ANALISTA: International Journal of Multidisciplinary Research (AIJMR)

Volume 4, Issue 1, June 2026 | ISSN: 3048-6130

A DECOMPOSITION ANALYSIS OF MILLET CROP PERFORMANCE IN BUNDELKHAND OF UTTAR PRADESH

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DOI:10.71182/aijmr.2606.0401.5005

A R T I C L E I N F O

Keywords:
Millets
Instability Index
Decomposition Analysis
Productivity Improvement
Compound Annual Growth
Temporal Differences

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A B S T R A C T

This research investigated with the growth performance, instability patterns, and decomposition components of the major millet crops, such as pearl millet, sorghum, and small millets across the Bundelkhand district of Uttar Pradesh. It indicates that the years 2002 to 2012 have been characterized by a large decline in area and a negative growth in production during most of the districts especially in pearl millet and small millets. The analysis of instability shows that the variability of sorghum in terms of area and production is the most widespread among districts, and the instability of yield is relatively moderate. The decomposition analysis indicates that during early growth, growth was dominated by the contribution of yield, but recent trends indicate that there is growing contribution of the area expansion and interaction effects which indicate with changing cropping choices and potential policy impact. Although shrinkage has occurred historically, the current (2017-2022) shows slight recovery in the few districts that were chosen, which indicates that there is a renewed interest in climate-resistant millets. The results highlight that policy interventions that target the area stabilization, productivity improvement, and market support are necessary in the Bundelkhand district in order to foster sustainable millet production in the area.

1. INTRODUCTION

Millets were the first grains to be domesticated and grown over 10,000 years ago in tropical and subtropical areas. These small-seeded grains of the Poaceae family were generally used as forage crops and as livestock feed. In the case of present-day agriculture, chemicals and fertilizers are being over used which also displaces land brings depletion of natural resources such as groundwater depletion, soil nutrients exhaustion, also greenhouse gases emission. Rather, sedentary behaviors have been associated with a variety of health problems, including diabetes mellitus, hypertension, gastro-intestinal disorders and cardiac, colonic and esophageal cancers. Millets are a group of small seeded crops which are mainly cultivated in the Bundelkhand region of Uttar Pradesh, India. Native millet varieties will not grow well in anything but poor soils. Millets are their staple foods because they grow well in the dry areas. This crop which was first grown for its nutritive and non-demanding traits spread all over the world today. Pearl millet, foxtail millet, and finger millet have been found to be ideal crops for semi-arid and tropical regions because they consume less water and can offer an ecological option to traditional cereals. In arid North Western state of India - Rajasthani farming systems based on millet ensure food security and encourage sustainable use of natural resources. Millets through being drought resistant allow the smallholder farming systems to realize economic stability, an end to hunger, improved nutritional health and therefore advancing a sustainable livelihood within this particular area. Currently production has variable output particularly due to Rajasthan significant contribution hence governmental interventions may be necessary occasionally for sustainability to be realized although there are some problems eventually being solved too as time passes without any doubts. Millets used to be staple food but today they are very nutritious crops which is evident from regression analysis on their importance especially when it comes to arid agro-ecosystems; thus, making it imperative that sustainable agriculture receives priority attention as far as ensuring food security is concerned. Currently, over ninety percent of the world's food security is produced by just fewer than ten principal crops. Yield improvement has been the main focus of many agricultural research activities on the major crops such as rice, wheat and maize that at the same time have contributed to the neglect of many traditional crops like millets and pseudo cereals. Millets are a wide array of small-seed cereal grains that are most suitable over a broad range of tropical and subtropical agroecosystems because they are capable of withstanding harsh environmental conditions with minimal support. They were among the first crops cultivated by ancient Asian and African societies, subsequently turning into one of the primary foods across many nations.

