated for analysing long-term changes in area, production, and productivity of Bengal gram and red gram in Adilabad, Mahbubnagar, and Nizamabad districts of Telangana during 1993-2022. Model adequacy was assessed using the coefficient of determination (R^2), Mean Absolute Percentage Error (MAPE), and Root Mean Squared Error (RMSE). Across crops, districts, and variables, the Generalized Additive Model (GAM) consistently provided superior fit compared to linear and other nonlinear models.

Bengal Gram

Bengal gram exhibited an overall increasing trend in production and productivity across all districts, though inter-annual variability was observed in cultivated area (Devi *et al*, 2017)^[1]. In Adilabad district, the average area under Bengal gram was 13.35 thousand hectares, with mean production of 14.97 thousand tonnes and productivity of 1132.75 kg ha⁻¹. In Mahbubnagar, the corresponding averages were 13.79

thousand hectares, 17.14 thousand tonnes, and 1105.66 kg ha⁻¹, while in Nizamabad district, mean production and productivity were relatively higher despite moderate area

coverage. GAM recorded the highest R² values and lowest RMSE and MAPE across all variables, indicating its ability to capture nonlinear growth behaviour.

Table 1: Summary statistics of Bengal gram area, production, and productivity (1993-2022)

Sl. No	District	Area (000 ha)	Production (000 t)	Productivity (kg ha ⁻¹)
1	Adilabad	13.35	14.97	1132.75
2	Mahbubnagar	13.79	17.14	1105.66
3	Nizamabad	13.12	21.02	1215.55

Table 2: Model-wise diagnostic statistics for Bengal gram area (1993-2022)

Districts	Type of Model	R ² value	RMSE	MAPE
Adilabad	Linear	0.725	5.30	0.507
	Quadratic	0.743	5.13	0.369
	Exponential	0.736	5.19	0.456
	Monomolecular	0.724	5.31	0.508
	GAM	0.782	4.71	0.334
Mahbubnagar	Linear	0.279	7.25	0.762
	Quadratic	0.706	4.63	0.615
	Exponential	0.201	7.63	0.923
	Monomolecular	0.285	7.24	0.759
	GAM	0.936	2.15	0.215
Nizamabad	Linear	0.259	9.08	0.881
	Quadratic	0.444	7.90	0.961
	Exponential	0.192	9.49	1.081
	Monomolecular	0.266	9.08	0.882
	GAM	0.692	5.86	0.389

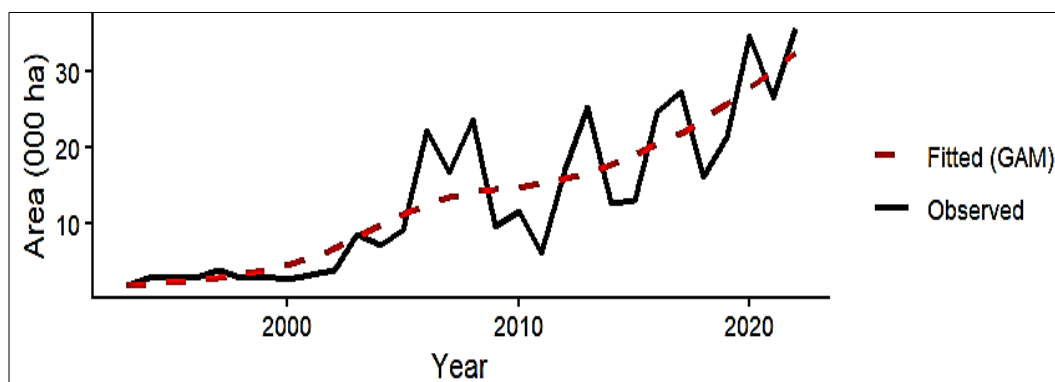


Fig 1: Trends of Bengal gram area in Adilabad district.

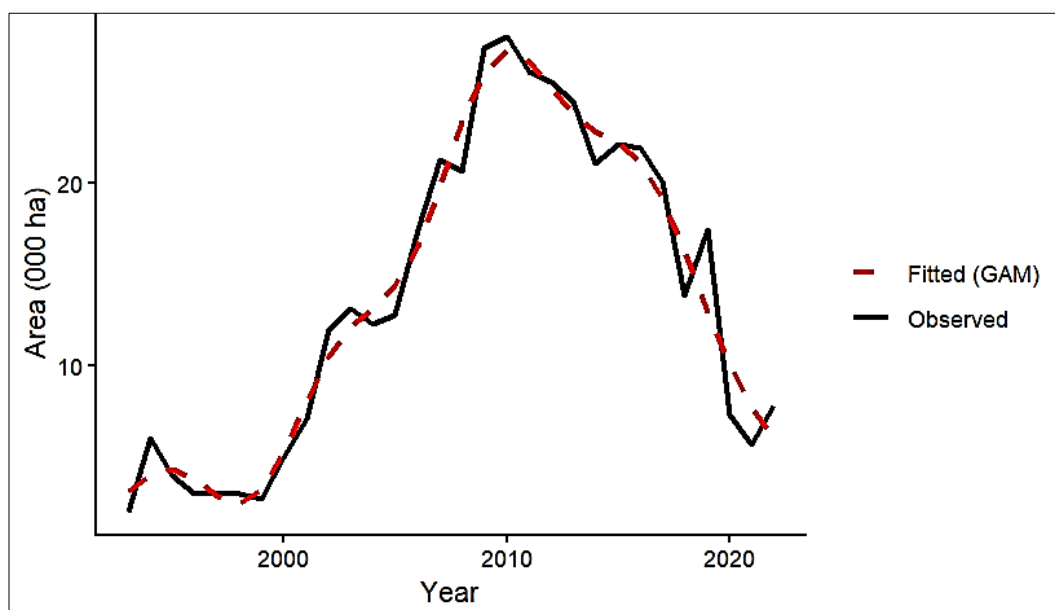


Fig 2: Trends of Bengal gram area in Mahabubnagar district.

