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COMPARATIVE ASSESSMENT OF INSTABILITY, GROWTH AND TREND DYNAMICS OF GRAM (*CICER ARIETINUM* L.) IN THE MIRZAPUR DISTRICT OF UTTAR PRADESH, INDIA

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ABSTRACT

Gram (*Cicer arietinum* L.) is a vital source of protein and essential nutrients, playing a key role in improving digestion and reducing the risk of disease. This study examines the instability and growth rates for both linear and compound rates of the area, production, and yield of gram in the Mirzapur district, Uttar Pradesh, from 1994 to 2022. The instability level was measured using the Cuddy Della Valle instability index, while growth rates were assessed through linear and compound growth rate analysis. A comparative evaluation was conducted for triennium, quinquennium, and the entire study period. The analysis reveals that production experienced the highest level of instability, whereas the area under cultivation remained the most stable. In terms of growth trends, the linear growth rate was highest for yield and lowest for the area, while a similar pattern was observed for the compound growth rate, with yield showing the maximum increase and area the minimum. To analyze trend patterns, three statistical models, such as linear, quadratic and cubic models were applied. Their accuracy was assessed using key statistical indicators, including the coefficient of determination (R^2), root mean square error (RMSE) and mean absolute percentage error (MAPE). The findings confirm that these models effectively captured the trends in the area, production, and yield of gram. Notably, the cubic model demonstrated the highest accuracy among them, making it the most suitable model for forecasting the future trends of gram production in Mirzapur.

Key words : Instability index, Growth rates, Linear model, Quadratic model, Cubic model.

Introduction

Mirzapur District, situated in eastern Uttar Pradesh, has a diverse agricultural landscape, with gram cultivation playing a significant role in local farming. However, over the years, gram production in the region has fluctuated due to a mix of environmental challenges and socio-economic factors. These variations impact farmers' livelihoods and overall agricultural stability. Analyzing the trends and growth patterns of gram production is crucial for developing effective policies that promote sustainable farming, enhance food security and boost farmers' incomes.

Mirzapur is located at 25.15°N latitude and 82.58°E longitude, with an average elevation of 80 meters (265 feet). It lies between 23.52° and 25.32° North latitude and 82.7° and 83.33° East longitude, forming part of Varanasi district. The city is bordered to the north and northeast by Varanasi district, to the south by Sonbhadra district and to the northwest by Prayagraj (Allahabad) district. Its northern and western boundaries are well-defined, except for a 13-kilometer stretch in the northeast where the Ganga River separates Chunar Tehsil from Varanasi district. Mirzapur is known for the Chanvar fields, one of the most fertile land tracts in India, situated on the Gangetic floodplains. Additionally, the city holds historical significance as the Mirzapur Clock Tower serves as the reference point for Indian Standard Time (IST), which is calculated based on the 82.5° E longitude passing through it.

Fig. 1 : Geographical Overview of the study Area of Mirzapur District, Uttar Pradesh, India.

Gram (*Cicer arietinum* L.), commonly known as chickpea, is a key pulse crop grown in Mirzapur for its high nutritional value and role in sustainable agriculture. It is an excellent source of protein, fiber, and essential minerals, making it a staple in Indian diets. Gram is also beneficial for soil health, as it helps fix nitrogen, improving soil fertility for subsequent crops. The crop thrives in semi-arid regions with moderate rainfall and well-drained soils, making it an important component of crop rotation systems. During the 2022 crop year, Mirzapur's gram production reached 1,76,680 quintals, cultivated across 13,868 hectares, with an average yield of 12.74 quintals per hectare (Source: DES, Department of Agriculture Cooperation & Farmers Welfare, Government of India, 2022).