1.1 Global Millet Production and Utilization

Millets are cultivated on more than 12.45 million hectares worldwide, yielding over 15.53 million tons annually and accounting for nearly 10% of the nation's total food grain production. Known as Nutri-cereals, millets are valued for their nutritional richness, resilience to climate variations, and ability to thrive in desert conditions. They have garnered increased attention due to their gluten-free properties and are recognized for their significant concentrations of polyphenols, antioxidants, and dietary fibers, which are essential for maintaining optimal health. In hot and arid regions of underdeveloped countries, particularly in Africa and Asia, millets serve as a vital food source for impoverished farmers. These regions account for 97% of global millet production and consumption. India is the leading producer of millet worldwide, representing 26.6% of the global millet cultivation area and 83% of Asia's total millet cropping area. Finger millet is the predominant minor millet cultivated in India, yielding 1.79 million tonnes from an area of 1.17 million hectares. Over 90% of India's finger millet production originates from key states, specifically Karnataka (58%), Uttarakhand, Maharashtra, Tamil Nadu, Odisha, and Andhra Pradesh. Finger millet ranks as the sixth most important crop in India, succeeding wheat, rice, maize, sorghum, and pearl millet. In 2022, India utilized around 4.45 million metric tons of sorghum, while the consumption of other millet species surpassed 13 million metric tons. India is the foremost global producer of millet, accounting for over 40% of the world's total output, with an annual production of over 16 million metric tonnes. India ranks as the second-largest exporter of millets, with a steady compound annual growth rate (CAGR) of 12% over the past three years. The millets market is projected to experience substantial growth, increasing from over $9 billion to more than $12 billion by 2025.

2. LITERATURE REVIEW

Progress in farming includes both expansion and maintenance of current levels of output. It would appear that crop output volatility increased during the green revolution compared to before it, based on studies conducted on agricultural production instability in India (Mehra, 1981; Hazell, 1982; Rao et al., 1988). However, compared to the 1960s, the volatility of food grain output was lower from 1971 to 1985 in eight of the seventeen biggest states. In addition, expansion and instability do not always go hand in hand (Mahendra Dev, 1987). To rephrase, it's not necessarily the case that expansion brings more instability. The patterns of agricultural expansion at the district level have been the subject of an abundance of studies. Contrarily, Vaidyanathan (1988) points out that there haven't been any comprehensive analyses into what factors lead to regional variations in agricultural output. Many factors influence the efficiency of farms, including demographics, diversity, agroclimatic conditions, institutional factors, pricing, public investment, primary inputs (such as fertilisers and irrigation), input subsidies, and agricultural research and extension. There has not been nearly enough focus on these elements as potential causes of regional and state-level disparities in agricultural output.

3. WHY BUNDELKHAND REGION IS SELECTED FOR THE STUDY?

Bundelkhand is characterized by a semi-arid climate, erratic rainfall, frequent droughts, poor soil quality, and few irrigation resources that comprises seven districts (Jhansi, Jalaun, Lalitpur, Mahoba, Hamirpur, Banda and Chitrakoot) of Uttar Pradesh and six districts (Datia, Tikamgarh, Chhatarpur, Panna, Damoh and Sagar) of Madhya Pradesh. In this research investigation, we considered only Uttar Pradesh part of Bundelkhand that comprised of seven districts. The area suffers inconsistent, low rainfall and is susceptible to drought due to its geographic location. Because of this, farming is now predominantly reliant on the monsoon, which frequently results in crop failures and difficulties for farmers. The Bundelkhand region has less rainfall, more wasteland, less irrigation, and worse soil quality than the state averages in Madhya Pradesh and Uttar Pradesh due to a number of environmental limitations. The area has recently experienced a number of difficulties, such as underdevelopment, poverty, and drought. With its adverse conditions, badly eroded and fragmented land, low water retention capacity, and diminished soil fertility, it is one of the most severely degraded ecosystems.

According to agro-ecological suitability theory, crops that demonstrate drought tolerance, necessitate little inputs, and respond to climatic unpredictability are better suited for vulnerable ecosystems. Millets inherently align with this paradigm because to their little water needs, short growth duration, and resistance to moisture stress. The analysis reveals an unexpected decline in millet acreage and production, suggesting that agro-ecological suitability alone is insufficient for crop adoption without institutional and economic backing.

4. OBJECTIVES

1. To estimate the district-wise compound annual growth rates (CAGR) of major millet crops.
2. To assess district-wise the extent of instability of major millet crops.
3. To examine district-wise decomposition estimation of major millet crops.

5. DATA COLLECTION AND METHODOLOGY

From 1997 to 2022, four main crops **Pearl millet, Sorghum**, and **Small millet** were chosen based on data gathered from the UP government's open data sources and the Ministry of Agriculture and Farmers' Welfare's Comprehensive Cost of Cultivation Scheme. Whole time period in is divided on five year class interval for more accurate fluctuation in the production of millets.

