



RESEARCH ARTICLE

A study on growth and instability in the area, production and productivity of bajra, jowar, ragi and small millets in India

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Abstract

The large-scale shift toward high-yielding wheat and rice varieties that accompanied India's Green Revolution era effectively marginalised millet crops, both in terms of farmland allocation and their role in everyday food consumption. The present research analysed long-term trends and variability in the area under cultivation, aggregate output and per-hectare yield of four commercially and nutritionally important millets, such as bajra, jowar, ragi and small millets, across India. Annual data covering seven decades (1950–51 to 2021–22) were retrieved from established government statistical repositories. Three quantitative tools were utilised: the compound annual growth rate (CAGR) to capture directional trends, the coefficient of variation (CV) to quantify dispersion and the Cuddy-Della Valle instability index (CDVI) to measure detrended variability. Area under cultivation contracted significantly for every crop studied, with CAGR values spanning -0.62 % to -3.64 %. Among the four crops, bajra alone achieved a statistically significant rise in total production (CAGR: +1.67 %, $p < 0.001$). Yield per hectare, by contrast, improved notably for all four crops, posting CAGR values between 0.79 % and 2.13 %. Stability assessment, adjusted for long-term trends, confirmed low levels of instability ($CDVI < 15$) across the area and the production and productivity dimensions for every crop examined. The main objective for this study is to understand and analyse the growth and instability in certain aspects, such as area, production, productivity of bajra, jowar, ragi and small millets.

Keywords: compound annual growth rate; instability index; millets; productivity; time series analysis

Introduction

India's farm sector continues to play a vital role in the national economy, accounting for around 17–18 % of gross domestic product (GDP) and supporting the livelihoods of a substantial share of the rural population (1). The sector also provides essential raw materials to a range of agro-based industries such as textiles, sugar and food processing, highlighting its strong interlinkages with industrial development (2). Moreover, agriculture remains a key contributor to rural employment and serves as an important engine of overall economic growth, particularly in developing economies (3). Millets are nutrient-rich and climate-resilient crops that can address food security and nutritional challenges in marginal environments (4). Millets have gained renewed policy and research attention due to their role in sustainable agriculture and nutrition security (4). India generates approximately 40 % of the total world millet output. Asia and Africa together account for about 97 % of worldwide millet production (5). Millets declined in prominence with the expansion of major cereals like rice and wheat despite their adaptability to marginal conditions (4). Between 1962 and 2010, per capita millet consumption among Indian households fell from 32.9 to 4.2 kg, while per capita wheat intake nearly doubled from 27 to 52 kg over the same period (6).

Millets perform an indispensable role as dietary staples across dryland and semi-arid farming systems, owing to their tolerance of pest and disease pressure and adaptability to varied agro-ecological environments (7). Their superior nutritional profile and compatibility with low-input, climate-resilient production systems have attracted growing scientific and policy interest. Millets sustain productive growth under harsh conditions, including prolonged moisture deficit (8). Despite these advantages, average millet yields (approximately 1111 kg/ha) remain well below irrigated paddy (2600 kg/ha) and wheat (3500 kg/ha), underscoring the need for investment in higher-yielding millet varieties (5). Agricultural growth is governed by factors including weather variability, water availability, access to inputs, policy environments and market dynamics (9). Millets require fewer inputs and perform well under low fertility, drought-prone conditions compared to major cereals (4). Their inherent toughness equips them to endure high temperatures, degraded soils and limited water and agrochemical inputs and the environmental footprint of millet farming is markedly smaller due to substantially lower fertiliser and pesticide requirements (6, 10).

Throughout Indian history, millets, particularly bajra, jowar, ragi and small millets, occupied a pivotal place in the food cultures

of numerous regional communities, underpinning a rich tradition of locally distinctive foods and fermented or non-fermented beverages. Over recent decades, however, their contribution to the national food basket has contracted significantly. This decline is attributed primarily to agricultural policies that systematically favoured the procurement, distribution and consumption of refined cereals such as rice and wheat, reinforced by rising disposable incomes and accelerating urbanisation (8). Notably, millets offer not only competitive protein content but also noteworthy concentrations of essential minerals, including iron, zinc and calcium, nutritional attributes that confer health benefits across all age groups and sexes, with specific advantages depending on variety and species. Nutritionists and food security experts accordingly advocate for deliberate dietary interventions aimed at replacing a meaningful share of rice, wheat and maize in Indian diets with these micronutrient-rich grain alternatives (6).

Understanding how the millet cultivation area, production and productivity have evolved and how stable these trends have been is essential to advancing agricultural sustainability and national food security. Area trends reveal farmer adoption and policy effectiveness; production volumes illuminate farming system efficiency and reveal how millet yields respond to key climate variables, including temperature fluctuations, rainfall variability and drought stress and productivity analysis, though not a standalone measure of ecological sustainability, as broader environmental indicators are also required to identify priority areas for improvements in soil management, crop agronomy and water use efficiency. The present investigation was therefore undertaken to quantify growth trajectories and instability patterns in the area, production and productivity of bajra, jowar, ragi and small millets in India over the period 1950–51 to 2021–22.