Gram is a rich source of protein and an important part of the human diet. Extensive research and statistical analyses by scientists have provided valuable insights, supporting policy development and sustainable agricultural practices. Sharma *et al.* (2013) analyzed the growth and trend of pulse production in India using time series data on area, production, yield, and trade from 1980-81 to 2008-09. Sharma *et al.* (2014) examined the growth rates, instability of variation of area, production, and productivity of different pulse crops in the various regions of Uttar Pradesh and total pulse crops for two periods before and after the launch of technological missions on pulse production in the country. More *et al.* (2015) compared the performance of pulse crops at the state level in high-growth periods and data from the years 1960-61 to 2010-11 were used. The performance of the crop was analyzed by decade, *i.e.*, period-i to period-v and overall period, with the help of statistical techniques like average, growth rate, Cuddy-Della Valle instability index, and decomposition model. Sachan *et al.* (2018) studied the regional growth analysis of pulse production in Uttar Pradesh, India. Singh and Bansal (2020) explored the status of pulses in Punjab with the computation of the compound annual growth rate and decomposition analysis using secondary data from the years 1985-86 to 2017-18. Pooja *et al.* (2023) developed a clear portrayal of the area and production of pulses in India. Regression modeling was applied for both the area and production of Pulses in India for a period of 71 years (1951-2021) using linear, logarithmic, quadratic, cubic, power and exponential models. Kumar *et al.* (2024) analyzed the instability and growth rate in area, production, and yield of major pulses in India. Kumar *et al.* (2025) investigated the instability and growth rates in area, production, and yield of lentil in India. Singh and Kumar (2025) analyzed the trend pattern in the area, production, and yield of pigeon pea in India. Singh *et al.* (2025) examined the trend patterns in area, production, and yield of lentil in India. The analysis is based on secondary time series data spanning the period from 2001-2023. Some other significant contributions toward time series analysis other than pulse crops have been carried out by Singh *et al.* (2020), Singh *et al.* (2021), Singh *et al.* (2024) and Mishra *et al.* (2025).

The study aims to analyze the instability index, growth rates (linear and compound growth rates) over a triennium, quinquennium, and gram's overall period, and trends in the Mirzapur district from 1994 to 2022. Statistical models such as linear, quadratic, and cubic models are used for the analysis, with their accuracy evaluated using R^2, RMSE, and MAPE.

Materials and Methods

This study is based on secondary time-series data on the area, production, and yield of gram in Mirzapur district, Uttar Pradesh, from 1994 to 2022. The data were sourced from the *Sankhikiya Patrika* (Statistical Bulletin) published by the Economics and Statistics Division, Planning Department, Government of Uttar Pradesh, and the Directorate of Economics and Statistics, Department of Agriculture Cooperation & Farmers Welfare, Government of India. To reduce random fluctuations and identify trends, triennium (three-year) and quinquennium (five-year) moving averages were applied.

Instability Index

The Cuddy-Della Valle Instability Index (CDV Index) is a widely used measure to quantify instability in time-series data while accounting for trends. It refines the traditional Coefficient of Variation (CV) by incorporating the influence of trends through the coefficient of determination (R^2) from a regression model. The formula is

$$I = CV\sqrt{1-R^2}$$

Linear Growth Rate

The equation gives a linear function:

$Y_t = a + bt$

where, t is the Time in years, an independent variable, Y_t is the trend value of the dependent variable and a and b are constants.

The above equation is fitted by using the least squares method of estimation.

The formula calculates the linear growth rate:

$$\text{Linear growth rate (LGR \%)} = \frac{\hat{b}}{\overline{Y}} \times 100$$

where, $\hat{b}$ is the slope and $\overline{Y}$ is the mean of variable Y.

Compound Growth Rate

This formula determines the average annual growth rate needed to raise the crop's value from its starting point to its peak over a specific period, assuming consistent yearly compounding.

$$y_t = a(1+r)^t$$

where, y_t is the time-series value of variable Y at time t, 'a' is a scalar quantity, and 'r' denotes the compound growth rate.

Taking logarithms on both sides of the above equation, we have

$$\log y_t = \log a + t\{\log(1+r)\}$$

i.e., $Y_t = A + Rt$

where, $Y_t = \log y_t$, $A = \log a$ and $R = \log(1+r)$.

The normal equations for estimating 'A' and 'R' are given below:

$$\Sigma Y_t = nA + R\Sigma t \quad \text{(i)}$$

$$\Sigma tY_t = A\Sigma t + R\Sigma t^2 \quad \text{(ii)}$$

Finally, on solving (i) and (ii), the estimated values of 'a' *and* 'r' are obtained as follows:

$$\hat{a} = anti\log(A)$$

$$\hat{r} = anti\log(R) - 1$$

Here, $\hat{r}$ denotes the estimated compound growth rate (CGR) and is generally expressed in terms of percentage as follows:

$$\hat{r} = [anti\log(R) - 1] \times 100$$

Statistical Methods used

1. Linear Regression Model

The linear model is given by

$Y_t = m + nt + \varepsilon_t$

where, Y_t represents the dependent variable (area, production, yield), t (the independent variable) denotes time in years, m is the model's intercept, n is the regression coefficient and ε_t is the normally distributed error term.