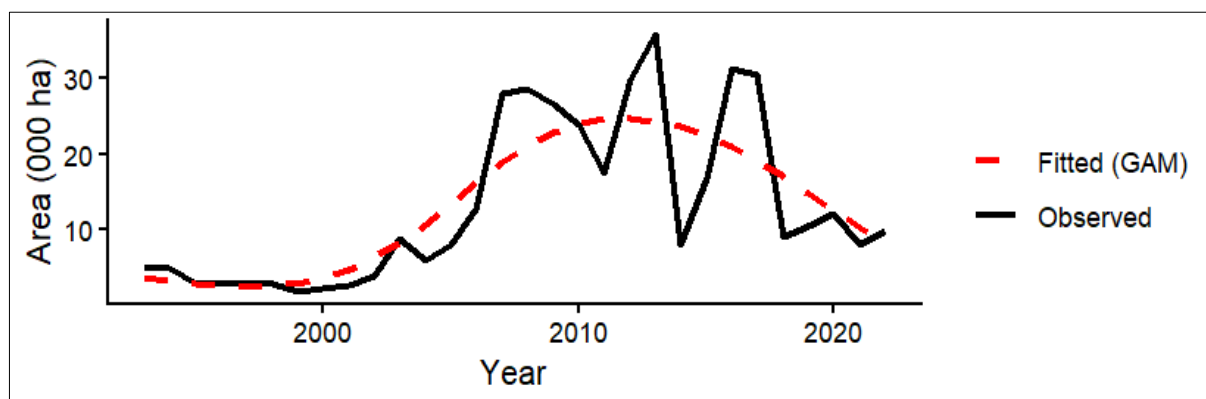


Fig 3: Trends of Bengal gram area in Nizamabad district.

Table 3: Model-wise diagnostic statistics for Bengal gram production (1993-2022)

Districts	Type of Model	R ² value	RMSE	MAPE
Adilabad	Linear	0.472	8.89	0.989
	Quadratic	0.531	8.39	1.209
	Exponential	0.382	9.62	1.721
	Monomolecular	0.473	8.88	0.998
	GAM	0.614	7.61	0.573
Mahbubnagar	Linear	0.207	12.58	1.616
	Quadratic	0.505	9.94	1.561
	Exponential	0.145	13.06	2.077
	Monomolecular	0.209	12.56	1.612
	GAM	0.654	8.31	0.768
Nizamabad	Linear	0.246	18.41	1.809
	Quadratic	0.404	16.36	2.065
	Exponential	0.173	19.28	2.835
	Monomolecular	0.247	18.39	1.803
	GAM	0.598	13.44	0.696

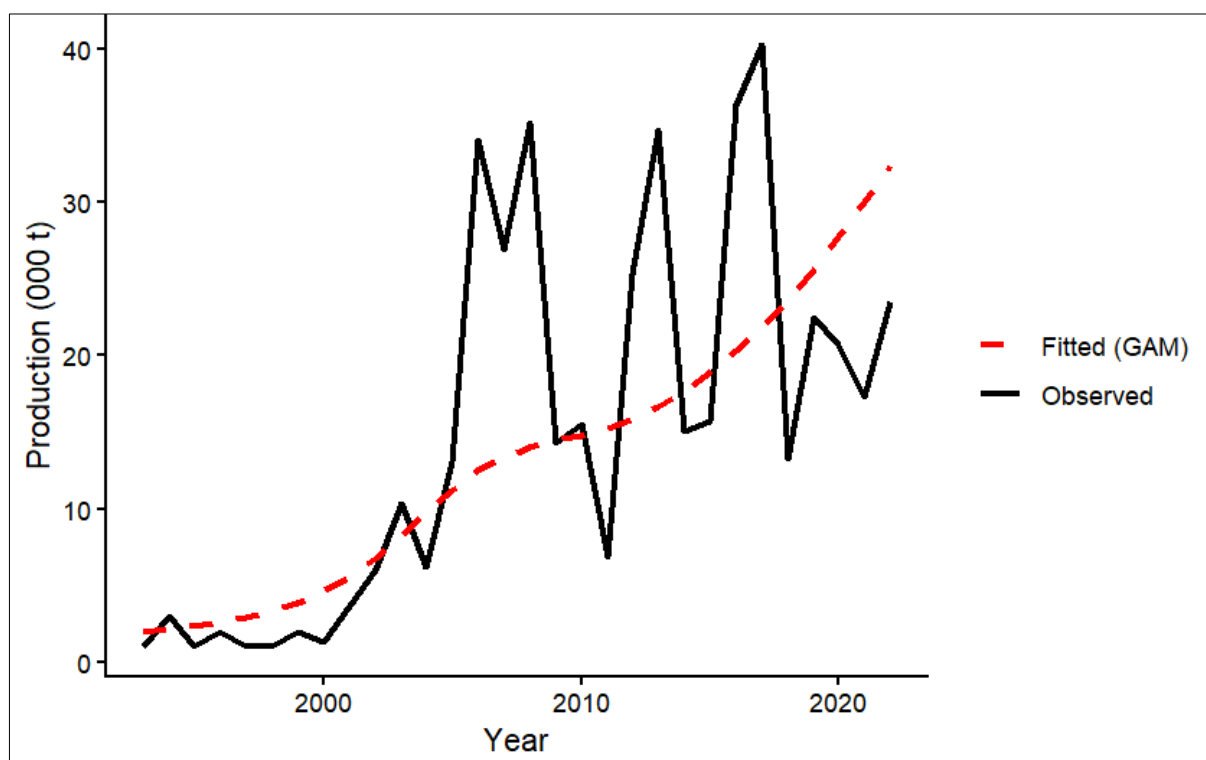


Fig 4: Trends of Bengal gram production in Adilabad district.