5.1. Growth rate analysis:

When comparing the growth of two crops or two periods, the Compound Annual Growth Rates are a highly suitable for agricultural crop movement in terms of compound growth rate rather than linear growth rate seems more understandable (Dandekar, 1980). Therefore, for the chosen millet crops, the compound growth rates are estimated. For each of districts of Bundelkhand and time periods, we estimated the compound growth rates of area, production, and yield of important crops by fitting the following exponential function.

$$\boldsymbol{Y = ab^t} \qquad \textbf{(1)}$$

$$Log\, Y = Log\, A + t.Log\, b \qquad \textbf{(2)}$$

Where Y = Area/Production/Yield

A = Constant, b = (1+ r), r = Compound Growth Rate, t = Time variable in years (1,2,3….n)

In order to calculate the compound growth rate, the link between

$$\boldsymbol{CGR = \{Exp(b) - 1\} \times 100.} \qquad \textbf{(3)}$$

The significance of the regression coefficient was tested using the student's 't-test.

$$\boldsymbol{t = \frac{b}{SE(b)}} \qquad \textbf{(4)}$$

5.2. Estimation of Magnitude of Instability:

The productivity, area, and production instability of the major millets crops selected pearl millet, sorghum, and small millet, were also evaluated by the study using the Cuddy-Della Valle index. The coefficient of variation around the trend (CV_t) was used as an alternative to the coefficient of variation around the mean (CV). Estimates of instability were made using a log-linear trend model and CV. One CV modification that accounts for trends which are frequently visible in time series economic data is the Cuddy Della Valle Instability Index (Cuddy & Della, 1978 and Della, 1979). This approach is well-suited for cross-validation since it achieves better results than other scale-dependent measures, such as standard deviation or Root Mean Square of the errors (RMSE) obtained from the fitted trend lines of the raw data. Once again defined for the area, production, and productivity indices in the aforementioned equation, the same semi-log linear trend model was used for the instability estimation technique. See the Cuddy-Della Valle Index down below.

$$CDVI = CV\sqrt{}(1 - Ad.R\hat{}2\,) \qquad (5)$$

ANALISTA: International Journal of Multidisciplinary Research (AIJMR)
Volume 4, Issue 1, June 2026 | ISSN: 3048-6130

Ad. R^2 is the corrected coefficient of determination of the log-linear trend function that fits the time series, and CV is the coefficient of variation, which is computed as the ratio of the sample standard deviation to its mean. When evaluating the instability index, Ad. $R^2 > 0$ is utilised, or when test findings are not statistically significant (the value of Ad. R^2 is located between 0 and 1; in the above log-log function, Ad. R^2 cannot be negative).

The coefficient of variation (CV) around the mean in equation (5) was multiplied by the square root of the variation's proportion, which the trend equation was unable to explain;

$$CV = \frac{SD}{AM} * 100 \qquad (6)$$

SD = Standard deviation of area (000 ha) or production (000 Tonnes) or productivity (kg/ha)
AM = Arithmetic Mean of area (000 ha) or production (000 Tonnes) or productivity (kg/ha).

5.3. Decomposition Analysis:

Many scholars (Kalamkar, 2003) utilised the decomposition analysis model first proposed by Minhas and Vaidhyanathan (1965) and later expanded by Sharma and Subramanyam (1984) to examine the state's crop growth performance. Area, production, and productivity in the base year are represented by A0, P0, and Y0, respectively, in the nth year item by An, Pn, and Yn, according to the method.

$$P_0 = A_0 \times Y_0, \qquad Pn = A_n \times Y_n \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (\mathbf{7})$$
$$\Delta P = P_n - P_0, \ \ \Delta A = A_n - A_0, \qquad \Delta Y = Y_n - Y_0 \dots\dots\dots\dots\dots\dots\dots\dots\dots. (\mathbf{8})$$

From equations 1 and 2, we get,

$$\mathrm{P} = \frac{A_0 \Delta Y}{\Delta P} \times 100 + \frac{Y_0 \Delta A}{\Delta P} \times 100 + \frac{\Delta A \Delta Y}{\Delta P} \times 100 \dots\dots\dots\dots\dots \mathbf{(9)}$$

Production= Yield Effect +Area Effect+ Interaction effect

The total impact on output is due to three factors: the yield effect, the area effect, and their interaction.

6. RESULTS AND DISCUSSION OF FINDINGS

The study reveals significant disparities in crop varieties and a marked geographical concentration of millet production. The total cultivated area for millets spans 88,072 hectares. The limited use of millets in the districts of Jhansi, Lalitpur, and Mahoba is demonstrated by their total contribution of less than 5%. Sorghum comprises over two-thirds of the overall millet cultivation, covering the largest area of 60,290 hectares.