2. Quadratic Model

Appropriate for data exhibiting peaks or troughs, the quadratic model is

$Y_t = m + nt + ot^2 + \varepsilon_t$

where, m is the model's intercept, n is the regression coefficient and o represents an additional regression coefficient related to the square of time, making the model capable of capturing parabolic trends.

3. Cubic Model

The cubic model is given by

$Y_t = m + nt + ot^2 + pt^3 + \varepsilon_t$

For data showing multiple peaks or troughs, the cubic model, incorporates a third-degree polynomial, allowing for more complex curve fitting.

where, m is the model's intercept and n, o and p are coefficients.

Results and Discussion

The secondary time-series data on the area, production, and yield of gram (chickpea) in the Mirzapur district of Uttar Pradesh from 1994 to 2022 have been

Table 1 : Time series data on area, production, and yield of gram (chickpea) in Mirzapur.

Year	Area (Hectares)	Production (Quintals)	Yield (Quintals/Hectares)
1994	19644	273890	13.94
1995	20297	225650	11.12
1996	19640	186730	9.51
1997	19944	177900	8.92
1998	18714	143930	7.69
1999	17662	159180	9.01
2000	15735	163680	10.40
2001	15778	134920	8.55
2002	17396	161280	9.27
2003	17815	192420	10.80
2004	16853	189340	11.23
2005	14864	145170	9.77
2006	15082	126010	8.35
2007	14980	164720	11.00
2008	14223	126050	8.86
2009	13965	132800	9.51
2010	13831	126210	9.13
2011	13633	141700	10.39
2012	13446	143620	10.68
2013	13382	151180	11.30
2014	13026	134400	10.32
2015	12259	132780	10.83
2016	12458	102240	8.21
2017	13382	153660	11.48
2018	13800	195580	14.17
2019	12817	162240	12.66
2020	13313	112660	8.46
2021	13676	188470	13.78
2022	13868	176680	12.74

(Source: Sankhikiya Patrika and Directorate of Economics and Statistics, Department of Agriculture Cooperation & Farmers Welfare, Government of India).

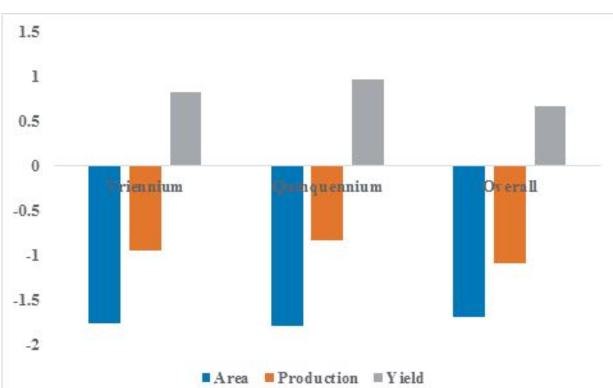

Fig. 2 : Linear growth rate for area, production, and yield of gram.

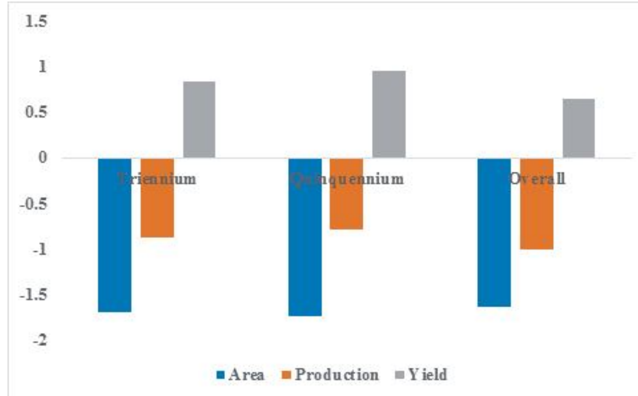

Fig. 3 : Compound growth rate for area, production and yield of gram.

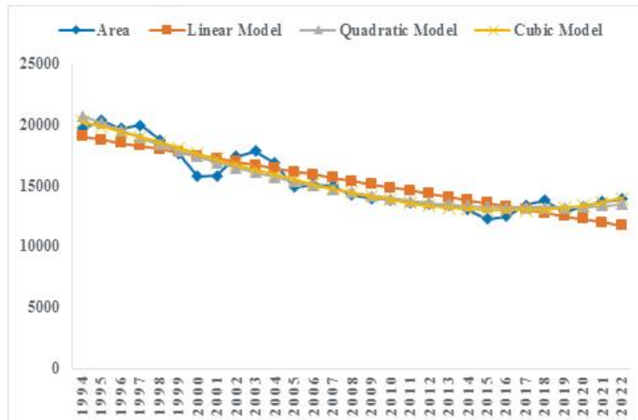

Fig. 4 : Predicted values for linear, quadratic, and cubic models for the area of gram.