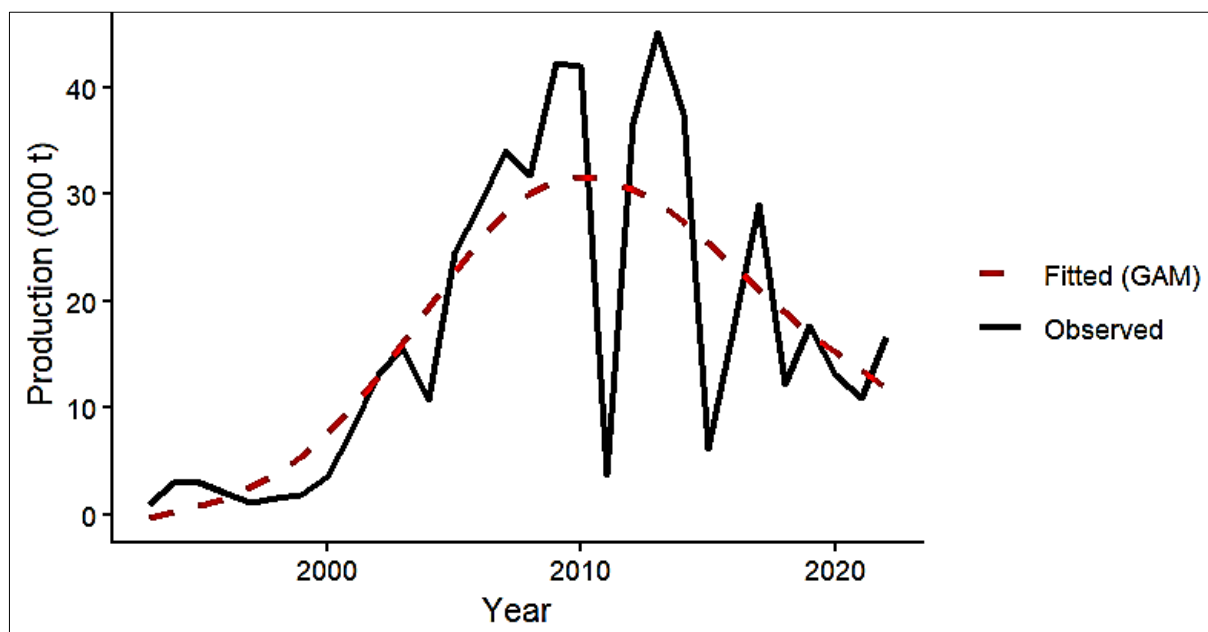


Fig 5: Trends of Bengal gram production in Mahabubnagar district.

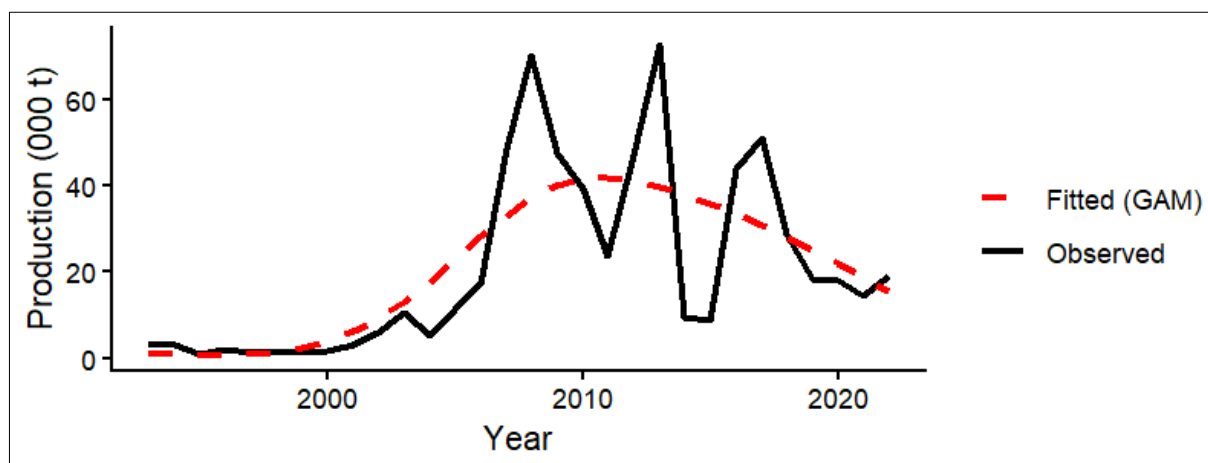


Fig 6: Trends of Bengal gram production in Nizamabad district.