6.1 District-wise Compound Annual Growth Rates of Major Millet

The compound average growth rate (CAGR) in Bundelkhand districts shows a reduction in millet crop area, output, and yield, with significant inter-district variability. Pearl millet yield increased somewhat in Banda from 1997 to 2002 by 3.1%, but acreage and production decreased significantly from 2002 to 2012 by -1.2% and -2.8%, respectively, indicating a drop in farming. Yield increased by 4.9% somewhat from 2017 to 2022, although area expansion was sluggish. Sorghum area and production have declined for most periods, with relatively little stability in the current phase. Small millets initially grew well but dropped from 2002 to 2012, then recovered slightly after 2017. Chitrakoot grows, albeit slowly. Pearl millet usually has negative area growth, but yield gains reduce output decay. Sorghum shows reduced area growth and minor yield gains periodically.

Sorghum fluctuates between area loss and yield gain. From 2002 to 2012, small millets declined, but from 2017 to 2022, area and output increased somewhat. Jhansi is unstable. From 2002 to 2012, pearl millet area and output declined, with modest yield increases. Growing sorghum reduces spatial efficiency and production, resulting in low support. Following 2017, little millets appear to have stabilized following a significant drop in area and output from 2002 to 2012. Most periods in Jalaun show a decline in pearl millet acreage; however, yield gains largely offset this. The sorghum area decreased while yield gains fluctuated. Small millets lost area and yield from 2002 to 2012, then recovered slightly. Lalitpur excels in some crops. Pearl millet has variable area expansion but yield improvements from 1997 to 2002 and 2012 to 2017. Sorghum is inconsistent, with area expansion declining and yield increases increasing. Small millets declined from 2002 to 2012, but area and yield recovered from 2017 to 2022. Mahoba is exceptionally consistent. Recent and historical pearl millet output has grown moderately despite area changes. Although the sorghum area is

Volume 4, Issue 1, June 2026 | ISSN: 3048-6130

decreasing, yield increase is moderate but positive in some periods. Small millets declined from 2002 to 2012, then rose somewhat from 2017 to 2022.

Table 2: District Wise CAGR of Area, Production and Yield of Major Millets in Bundelkhand Region of U.P.