Table 2 : Statistical coefficients for area, production, and yield of gram in Mirzapur.

	Area	Production	Yield
C.V.	15.92	21.97	16.69
R^2	0.79	0.17	0.11
I	7.22	19.68	15.91

comprehensively analyzed. Key statistical indicators, including the coefficient of variation (CV), coefficient of determination (R^2) and the Cuddy-Della Valle instability index (I), are summarized in Table 2. Tables 3 and 4 provide insights into the linear and compound growth rates of area, production, and yield, respectively. Furthermore, predicted values have been estimated by fitting linear, quadratic, and cubic models to the secondary time-series data, with the results presented in Tables 5, 6 and 7.

Statistical analysis

The analysis of instability indices (Table 2) reveals that gram production experiences the highest instability (19.68%), followed by yield (15.91%) and area (7.22%). The relatively lower instability in the cultivated area suggests that land allocation for gram has remained fairly

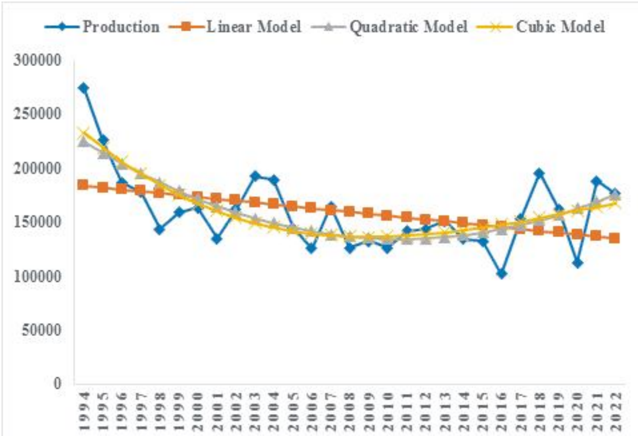

Fig. 5 : Predicted values for linear, quadratic, and cubic models for the production of gram.

Table 3 : Linear growth rate of gram in Mirzapur.

	Triennium	Quinquennium	Overall
Area	-1.77	-1.80	-1.70
Production	-0.95	-0.83	-1.09
Yield	0.83	0.97	0.66

Table 4 : Compound growth rate of gram in Mirzapur.

	Triennium	Quinquennium	Overall
Area	-1.70	-1.74	-1.63
Production	-0.88	-0.79	-1.00
Yield	0.83	0.95	0.64

stable over the years. However, production and yield have shown significant fluctuations, likely due to environmental conditions, agronomic practices and market influences. Additionally, the low R^2 values indicate that variations in area, production and yield are influenced by multiple external factors beyond simple linear trends.

Growth Rate analysis

Linear Growth Rate

The linear growth rate analysis (Table 3) indicates a slight decline in the cultivated area of gram, with a more pronounced decrease during the quinquennium (-1.80%) compared to the triennium (-1.77%). In terms of production, the linear growth rate shows a minor improvement in the quinquennium (-0.83%) compared to the triennium (-0.95%). Yield, however, exhibits a slight positive growth, with a linear increase of 0.97% in the quinquennium compared to 0.83% in the triennium. Over the entire study period, yield experienced the highest linear decline (-0.66%) compared to production (-1.09%) and cultivated area (-1.70%).

Compound Growth Rate

The compound growth rate analysis (Table 4) reveals

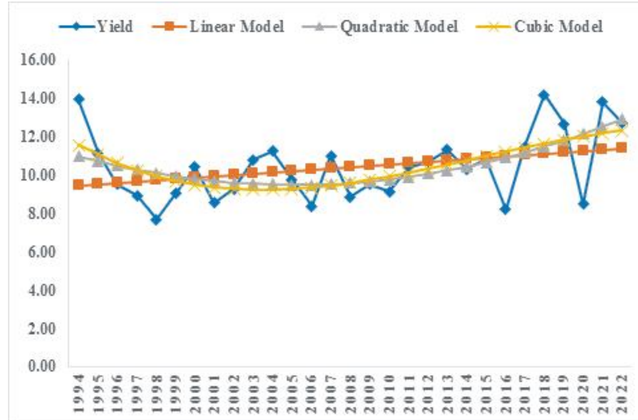

Fig. 6 : Predicted values for linear, quadratic, and cubic models for the yield of gram.