Materials and Methods

Data source and nature

This study relies entirely on secondary data collected from reliable government and institutional sources. Annual time-series data covering the period from 1950–51 to 2021–22 were obtained on area cultivated (hectare), total production and yield levels of bajra, jowar, ragi and small millets. The data were sourced from the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India, as well as the Indiastat database. For analysis and interpretation, the compiled dataset was processed using SPSS Statistics.

Statistical framework

Three analytical methods were employed to fulfil the study objectives: Compound annual growth rate (CAGR) analysis for trend quantification, Coefficient of variation (CV) to assess overall variability and the Cuddy-Della Valle instability index (CDVI) for variability measurement.

Compound annual growth rate (CAGR)

CAGR was estimated by fitting an exponential (log-linear) trend model to the time-series data (11):

$$\ln(Y_t) = a + b \cdot t + \epsilon_t \quad (\text{Eqn.1})$$

where Y_t is the value (area/production/yield) in year t , a is the intercept, b is the regression coefficient and ϵ_t is the error term. CAGR (%) was derived as: $\text{CAGR} = (e^b - 1) \times 100$. Statistical significance of b was tested using the t -statistic.

Coefficient of variation

The CV was computed to measure relative variability in the time series.

$$\text{CV} = \frac{\text{Standard deviation}}{\text{Mean}} \times 100 \quad (\text{Eqn. 2})$$

Cuddy-Della Valle instability index

To measure true instability after accounting for the trend component, the Cuddy-Della Valle instability index was computed as (12):

$$\text{CDVI} = \text{CV} \times \sqrt{(1 - R^2)} \quad (\text{Eqn. 3})$$

Where R^2 is the coefficient of determination from the exponential trend regression. A CDVI < 15 indicates low instability, 15–30 moderate instability and > 30 high instability.

Results and Discussion

Long-run growth performance in cultivated area, aggregate production and per-hectare productivity of bajra, jowar, ragi and small millets was quantified using CAGR analysis. Variability around these trends was characterised using two complementary indices, the CV and the CDVI, to capture both absolute and detrended fluctuation.

Bajra: Area, production and productivity trends and variability

Data summarised in Table 1 and illustrated in Fig 1–3 revealed that the Bajra area contracted at a statistically significant pace (CAGR: -0.62 %, $p < 0.001$), yet production expanded at a meaningful annual compound rate of 1.67 % ($p < 0.001$), driven entirely by productivity growth (CAGR: 2.13 %, $p < 0.001$). All instability indicators remained low (CDVI < 3). The production increase is principally attributable to widespread adoption of hybrid and high-yielding varieties (HYVs), supported by ICRISAT-led breeding programs in key producing states such as Rajasthan, Gujarat and Uttar Pradesh (13). Supplemental irrigation and improved agronomic management further amplified yield gains. Bajra's inherent drought and heat tolerance enabled cultivation to persist in semi-arid zones even as competing crops receded. Comparable productivity-driven production growth has been documented for pearl millet in sub-Saharan Africa, confirming that targeted HYV adoption can overcome area constraints (5). These findings are

Table 1. Growth and instability in area, production and productivity of bajra in India

Particulars		Area (log)	Production (log)	Productivity (log)
	T value	10.275	13.337	21.849
Growth	CAGR (%)	-0.62**	1.67**	2.13**
	p value	0.001	0.001	0.001
Instability	CV	1.044	1.822	8.052
	CDVI	0.659	0.968	2.879

*Significant at 10 % level ($p < 0.10$), ** Significant at 5 % level ($p < 0.05$), *** Significant at 1 % level ($p < 0.001$). Growth rates (CAGR) and associated statistics are estimated using log-transformed series.