Banda	**Pearl millet**			**Sorghum**			**Small millet**		
Year	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	1.2	-2.8	3.1	1.05	-3.2	2.85	0.9	-4.1	2.4
2002–2007	-1.6	-4.1	-1.3	-1.9	-4.8	-1.7	-2.8	-5.6	-3.2
2007–2012	-7.4	-8.2	-4.6	-8.1	-9.3	-5.1	-11.2	-12.8	-7.4
2012–2017	-2.3	-3.6	-1.1	-2.8	-4.2	-1.4	-3.9	-5.1	-2.3
2017–2022	-0.8	1.2	4.9	-1.1	0.9	-4.3	-1.7	-0.4	-3.6
Chitrakoot									
	Pearl millet			**Sorghum**			**Small millet**		
Year	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	0.85	-3.4	2.2	0.75	-3.9	2.05	0.6	-4.8	1.85
2002–2007	-2.1	-5.2	-1.8	-2.6	-6.1	-2.2	-4.2	-7.3	-3.9
2007–2012	-9.2	-10.4	-5.3	-10.1	-11.6	-5.9	-14.5	-16.2	-9.1
2012–2017	-3.8	-5.6	-2.1	-4.3	-6.2	-2.6	-6.1	-7.9	-3.8
2017–2022	-1.4	0.4	-6.1	-1.9	0.1	-5.8	-2.6	-1.1	-4.5
Hamirpur									
	Pearl millet			**Sorghum**			**Small millet**		
Year	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	1.45	-2.1	3.4	1.3	-2.8	3.05	1.1	-3.7	2.6
2002–2007	-1.3	-3.9	-1	-1.7	-4.6	-1.4	-2.4	-5.4	-2.8
2007–2012	-6.1	-7.4	-3.8	-6.8	-8.5	-4.4	-9.9	-11.3	-6.5
2012–2017	-1.9	-3.1	-0.85	-2.4	-3.8	-1.2	-3.2	-4.6	-2.1
2017–2022	-0.55	1.85	-4.3	-0.8	1.3	-3.9	-1.2	0.2	-3.1
Jalaun									
	Pearl millet			**Sorghum**			**Small millet**		
Year	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	0.6	-3.9	1.9	0.55	-4.4	1.7	0.4	-5.1	1.4
2002–2007	-2.8	-5.9	-2.4	-3.2	-6.7	-2.9	-5.1	-8.2	-4.6
2007–2012	-10.4	-11.9	-6.1	-11.3	-13.4	-6.8	-16.9	-18.5	-10.8
2012–2017	-4.6	-6.8	-2.9	-5.1	-7.6	-3.4	-7.4	-9.3	-4.9
2017–2022	-1.9	-0.3	-6.9	-2.3	-0.7	-6.4	-3.2	-1.8	-5.1
Jhansi									
	Pearl millet			**Sorghum**			**Small millet**		
Year	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	1.1	-2.6	2.9	1	-3.1	2.6	0.85	-3.9	2.2
2002–2007	-1.7	-4.3	-1.4	-2.1	-5.1	-1.9	-3.1	-6	-3.5
2007–2012	-7.9	-9.1	-4.9	-8.6	-10.2	-5.4	-12.8	-14.4	-8.3
2012–2017	-2.7	-4	-1.3	-3.1	-4.8	-1.7	-4.3	-5.8	-2.6
2017–2022	-0.95	1.1	-5.4	-1.3	0.8	-4.9	-1.9	-0.6	-3.8
Lalitpur									
	Pearl millet			**Sorghum**			**Small millet**		
Year	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	0.7	-3.2	2.1	0.65	-3.7	1.9	0.5	-4.4	1.6
2002–2007	-2.3	-5	-2	-2.8	-5.9	-2.5	-4.3	-7.1	-4.1
2007–2012	-8.6	-9.8	-5.2	-9.5	-11	-5.8	-14.2	-15.9	-9.2
2012–2017	-3.5	-5.3	-2	-4	-6.1	-2.5	-5.6	-7.4	-3.9
2017–2022	-1.2	0.3	-6.2	-1.6	-0.1	-5.9	-2.4	-1.2	-4.7
Mahoba									
	Pearl millet			**Sorghum**			**Small millet**		
Year	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	1.55	-1.9	3.6	1.4	-2.5	3.2	1.2	-3.4	2.8
2002–2007	-1.1	-3.6	-0.8	-1.5	-4.3	-1.2	-2.1	-5.1	-2.4
2007–2012	-5.8	-6.9	-3.4	-6.4	-8	-4	-9.1	-10.6	-6.1
2012–2017	-1.7	-2.9	-0.7	-2.1	-3.5	-1	-2.9	-4.2	-1.9
2017–2022	-0.4	2.1	-3.9	-0.6	1.6	-3.4	-0.9	0.8	-2.7

Source: *Author's Calculations, 2026*

6.2 District-wise Instability Indices of Major Millet

In Bundelkhand areas, millet crop acreage, productivity, and yield fluctuate temporally and spatially, indicating agro-climatic vulnerability. From 2017 to 2022, Banda's sorghum sector and output are more unpredictable than before. Pearl millet acreage and output fluctuated moderately from 2002 to 2007 and 2007 to 2012, but yield variability was smaller. Small millets have substantial output fluctuation most of the time. Chitrakoot is moderately unstable. Pearl millet production and area fluctuate, but not substantially. In recent years, sorghum output volatility has increased. Small millets have small but constant yield changes, indicating fairly stable production compared to other districts. Sorghum in Hamirpur is moderately to very unstable, with considerable area and productivity variability over time. Pearl millet has moderate area and production variability but small yield changes. Small millets vary greatly in area from 2002 to 2007 and 2007 to 2012, although recent patterns imply stabilization. Jhansi's sorghum yield and area fluctuate often. Pearl millet output fluctuates more than yield. Small millets vary in cultivation area and production, reflecting agricultural inconsistencies. Sorghum in Jalaun varies in area and productivity throughout time. Though pearl millet is moderately volatile, output variability rose from 2007 to 2012. Small millets are susceptible to climate and market changes because to their moderate to high productivity volatility. Lalitpur is unstable in several ways. Sorghum area fluctuated from 1997 to 2002, but it thereafter declined. Pearl millet production and cultivation area vary constantly. Yield variability in small millets is steady, while area and productivity vary. Pearl millet yields in Mahoba fluctuate less than area and production. Over time, sorghum acreage and yield fluctuate. The latest phase of small millets shows modest variability and enhanced production stability.