Table 5 : Predicted values for area of gram.

Year	Area	Predicted Values		
		Linear Model	Quadratic Model	Cubic Model
1994	19644	19009.69	20723.14	20227.91
1995	20297	18749.10	20095.39	19812.40
1996	19640	18488.52	19494.83	19384.78
1997	19944	18227.93	18921.47	18948.08
1998	18714	17967.34	18375.31	18505.31
1999	17662	17706.76	17856.35	18059.52
2000	15735	17446.17	17364.58	17613.70
2001	15778	17185.59	16900.01	17170.90
2002	17396	16925.00	16462.64	16734.14
2003	17815	16664.41	16052.47	16306.43
2004	16853	16403.83	15669.49	15890.80
2005	14864	16143.24	15313.71	15490.28
2006	15082	15882.66	14985.13	15107.88
2007	14980	15622.07	14683.75	14746.64
2008	14223	15361.48	14409.57	14409.57
2009	13965	15100.90	14162.58	14099.69
2010	13831	14840.31	13942.79	13820.04
2011	13633	14579.72	13750.20	13573.63
2012	13446	14319.14	13584.80	13363.49
2013	13382	14058.55	13446.61	13192.64
2014	13026	13797.97	13335.61	13064.11
2015	12259	13537.38	13251.80	12980.91
2016	12458	13276.79	13195.20	12946.08
2017	13382	13016.21	13165.79	12962.62
2018	13800	12755.62	13163.59	13033.58
2019	12817	12495.03	13188.57	13161.97
2020	13313	12234.45	13240.76	13350.81
2021	13676	11973.86	13320.14	13603.13
2022	13868	11713.28	13426.73	13921.95

Table 6 : Predicted values for Production of gram.

Year	Production	Predicted Values		
		Linear Model	Quadratic Model	Cubic Model
1994	273890	183881.38	224691.27	232938.89
1995	225650	182138.84	214203.75	218916.68
1996	186730	180396.31	204364.02	206196.82
1997	177900	178653.77	195172.06	194728.96
1998	143930	176911.23	186627.87	184462.75
1999	159180	175168.69	178731.46	175347.82
2000	163680	173426.16	171482.83	167333.84
2001	134920	171683.62	164881.97	160370.45
2002	161280	169941.08	158928.89	154407.30
2003	192420	168198.55	153623.59	149394.04
2004	189340	166456.01	148966.06	145280.31
2005	145170	164713.47	144956.30	142015.76
2006	126010	162970.94	141594.33	139550.05
2007	164720	161228.40	138880.13	137832.81
2008	126050	159485.86	136813.70	136813.70
2009	132800	157743.33	135395.05	136442.37
2010	126210	156000.79	134624.18	136668.46
2011	141700	154258.25	134501.08	137441.63
2012	143620	152515.71	135025.76	138711.51
2013	151180	150773.18	136198.22	140427.77
2014	134400	149030.64	138018.45	142540.04
2015	132780	147288.10	140486.46	144997.97
2016	102240	145545.57	143602.24	147751.22
2017	153660	143803.03	147365.80	150749.44
2018	195580	142060.49	151777.13	153942.26
2019	162240	140317.96	156836.24	157279.34
2020	112660	138575.42	162543.13	160710.33
2021	188470	136832.88	168897.79	164184.87
2022	176680	135090.34	175900.23	167652.61

Table 7 : Predicted Values for yield of gram.

Year	Yield	Predicted Values		
		Linear Model	Quadratic Model	Cubic Model
1994	13.94	9.45	10.96	11.56
1995	11.12	9.52	10.70	11.05
1996	9.51	9.59	10.47	10.61
1997	8.92	9.66	10.27	10.24
1998	7.69	9.73	10.09	9.93
1999	9.01	9.79	9.93	9.68
2000	10.40	9.86	9.79	9.49
2001	8.55	9.93	9.68	9.35
2002	9.27	10.00	9.59	9.26
2003	10.80	10.07	9.53	9.22
2004	11.23	10.14	9.49	9.22
2005	9.77	10.21	9.48	9.26
2006	8.35	10.28	9.49	9.34
2007	11.00	10.35	9.52	9.44
2008	8.86	10.42	9.58	9.58
2009	9.51	10.49	9.66	9.74
2010	9.13	10.56	9.76	9.91
2011	10.39	10.62	9.89	10.11
2012	10.68	10.69	10.05	10.32
2013	11.30	10.76	10.22	10.53
2014	10.32	10.83	10.42	10.75
2015	10.83	10.90	10.65	10.98
2016	8.21	10.97	10.90	11.20
2017	11.48	11.04	11.17	11.42
2018	14.17	11.11	11.47	11.63
2019	12.66	11.18	11.79	11.82
2020	8.46	11.25	12.13	12.00
2021	13.78	11.32	12.50	12.16
2022	12.74	11.38	12.89	12.29