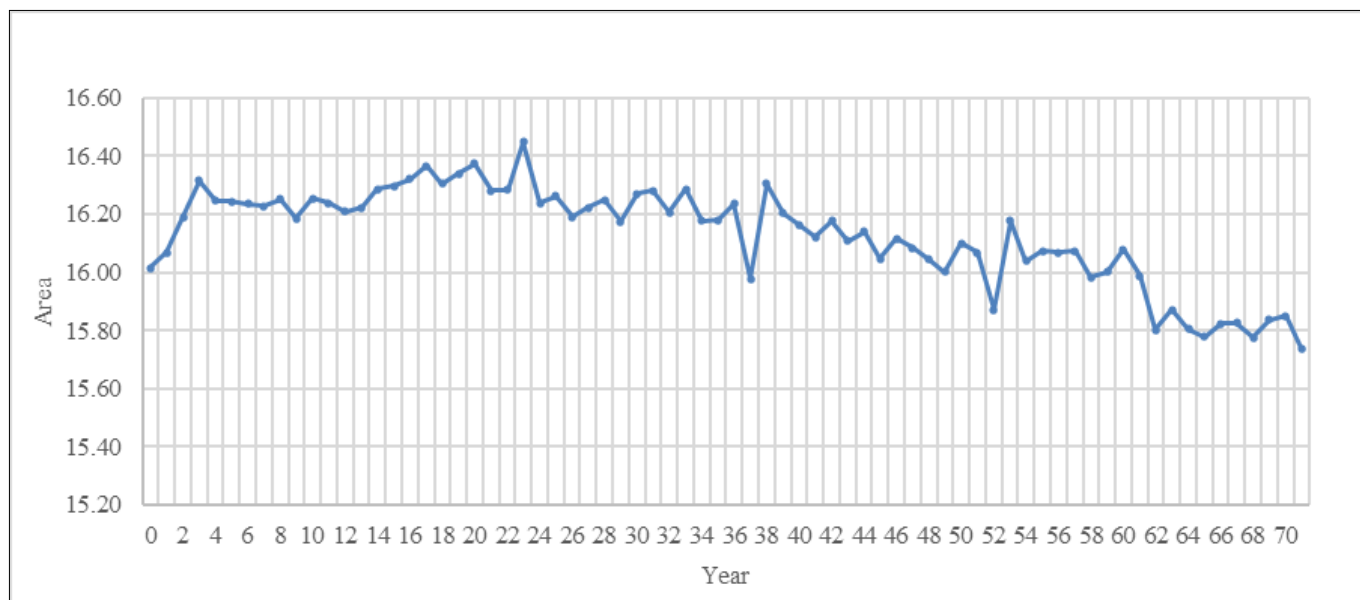


Fig. 1. Area under bajra (log).

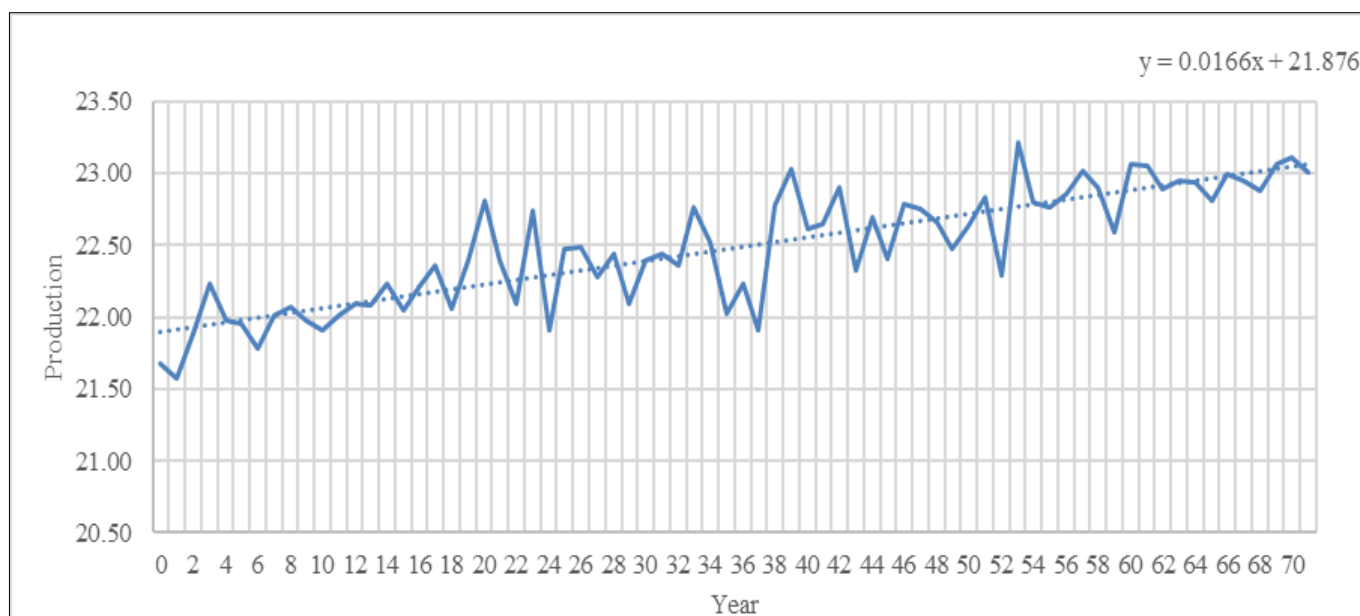


Fig. 2. Bajra production (log).