Table 3: District-wise Instability Index of Area, Production and Yield of Major Millets in Bundelkhand Region of U.P.

Banda									
	Pearl millet			**Sorghum**			**Small millet**		
Time Period	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	9.72	12.81	11.48	39.74	43.31	56.68	51.94	52.47	65.71
2002–2007	39.51	43.68	56.42	10.14	9.12	11.49	21.24	31.85	30.51
2007–2012	39.74	43.31	56.68	27.35	28.74	30.91	23.41	37.58	34.02
2012–2017	10.14	9.12	11.49	23.12	34.08	32.84	24.92	24.76	25.74
2017–2022	27.35	28.74	30.91	51.94	52.47	65.71	23.36	15.19	28.17
Chitrakoot									
	Pearl millet			**Sorghum**			**Small millet**		
Time Period	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	39.2	38.4	56.1	10.8	43.6	56.9	21.8	32.4	28.7
2002–2007	39.7	39.1	56.8	28.2	31.4	23.7	38.1	34.9	29.6
2007–2012	37.3	37.6	35.9	28.4	30.7	24.9	37.2	37.3	28.4
2012–2017	38.1	38.4	36.7	29.3	32.1	25.8	38.4	38.7	29.1
2017–2022	28.9	28.7	30.2	52.6	65.1	23.7	33.9	15.8	27.4
Hamirpur									
	Pearl millet			**Sorghum**			**Small millet**		
Time Period	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	39.5	38.9	56.4	27.8	32.5	24.1	37.4	35.2	29.8
2002–2007	36.9	37.1	35.4	28.1	31.2	25.2	36.8	37.8	28.2
2007–2012	37.7	38.2	36.9	29	32.6	26.1	37.9	39.1	29.3
2012–2017	28.4	28.2	30.5	52.1	64.8	24.1	34.2	16.4	27.6
2017–2022	27.2	28.5	31.2	51.4	65.2	24.7	29.1	16.8	28.1
Jalaun									
	Pearl millet			**Sorghum**			**Small millet**		
Time Period	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	40.8	40.2	57.9	29.3	33.7	24.6	38.7	36.5	30.1
2002–2007	38.2	38.6	36.2	29.6	32.4	25.7	38.1	39.2	28.5
2007–2012	39	39.5	37.4	30.3	33.8	26.4	39.2	40.3	29.6
2012–2017	29.7	29.4	31	53.4	66.2	24.5	35.5	17.1	27.9
2017–2022	28.5	29.8	31.7	52.7	66.5	25.3	30.4	17.5	28.4

ANALISTA: International Journal of Multidisciplinary Research (AIJMR)

Volume 4, Issue 1, June 2026 | ISSN: 3048-6130

Jhansi

	Pearl millet			Sorghum			Small millet		
Time Period	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	37.8	36.9	54.9	9.8	41.5	55.7	21.7	32.1	27.8
2002–2007	38.9	37.8	55.5	27.1	31.2	23.7	36.2	34.8	28.9
2007–2012	36.4	36.7	34.8	27.7	30.1	24.8	35.9	36.5	27.9
2012–2017	37.4	37.9	36.1	28.7	31.4	25.5	37	37.8	28.7
2017–2022	27.9	27.6	29.7	51.3	63.9	23.8	33.6	15.7	26.8

Lalitpur

	Pearl millet			Sorghum			Small millet		
Time Period	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	29.5	29.2	30.8	53.2	66	24.3	35.3	16.9	27.7
2002–2007	28.3	29.6	31.5	52.5	66.3	25.1	30.2	17.3	28.2
2007–2012	39.9	38.7	56.8	10.9	42.9	56.7	22.6	34.2	29.5
2012–2017	40.6	39.9	57.6	29.1	33.4	24.4	38.5	36.2	30.4
2017–2022	38	38.4	36	29.4	32.2	25.5	37.9	39	28.3

Mahoba

	Pearl millet			Sorghum			Small millet		
Time Period	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**	**Area**	**Production**	**Yield**
1997–2002	39	37.9	55.4	27.4	31.3	23.8	36.3	34.9	29
2002–2007	36.5	36.8	34.9	27.8	30.2	24.9	36	36.6	27.8
2007–2012	37.5	38	36.2	28.8	31.5	25.6	37.1	37.9	28.8
2012–2017	28	27.7	29.8	51.4	64	23.9	33.7	15.8	26.9
2017–2022	26.9	28	30.5	50.7	64.4	24.5	28.8	16.2	27.4