a slight decline in the area under gram cultivation, with a more significant decrease during the quinquennium (-1.74%) compared to the triennium (-1.70%). In terms of production, the compound growth rate shows a minor improvement in the quinquennium (-0.79%) compared to the triennium (-0.88%). Meanwhile, yield exhibited a slight increase, rising to 0.95% in the quinquennium from 0.83% in the triennium. Over the entire study period, yield recorded the highest compound growth rate (0.64%), followed by production (-1.00%) and area (-1.63%).

These findings highlight the urgent need for targeted policy interventions to stabilize and enhance gram yield. Strategic initiatives such as adopting improved agronomic practices, promoting high-yielding and climate-resilient varieties, and ensuring efficient input management can help counter the declining trends and support the long-term sustainability of gram cultivation in the Mirzapur district.

The triennium, quinquennium, and overall year linear growth rate and compound growth rate of area, production and yield of gram in the Mirzapur district of Uttar Pradesh are elaborated in Figs. 2 and 3, respectively.

The graphical representation illustrating the relative impact of predicted values on the observed values of gram area, production and yield is presented in Figs. 4 to 6.

The computed values of R^2, RMSE and MAPE for the fitted models (linear, quadratic and cubic models) related to gram area, production, and yield are presented

Table 8 : Evaluation of model accuracy for area, production, and yield of gram.

Models	Area			Production			Yield		
	RMSE	MAPE	R^2	RMSE	MAPE	R^2	RMSE	MAPE	R^2
Linear	1108.415	0.067	0.795	31864.660	0.161	0.173	1.639	0.124	0.111
Quadratic	711.517	0.034	0.915	24609.017	0.123	0.507	1.458	0.113	0.296
Cubic	673.209	0.030	0.924	24308.247	0.122	0.519	1.431	0.110	0.322

in Table 8.

The results obtained from Table 8 are summarized as:

i. The R^2 values for the linear, quadratic, and cubic models exceed 0.5 for the area and for the quadratic model of gram production. However, the R^2 values for gram yield and the linear or cubic models of production are below 0.5.

ii. Among all models, the cubic model demonstrated the highest R^2 for area, production, and yield of gram. Additionally, it exhibited the lowest RMSE and MAPE across these parameters, indicating superior performance.

Based on these findings, the fitted models effectively analyze trends in the area, production, and yield of gram in Mirzapur. Moreover, the cubic model provides the highest accuracy in capturing trend patterns compared to the other models.

Conclusion

This study provides a detailed analysis of the instability and growth trends in the area, production and yield of gram in Mirzapur district, Uttar Pradesh, from 1994 to 2022. To capture long-term patterns, triennium (three-year) and quinquennium (five-year) moving averages were applied, helping to smooth out random fluctuations in the data. Different trend models, including linear, quadratic and cubic, were used to examine the patterns, and their performance was assessed using statistical measures such as R^2, RMSE, and MAPE.

The results indicate that gram production experienced the highest level of instability (19.68%), while the cultivated area remained relatively stable, showing the lowest instability (7.22%). This suggests that although farmers have consistently allocated land for gram cultivation, variations in production levels have been driven by external factors such as climate fluctuations, pest outbreaks, soil fertility decline, and advancements in agricultural technology.

The linear growth rate indicates that yield experienced the highest growth rate (0.66%) over the study period, followed by area (-1.70%) and production (-1.09%). Similarly, the compound growth rate analysis of yield confirms highest growth rate (0.64%), surpassing the declines in area (-1.63%) and production (-1.00%). These findings highlight the pressing need for strategic measures to mitigate yield stagnation and production variability, ensuring the long-term viability of gram cultivation.

The analysis results indicate that the fitted models (linear, quadratic, and cubic models) effectively estimate trends in the area, production, and yield of gram. Moreover, based on the R^2, RMSE, and MAPE values, the cubic model exhibits the highest accuracy among all models, making it the most reliable for forecasting the future trends of gram in Mirzapur.

Competing interests

Authors have declared that no competing interests exists.

Authors contributions

The work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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