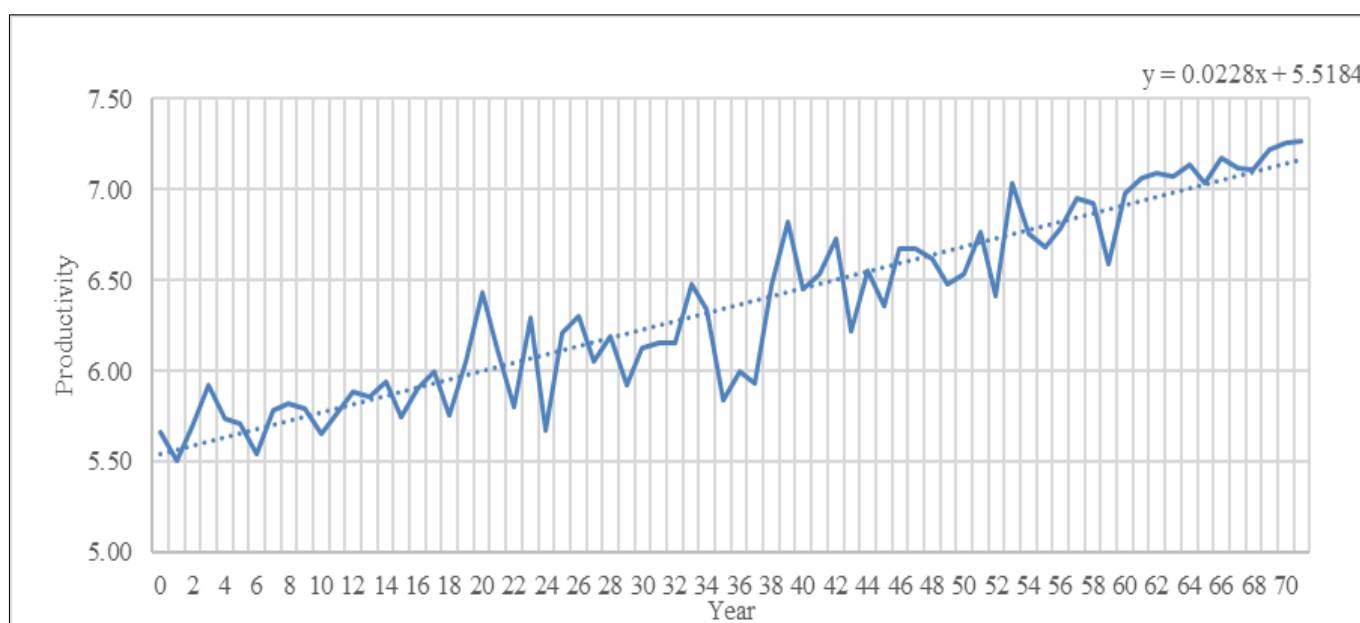


Fig. 3. Bajra productivity (log).

consistent with earlier trend studies on Bajra in India (14).

Jowar: Area, production and productivity trends and variability

Data presented in Table 2 and Fig. 4–6 demonstrated a trajectory of persistent decline in both area (CAGR: -1.91 %, $p < 0.001$) and production (CAGR: -0.68 %, $p < 0.001$), while productivity improved significantly (CAGR: +1.26 %, $p < 0.001$). All variability indicators confirmed a stable pattern throughout (CDVI < 2). This intensification under contraction reflects a convergence of structural forces: displacement by Green Revolution-favoured rice and wheat, inadequate minimum support price (MSP) relative to competing cereals and falling domestic demand as urban consumers shifted dietary preferences (15). This trajectory parallels sorghum area contraction documented in East Africa and China, where commodity policy shifts similarly reduced traditional cereal coverage (5). The persistence of productivity growth signals latent technological potential; however, without market integration and procurement reform, Jowar's agricultural recovery remains constrained. These findings are consistent with results reported in previous analyses of Jowar cultivation trends (16).

Table 2. Growth and instability in area, production and productivity of jowar in India

Particulars	Area (log)	Production (log)	Productivity (log)
T value	17.548	4.536	17.936
Growth			
CAGR (%)	-1.91**	-0.68**	1.26**
p value	0.001	0.001	0.001
Instability			
CV	2.743	1.307	4.434
CDVI	1.180	1.149	1.874

*Significant at 10 % level ($p < 0.10$), ** Significant at 5 % level ($p < 0.05$), *** Significant at 1 % level ($p < 0.001$). Growth rates (CAGR) and associated statistics are estimated using log-transformed series.

Ragi: Area, production and productivity trends and variability

Statistical analysis of ragi cultivation patterns in Table 3 and illustrated in Fig. 7–9 revealed a significant long-run decline in cultivated area (CAGR: -1.27 %, $p < 0.01$), while total production remained statistically stagnant (CAGR: +0.09 %, $p = 0.451$). Productivity demonstrated a statistically significant upward shift (CAGR: +1.38 %, $p < 0.001$), with all instability indicators remaining