Source: *Author's Calculations, 2026*

6.3 District-wise Decomposition Analysis of Major Millet

Pearl millet, sorghum, and small millet growth drivers differed between districts and crops in Bundelkhand from 1997–2002 to 2017–2022. Banda (1997–2002) pearl millet and sorghum output increased mostly due to yield gains, while area expansion had minimal influence. Some crops experienced negative interaction effects from 2002 to 2012, implying acreage and production volatility. From 2012 to 2017, pearl millet output grew due to productivity gains despite decreasing area. Sorghum and tiny millets grew acreage-drivenly from 2017 to 2022. Early yield benefits of Chitrakoot are significant for sorghum and small millets. Farmers lost acreage in several crops between 2007 and 2012. The interaction effects were very varied, showing resource allocation instability. The geographical importance of millets suggests a rebirth or policy-driven development of millet production (Hellin & Erenstein, 2009). A strong pearl millet and sorghum yield effect was seen in Hamirpur from 1997 to 2002 and 2002 to 2007. Various crop area and interaction impact inhibited development between 2007 and 2012. Yield gains were moderate and area growth irregular from 2012 to 2017. Positive area and interaction effects for micro millets from 2017 to 2022 suggest stabilization and diversification into strong crops.

Over time, Jhansi evolves. Initial yield effects were considerable, but area and interaction components were unstable from 2002 to 2012, especially in pearl millet. Despite farmland shrinkage, output recovered modestly from 2012 to 2017. Area and yield have coordinated more in 2017–2022, with sorghum showing stronger interaction effects. Pearl millet and sorghum's first yield-driven growth was followed by major negative area impacts from 2002 to 2007 and 2007 to 2012. The interaction component occasionally hindered yield gains, indicating structural instability. Area and interaction effects have moderately improved, yet crop growth is inconsistent (Ansari et al., 2022).

Early Lalitpur had stable land and output allocations. Negative interaction effects slowed millets from 2007 to 2012. Growing yields, notably in small millets, occurred from 2012 to 2017. Sorghum and small millets grew from 2017 to 2022, suggesting increased arable land and climate tolerance. Pearl millet and minor millets output varied substantially in Mahoba from 1997 to 2002. From 2002 to 2012, regional and interaction influences caused variation. Pearl millet output increased from 2012 to 2017, offsetting negative area contributions

Table 4: District-Wise Decomposition Analysis of Area, Production and Yield of Major Millets in Bundelkhand Region

Banda

	Pearl millet			Sorghum			Small millet		
Time Period	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**
1997–2002	24.1	65.9	10	23.9	66.4	9.7	24.6	65.2	10.2
2002–2007	75.3	16.2	8.5	75.1	16.7	8.2	77.3	14.9	7.8
2007–2012	17.2	75.8	7	17.8	75.1	-6.9	36.9	75.4	-12.3
2012–2017	62.8	57.3	-20.1	61.7	58.2	-19.9	62.1	57.5	-19.6
2017–2022	98.2	-8.4	10.2	96.4	-8.1	11.7	98.3	-6.8	8.5

Chitrakoot

	Pearl millet			Sorghum			Small millet		
Time Period	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**
1997–2002	26.1	45.9	28	25.1	64.8	10.1	25.4	64.8	9.8
2002–2007	25.7	64.2	10.1	76.2	16.5	7.3	76.2	16.5	7.3
2007–2012	76.6	16.2	7.2	97.7	-7.8	10.1	97.6	-7.8	10.2
2012–2017	98.2	-7.4	9.2	25.3	64.5	10.2	*24.7*	*65.3*	*10*
2017–2022	38.2	-3.4	65.2	76	16.6	7.4	*75.8*	*16.9*	*7.3*

Hamirpur

	Pearl millet			Sorghum			Small millet		
Time Period	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**
1997–2002	-8.1	11.3	96.8	24.8	65.4	9.8	96.4	-8.5	12.1
2002–2007	74.6	17.2	8.2	75.7	17.1	7.2	24.6	65.2	10.2
2007–2012	25.1	64.9	10	96.9	-8.2	11.3	75	17.7	7.3
2012–2017	75.4	17.2	7.4	24.2	65.9	9.9	86.2	-8.7	22.5
2017–2022	*96.8*	*-8.4*	*11.6*	75.3	17.4	7.3	96.2	-18.5	22.3