Table 4: Model-wise diagnostic statistics for Bengal gram productivity (1993-2022)

Districts	Type of Model	R ²	RMSE	MAPE
Adilabad	Linear	0.489	301.52	0.343
	Quadratic	0.592	269.44	0.306
	Exponential	0.437	316.33	0.376
	Monomolecular	0.494	300.12	0.341
	GAM	0.716	224.52	0.241
Mahbubnagar	Linear	0.226	439.39	0.636
	Quadratic	0.321	411.97	0.627
	Exponential	0.202	446.62	0.653
	Monomolecular	0.229	438.50	0.636
	GAM	0.456	368.27	0.551
Nizamabad	Linear	0.347	426.00	0.356
	Quadratic	0.521	364.69	0.311
	Exponential	0.296	442.28	0.397
	Monomolecular	0.352	424.27	0.354
	GAM	0.658	308.22	0.242

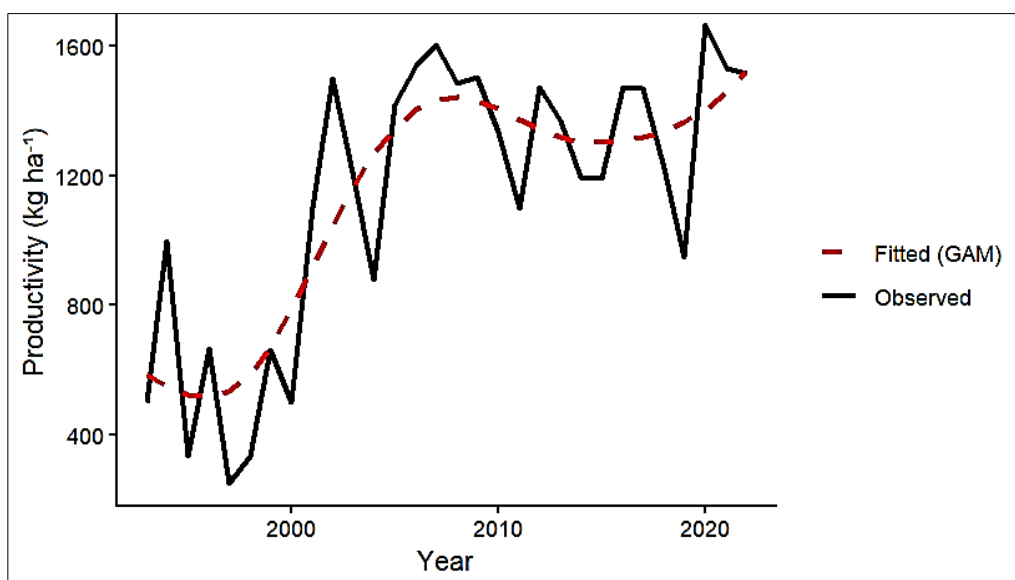


Fig 7: Trends of Bengal gram productivity in Adilabad district.

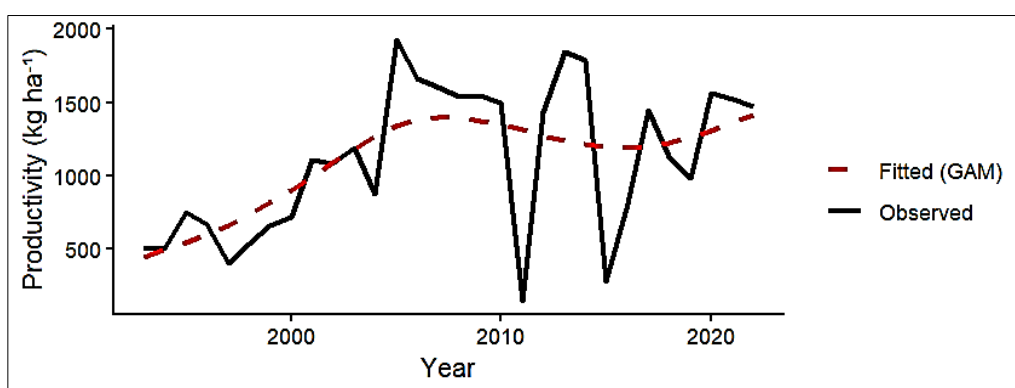


Fig 8; Trends of Bengal gram productivity in Mahabubnagar district.

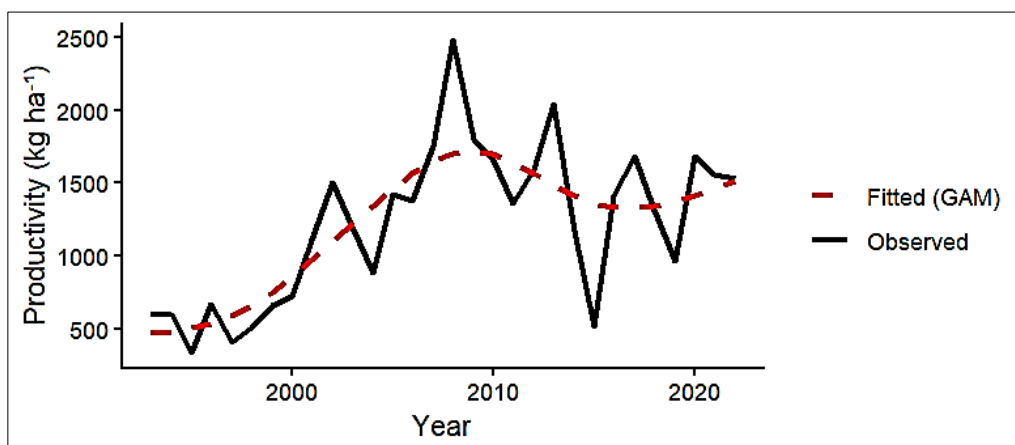


Fig 9: Trends of Bengal gram productivity in Nizamabad district.