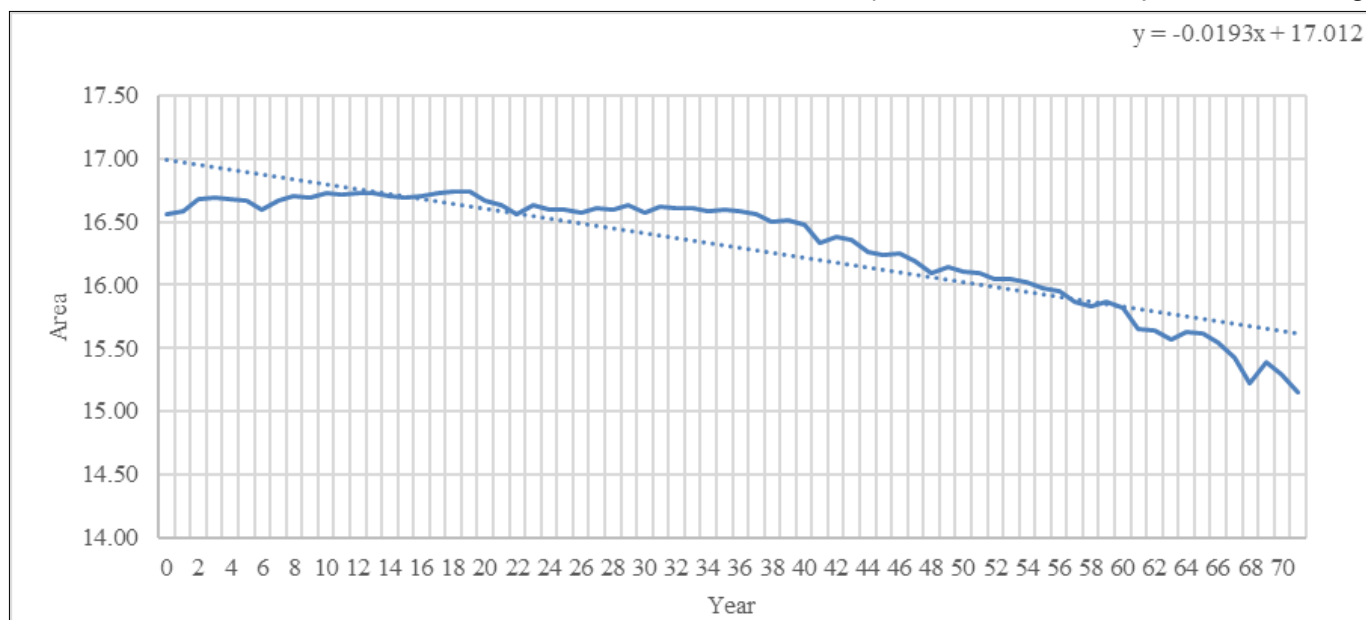


Fig. 4. Area under jowar (log).

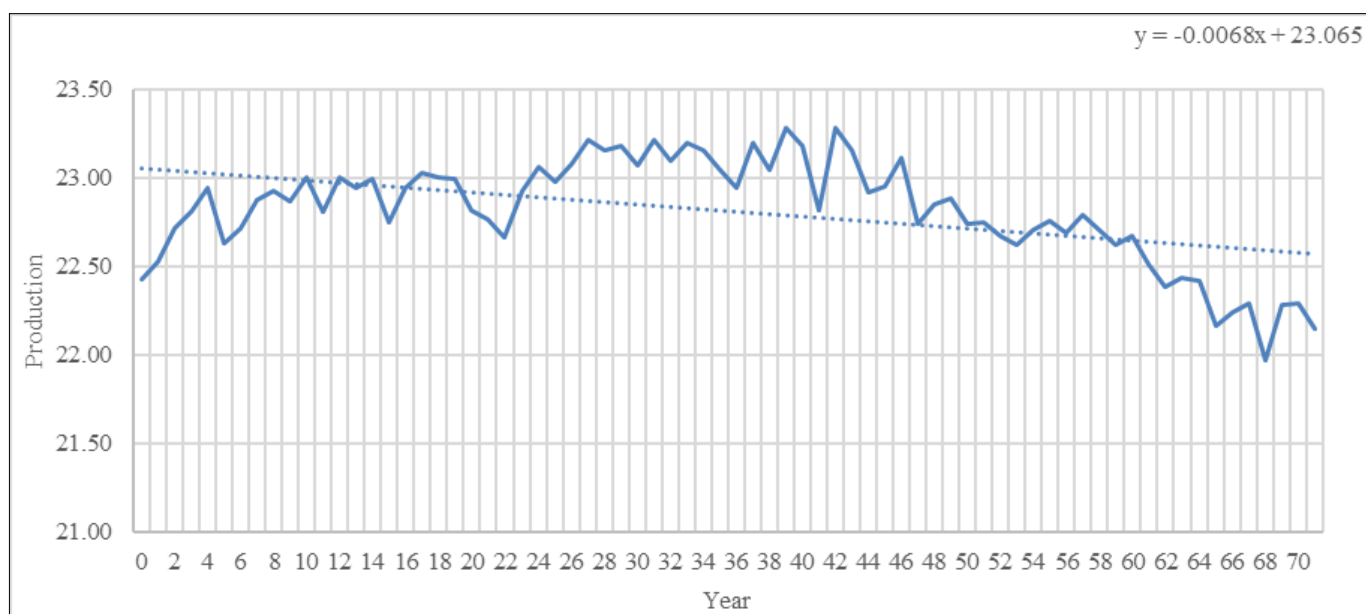


Fig. 5. Jowar production (log).