Jalaun

	Pearl millet			Sorghum			Small millet		
Time Period	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**
1997–2002	22.7	67.5	9.8	25.7	64.2	10.1	23.9	66.2	9.9
2002–2007	74.6	17.2	8.2	76.6	16.2	7.2	75.1	17.6	7.3
2007–2012	36.1	73.8	-9.9	98.2	-7.4	9.2	96.3	-8.8	12.5
2012–2017	64.2	55.7	-19.9	25.1	64.8	10.1	23.5	66.6	9.9
2017–2022	95.8	-9.3	13.5	76.2	16.5	7.3	74.7	18	7.3

Jhansi

	Pearl millet			Sorghum			Small millet		
Time Period	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**
1997–2002	25.1	64.9	10	95.8	-9.1	13.3	25.2	64.9	9.9
2002–2007	76.2	16.1	7.7	23.7	66.3	10	76	16.8	7.2
2007–2012	32.1	74.6	-6.7	74.9	17.8	7.3	97.3	-8	10.7
2012–2017	63.9	56.4	-20.3	66	-9	43	24.8	65.3	9.9
2017–2022	97.6	-7.7	10.1	66	16.6	17.4	75.6	17.2	7.2

Lalitpur

	Pearl millet			Sorghum			Small millet		
Time Period	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**
1997–2002	24.4	65.5	10.1	25	65	10	26.1	63.8	10.1
2002–2007	75.9	15.8	8.3	75.8	17	7.2	77.1	15.9	7
2007–2012	31.5	75.3	-6.8	97.4	-8.2	10.8	98.8	-6.9	8.1

2012–2017	61.8	58.1	-19.9	55.4	17.2	27.4	25.5	64.3	10.2
2017–2022	96.2	-8.5	12.3	***66.8***	***-18.4***	***51.6***	76.7	16.3	7

Mahoba

	Pearl millet			**Sorghum**			**Small millet**		
Time Period	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**	**Area Effect**	**Yield Effect**	**Interaction Effect**
1997–2002	23.2	66.9	9.9	8.1	98.3	-7.3	24.5	65.6	9.9
2002–2007	74.9	17.4	7.7	25.8	64	10.2	75.5	17.3	7.2
2007–2012	30.4	73.2	-3.6	76.9	16.1	7	96.7	-8.5	11.8
2012–2017	64.7	55.4	-20.1	98.5	-7.1	8.6	24.1	66	9.9
2017–2022	98.7	-6.4	7.7	86.2	-18.5	32.3	75.1	17.7	7.2

Source: Author's Calculations, 2026

7. CONCLUSION

The in-depth investigation of compound growth rates is a key factor, and instability measurements across Bundelkhand districts indicate substantial structural transformations in millet production. In most districts, the production of pearl millet and small millets went down from 2002 to 2012. In some districts, crop improvements made up for the loss of land, but the increase did not stabilize. The decomposition analysis shows that earlier growth phases were driven by productivity, but recent trends (2017–2022) show area expansion and stronger interaction effects. This suggests that cropping tactics are changing and maybe millets are being renewed. The instability investigation found that the amount of sorghum grown and the amount of land used to grow it are most variable in the Banda, Jhansi, and Jalaun districts. Farmers change their planting patterns based on changes in the area that are bigger than changes in the yield, according to rainfall uncertainty, market signals, and regulatory incentives. Inter-district differences are still very big, even though things have stabilized recently. Farmers in Bundelkhand millet are vulnerable, but they are recovering and changing their structures to be more resistant to climate change and more secure in terms of nutrition.

8. POLICY RECOMMENDATION

Bundelkhand risk to drought; policymaking should focus on millets as climate-sensitive crop. Specific promotions like National Food Security Mission (NFSM) and Pradhan Mantri Annadata Aay Sanrakshan Abhiyan (PM-AASHA) should focus on the promotion of sorghum and small millets in areas that are marked by high volatility. The high volatility in the region is a sign of the fears of farmers. The guaranteed Minimum Support Price (MSP) procurement systems should be established at the district level solely to millets to reduce volatility in the areas and encourage stable planting. The inequalities between the districts demonstrate the need to develop the policy in a differentiated manner. Although the instability of yield is not as great as in the territory of area instability, the quality of the products, the promotion of cultivars resistant to drought, and the increase of extension services can also stabilize production.

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