Red Gram

Red gram showed mixed trends in cultivated area, while production and productivity generally improved over time (Eswara *et al*, 1993)^[2]. In Adilabad district, the average area, production, and productivity were 40.62 thousand hectares, 23.09 thousand tonnes, and 551.09 kg ha⁻¹, respectively. Mahbubnagar district recorded the largest average area under

red gram (84.65 thousand hectares), though productivity remained comparatively lower. In Nizamabad district, red gram was cultivated on a smaller scale, but productivity levels were relatively higher. GAM again outperformed other models across all districts, reflecting its robustness in modelling highly variable datasets, similar to the findings of Sharma *et al*, 2013^[13].

Table 5: Summary statistics of Red gram area, production, and productivity (1993-2022)

Sl. No	Districts	Area (000'ha)	Production (000't)	Productivity (kg ha ⁻¹)
1	Adilabad	40.62	23.09	551.09
2	Mahbubnagar	84.65	37.09	399.21
3	Nizamabad	3.61	2.44	620.43

Table 6: Model-wise diagnostic statistics for Red gram area (1993-2022)

Districts	Type of Model	R ² value	RMSE	MAPE
Adilabad	Linear	0.364	3.883	0.076
	Quadratic	0.364	3.882	0.076
	Exponential	0.367	3.884	0.078
	Monomolecular	0.363	3.883	0.075
	GAM	0.461	3.549	0.071
Mahbubnagar	Linear	0.859	13.899	0.124
	Quadratic	0.864	13.654	0.132
	Exponential	0.807	16.257	0.176
	Monomolecular	0.859	13.889	0.124
	GAM	0.913	10.881	0.094
Nizamabad	Linear	0.418	1.012	0.215
	Quadratic	0.419	1.011	0.214
	Exponential	0.409	1.018	0.212
	Monomolecular	0.417	1.013	0.216
	GAM	0.548	0.891	0.183

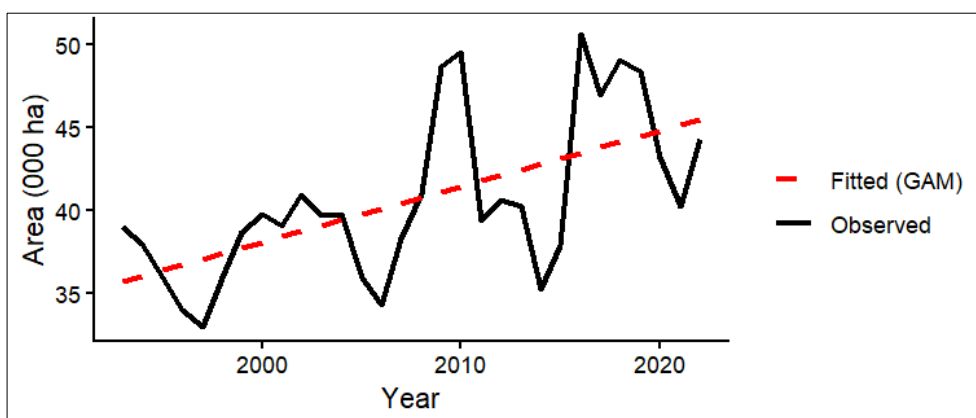
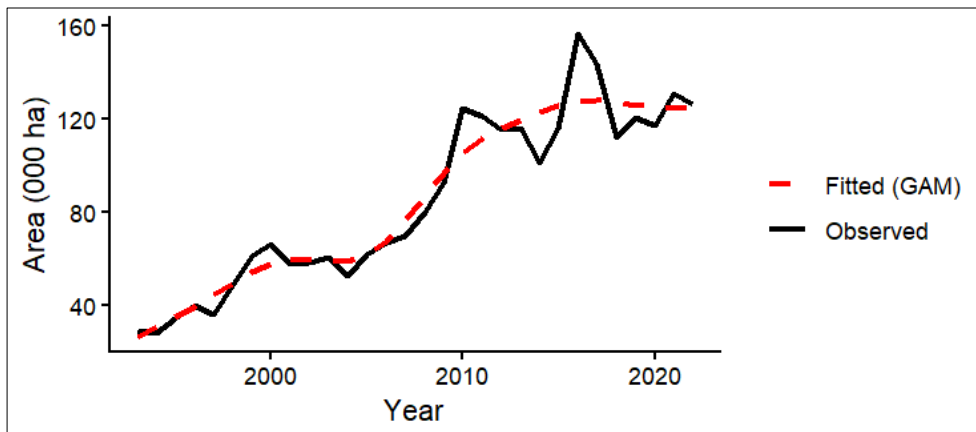
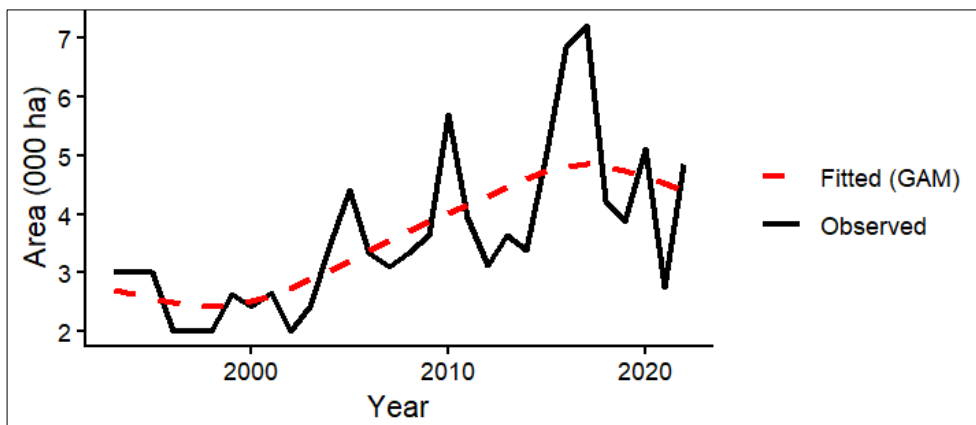
**Fig 10:** Trends of Red gram area in Adilabad district.**Fig 11:** Trends of Red gram area in Mahabubnagar district.**Fig 12:** Trends of Red gram area in Nizamabad district.