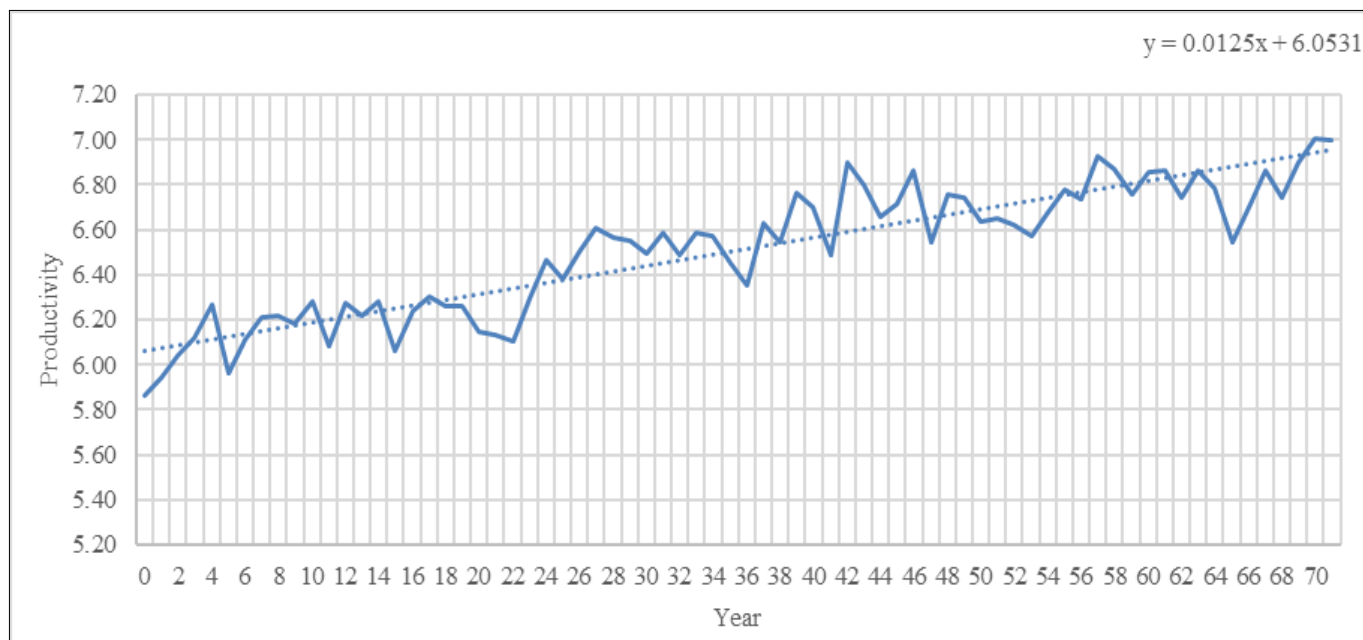


Fig. 6. Jowar productivity (log).

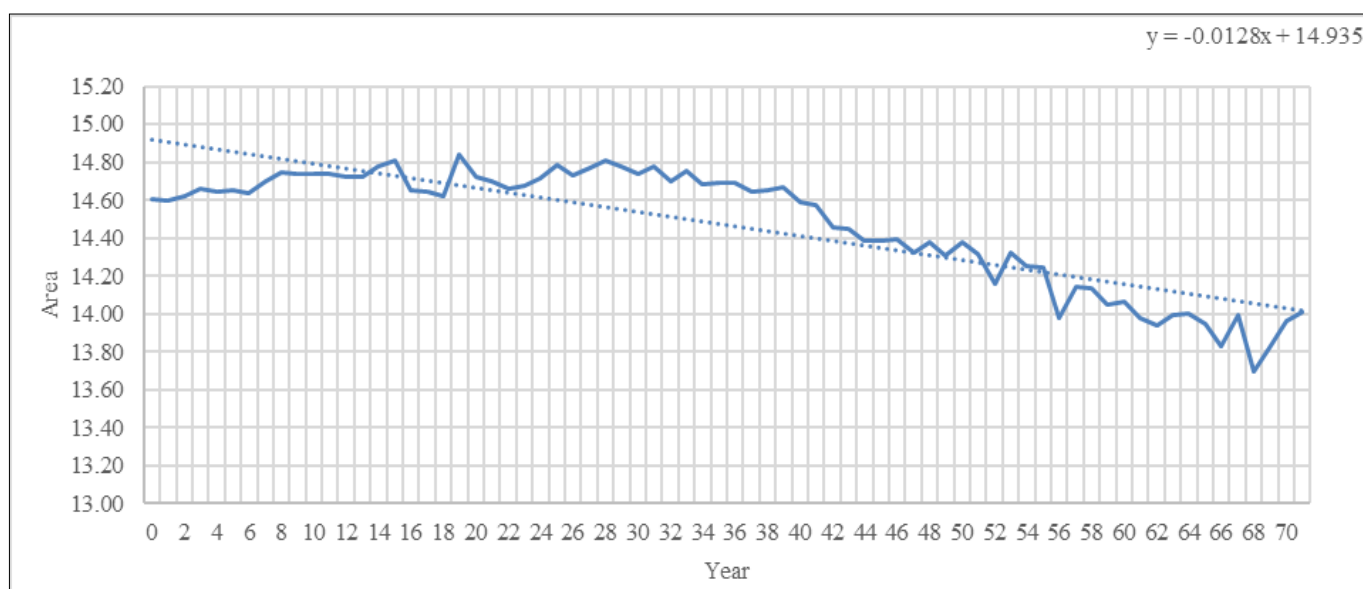


Fig. 7. Area under ragi (log).