Table 7: Model-wise diagnostic statistics for Red gram production (1993-2022)

Districts	Type of Model	R ² value	RMSE	MAPE
Adilabad	Linear	0.804	5.887	0.428
	Quadratic	0.811	5.774	0.449
	Exponential	0.729	6.918	0.657
	Monomolecular	0.805	5.877	0.428
	GAM	0.865	4.884	0.375
Mahbubnagar	Linear	0.662	15.396	0.384
	Quadratic	0.665	15.331	0.357
	Exponential	0.636	15.959	0.495
	Monomolecular	0.661	15.415	0.385
	GAM	0.707	14.333	0.348
Nizamabad	Linear	0.436	1.363	0.548
	Quadratic	0.438	1.361	0.566
	Exponential	0.404	1.401	0.543
	Monomolecular	0.437	1.362	0.550
	GAM	0.535	1.237	0.401

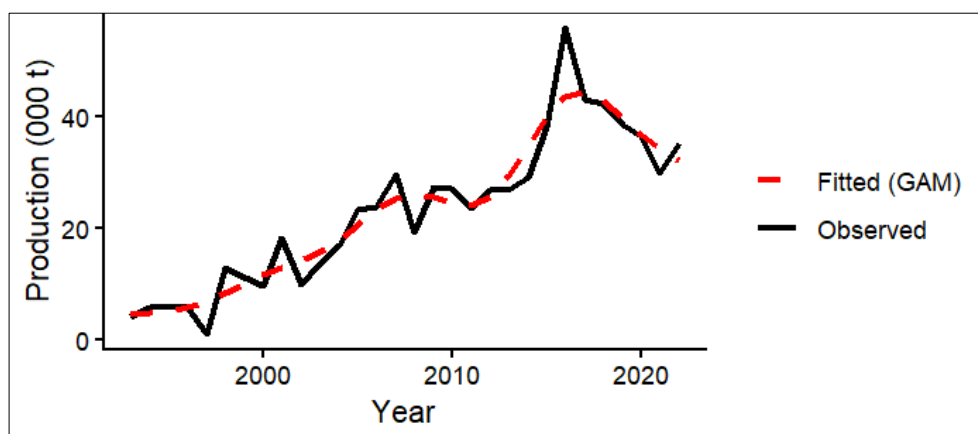
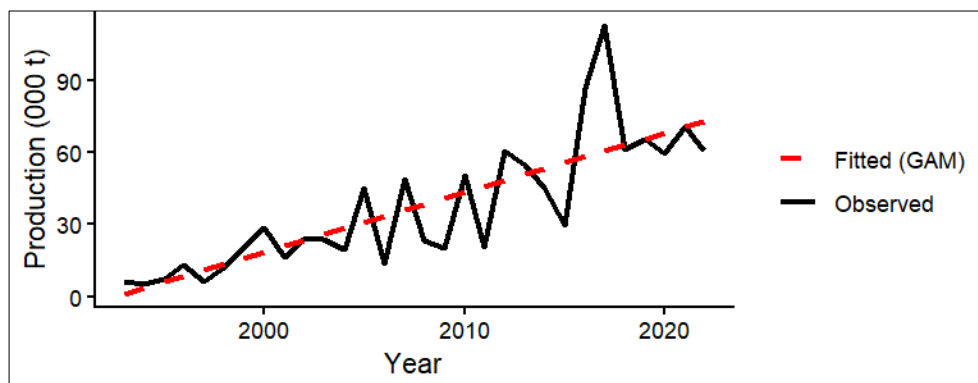
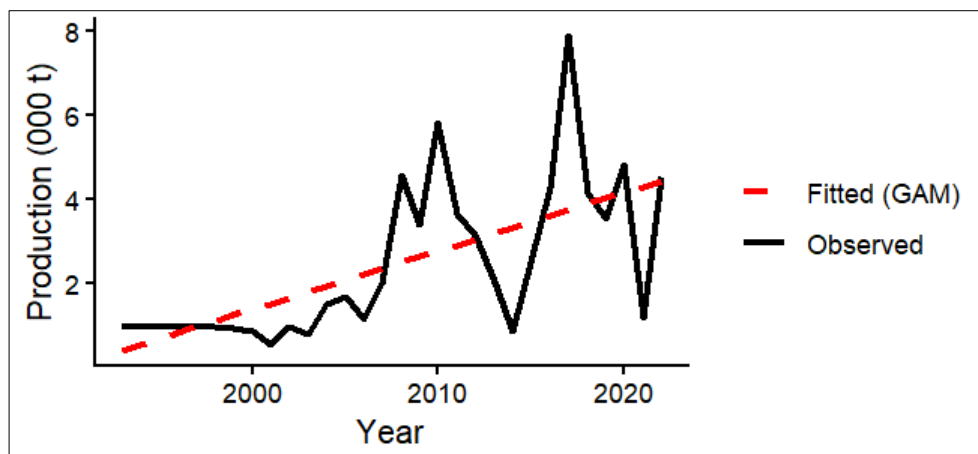
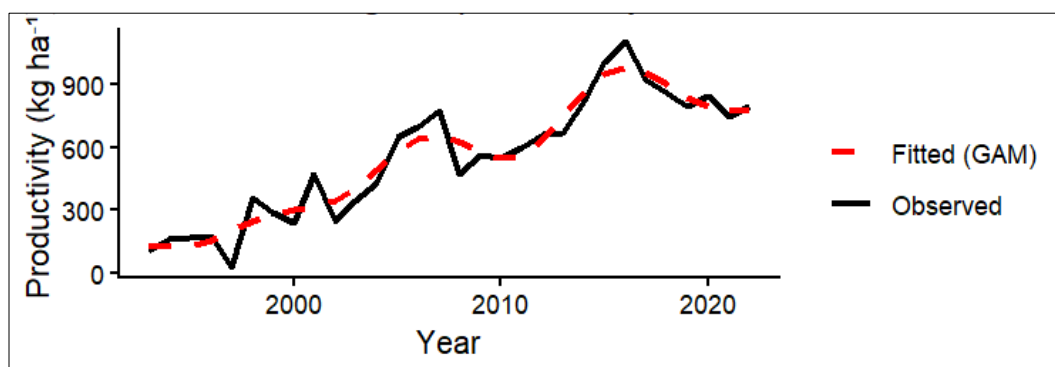
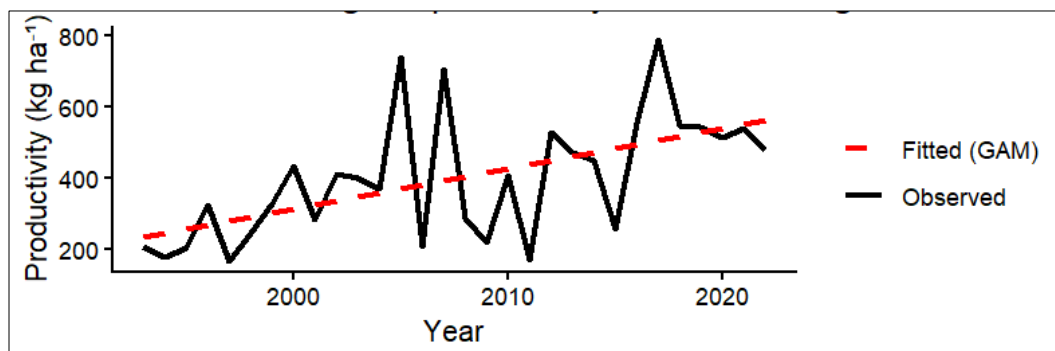
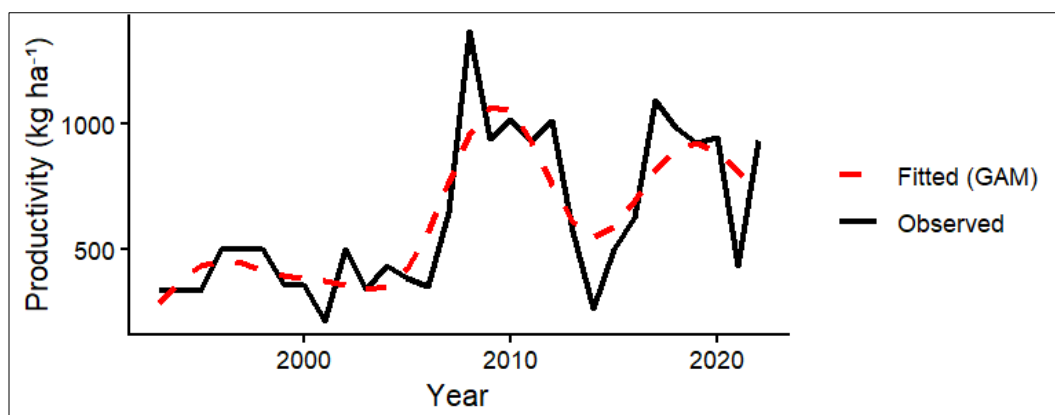
**Fig 13:** Trends of Red gram production in Adilabad district.**Fig 14:** Trends of Red gram production in Mahabubnagar district.**Fig 15:** Trends of Red gram production in Nizamabad district.

Table 8: Model-wise diagnostic statistics for red gram productivity (1993-2022)

Districts	Type of Model	R ² value	RMSE	MAPE
Adilabad	Linear	0.798	128.357	0.402
	Quadratic	0.821	120.572	0.414
	Exponential	0.715	152.388	0.588
	Monomolecular	0.801	127.484	0.399
	GAM	0.865	104.616	0.347
Mahabubnagar	Linear	0.323	140.556	0.308
	Quadratic	0.331	139.871	0.301
	Exponential	0.311	141.829	0.317
	Monomolecular	0.324	140.455	0.307
	GAM	0.414	130.773	0.278
Nizamabad	Linear	0.326	248.112	0.365
	Quadratic	0.337	245.983	0.388
	Exponential	0.306	251.788	0.373
	Monomolecular	0.327	247.883	0.366
	GAM	0.491	215.759	0.329

**Fig 16:** Trends of Red gram productivity in Adilabad district.**Fig 17:** Trends of Red gram productivity in Mahabubnagar district.**Fig 18:** Trends of Red gram productivity in Nizamabad district.

4. Discussion

The consistent selection of GAM as the best-fitted model across crops and districts highlights its effectiveness in capturing nonlinear trends and structural changes in

agricultural time-series data. The observed improvements in production and productivity, even in districts with declining cultivated area, suggest the influence of technological progress, improved varieties, and better crop management

practices. These results emphasize the suitability of GAM for reliable trend analysis and forecasting of pulse crops, thereby supporting evidence-based agricultural planning and policy formulation.