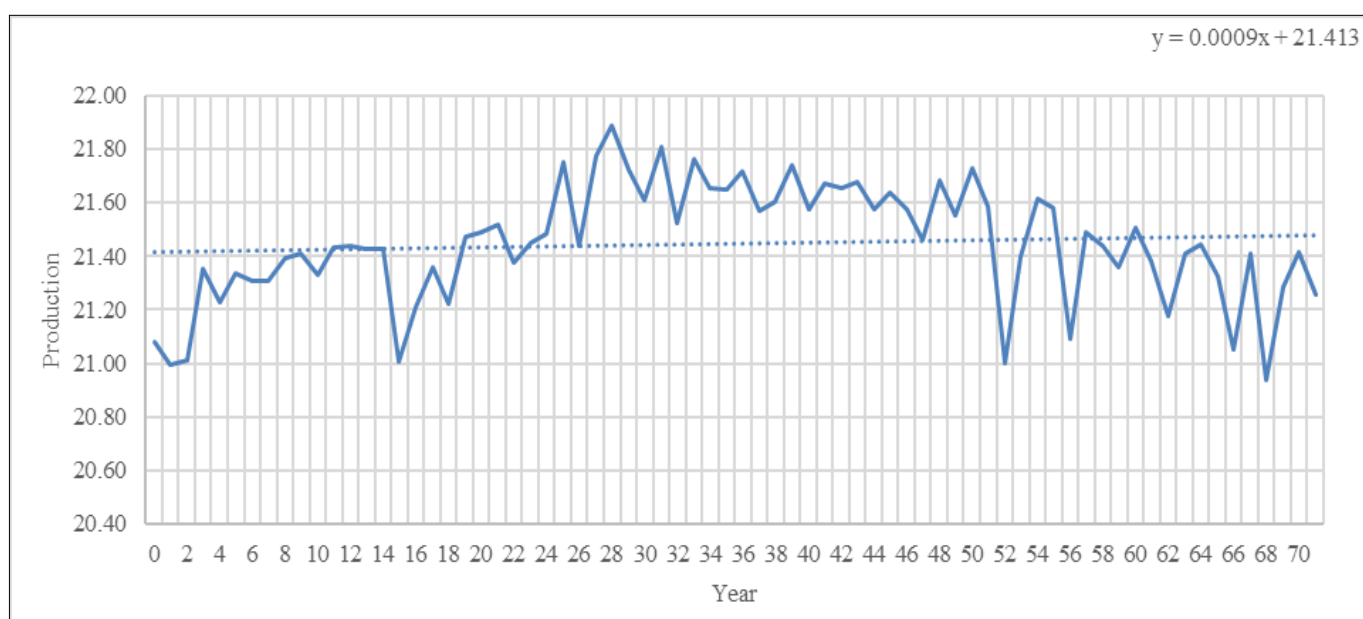


Fig. 8. Ragi production (log).

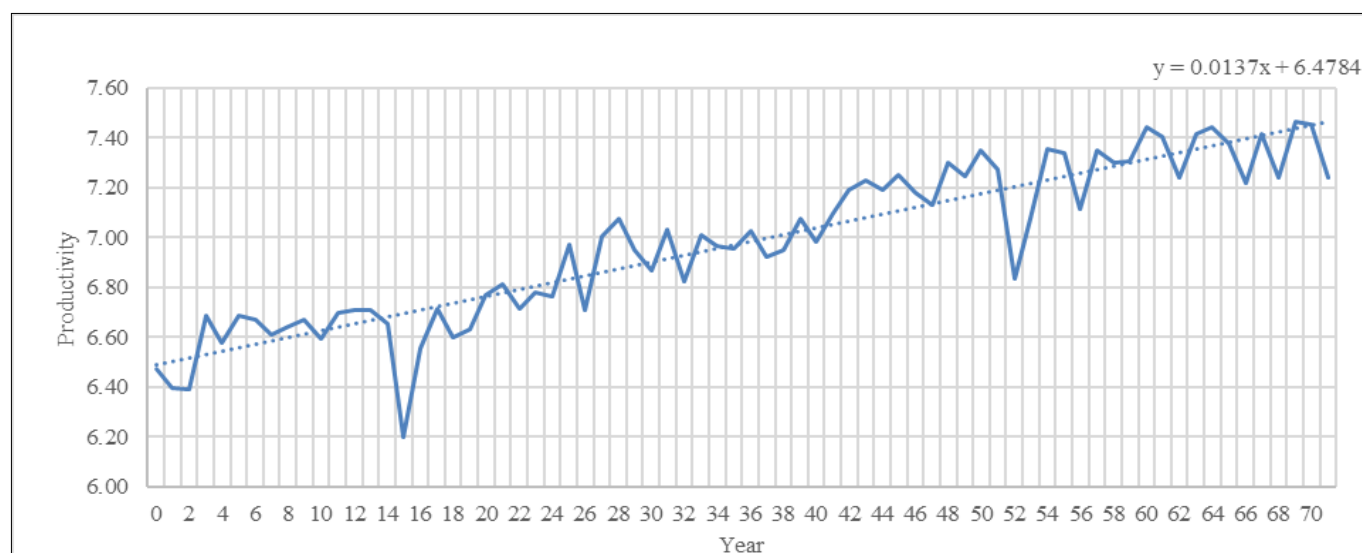


Fig. 9. Ragi productivity (log).