5. Summary

The present study examined long-term trends in area, production, and productivity of major pulse crops, namely Bengal gram and Red gram, in three districts of Telangana state Adilabad, Mahbubnagar, and Nizamabad using 30 years of district-level data from 1993-2022. To capture temporal dynamics, several growth models, including linear, quadratic, exponential, monomolecular, and Generalized Additive Models (GAM), were fitted and compared using standard diagnostic criteria such as the coefficient of determination (R^2), Mean Absolute Percentage Error (MAPE), and Root Mean Squared Error (RMSE).

The results indicated that Bengal gram showed an overall increasing trend in production and productivity across all three districts, although area under cultivation exhibited district-specific variations. Red gram also displayed improvements in production and productivity, despite declining or fluctuating cultivated area in certain districts. Across crops, districts, and variables, the Generalized Additive Model (GAM) consistently outperformed other models by providing higher explanatory power and lower prediction errors.

The fitted GAM curves closely followed observed values, confirming their ability to capture nonlinear patterns and structural changes in pulse crop performance. Overall, the findings or results demonstrate the suitability of GAM for modelling agricultural time-series data and provide reliable insights for understanding crop growth behaviour. The study established the importance of advanced statistical approaches for effective analysis, forecasting, and planning of pulse crop production in selected districts of Telangana state.

6. Conclusion

The present study applied linear and non-linear growth models to analyse the long-term behaviour of area, production, and productivity of Bengal gram and Red gram in selected districts of Telangana state using district-level data from 1993 to 2022. Model comparison based on diagnostic measures such as R^2 , RMSE, and MAPE revealed that the Generalized Additive Model (GAM) consistently outperformed conventional parametric models across crops, districts, response variables and consideration.

The findings showed that Bengal gram exhibited a general increase in production and productivity in all three districts, although changes in cultivated area varied across locations. Red gram also demonstrated improvements in productivity and output despite fluctuations or declines in area in certain districts, indicating the influence of technological progress and improved crop management practices. The fitted GAM curves closely matched the observed data, confirming their ability to capture non-linear trends and temporal variability inherent in agricultural time-series data.

Overall, the results highlight the effectiveness of GAM as a robust and flexible modelling framework for analysing crop performance over the period. The study provides valuable insights for researchers and policymakers by offering a reliable approach for understanding growth dynamics and supporting informed decision-making in pulse crop planning and development in Telangana state.

Future studies may improve the present existing analysis by including weather-related variables such as rainfall and temperature to better explain variations in pulse crop

performance. The modelling framework can be extended using spatial and time-based approaches to capture regional differences across districts. Advanced methods, including machine learning techniques, may also be used and applied to enhance prediction accuracy. Further validation of forecasts using future or unseen data would strengthen the reliability of the results. In addition, the approach can be used to assess the impact of improved technologies and policy interventions on the growth and sustainability of pulse crop production.

References

1. Devi YL, Arivelarasan T, Kapngaihlian J. Pulses production in India: trend and decomposition analysis. *Econ Aff.* 2017;62(3):435-438.
2. Eswara Prasad Y, Manohar Rao M, Vijayabhinandana B. Analysis of On-Farm Trials and Level of Technology on Oilseeds and Pulse Crop in Northern Telangana Zone of Andhra Pradesh. *Indian J Agric Econ.* 1993;48(902-2018):351-356.
3. Gautam AK, Sisodia BVS. Analysis of trends and growth rate of wheat crop and forecast of its production in Uttar Pradesh. *J Pharmacogn Phytochem.* 2018;7(5):3306-3310.
4. Guntukula R. Production and growth of pulses in Telangana State: an economic analysis. *Econ Aff.* 2018;63(1):269-276.
5. Guntukula R, Goyari P. How does the yield variability in rainfed crops respond to climate variables? Evidence from pulses yields in Telangana, India. *J Agric Dev Emerg Econ.* 2022;12(2):262-280.
6. Kalamkar SS, Shende NV, Atkare VG. Coarse cereals and pulses production in India: trends and decomposition analysis. *Agric Situ India.* 2002;59(1):581-587.
7. Khan S, Bhardwaj RK, Saxena RR, Bhagat RK, Jatav GK. Non-linear statistical modelling for area, production and productivity of rice crop in Chhattisgarh. *Asian J Soil Sci.* 2013;8(1):98-102.
8. Kumar TM, Darshan MB, Gowda CS, Rani SS. Comparison of nonlinear statistical growth models for describing coffee export trends in India. *Asian J Hortic.* 2012;7(1):31-35.
9. Malhi RKM, Kiran S. Analysis of trends in area, production and yield of important crops of India. *Int J Agric Appl Res.* 2015;7(1):86-92.
10. Pasala S, Rudra M. The performance of area, production and productivity of pulses in Andhra Pradesh (with reference to 13 districts of Andhra Pradesh). *Int Res Acad J Multidiscip Soc Sci.* 2017;6(1):97-103.
11. Sathish Kumar M, Lad YA, Mahera AB. Trend analysis of area, production and productivity of minor millets in India. *Bharatiya Food Ind J.* 2022;14(2):14-18.
12. Shah NA, Hassan A, Farooq A. Growth and trend in area, production and yield of major crops of Khyber Pakhtunkhwa, Pakistan. *Asian J Agric Rural Dev.* 2014;4(2):149-155.
13. Sharma MK, Sisodia BVS, Lal K. Growth and trends of pulse production in India. *J Food Legumes.* 2013;26(1 and 2):86-92.
14. Ramakrishnan M, Satish L, Sharma A, Kurungara Vinod K, Emamverdian A, Zhou M, Wei Q. Transposable elements in plants: Recent advancements, tools and prospects. *Plant Molecular Biology Reporter.* 2022 Dec;40(4):628-45.