Table 3. Growth and instability in area, production and productivity of ragi in India

Particulars		Area (log)	Production (log)	Productivity (log)
Growth	T value	14.099	0.757	19.611
	CAGR (%)	-1.27**	0.09	1.38**
	p value	0.001	0.451	0.001
Instability	CV	2.149	1.013	4.471
	CDVI	1.096	1.009	1.754

*Significant at 10 % level ($p < 0.10$), ** Significant at 5 % level ($p < 0.05$), *** Significant at 1 % level ($p < 0.001$). Growth rates (CAGR) and associated statistics are estimated using log-transformed series.

low (CDVI < 2). This paradox of yield improvement without aggregate production gain reflects near-perfect offsetting of area loss by productivity increase, a pattern of intensification under geographic contraction. Since ragi cultivation is concentrated in Karnataka and Andhra Pradesh/Telangana, land surrendered to higher-value crops directly neutralises efficiency gains at the national level. Given ragi's exceptional nutritional profile, particularly its high calcium and iron content, continued area erosion poses a serious risk to dietary security among dryland farming communities (17). Targeted area-protection policies and

stronger MSP support are essential to convert yield improvements into actual production gains.

Small millets: Area, production and productivity trends and variability

Among all four millet categories examined, small millets experienced the most pronounced structural decline, as presented in Table 4 and Fig. 10–12. Area contracted sharply at a highly significant rate (CAGR: -3.64 %, $p < 0.001$) and production fell correspondingly (CAGR: -2.88 %, $p < 0.01$), even as productivity improved modestly (CAGR: +0.79 %, $p < 0.001$). Low instability values (CDVI < 3) confirm that this decline is structural rather than climate-driven. These crops, including kodo, little, barnyard and foxtail millets, are cultivated predominantly by tribal and smallholder communities with limited market linkages, extension access and procurement infrastructure (18). Their abandonment reflects dietary transitions and market exclusion, mirroring patterns documented globally for traditional minor cereals displaced by commodity crop expansion (5). Given climate projections indicating increasing aridity across Indian drylands, the continued erosion of these inherently climate-resilient crops represents a critical and underappreciated food security risk (19).

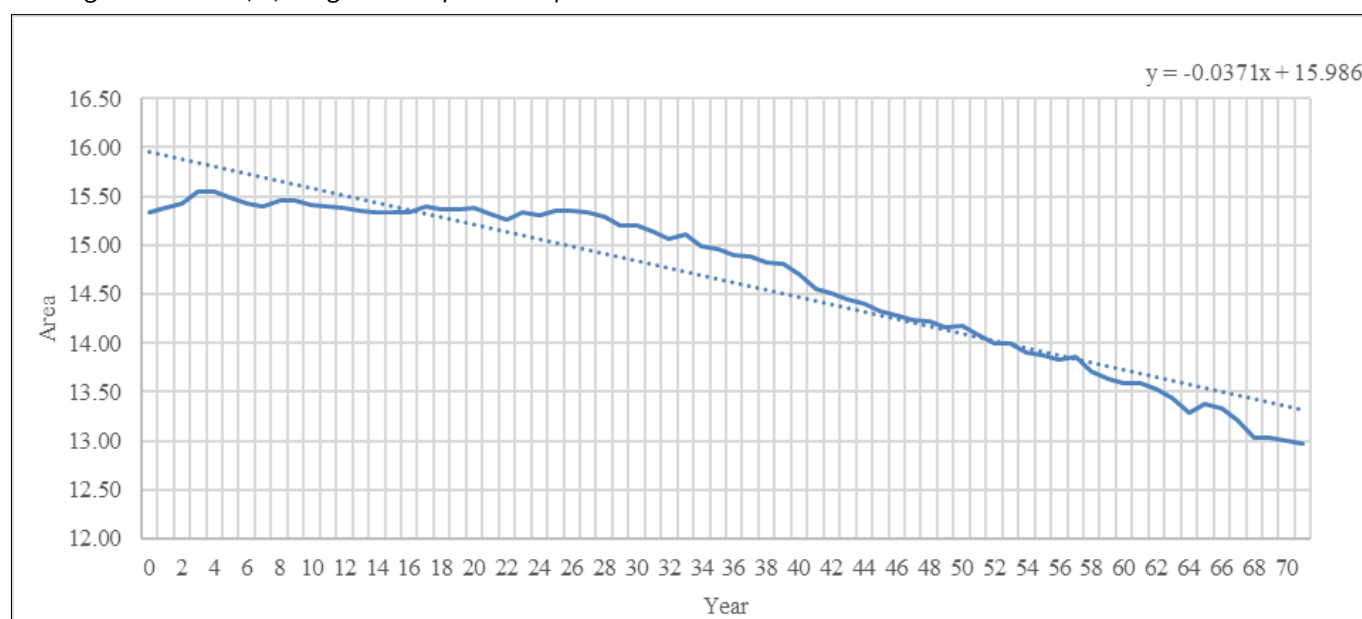


Fig. 10. Small millet area (log).

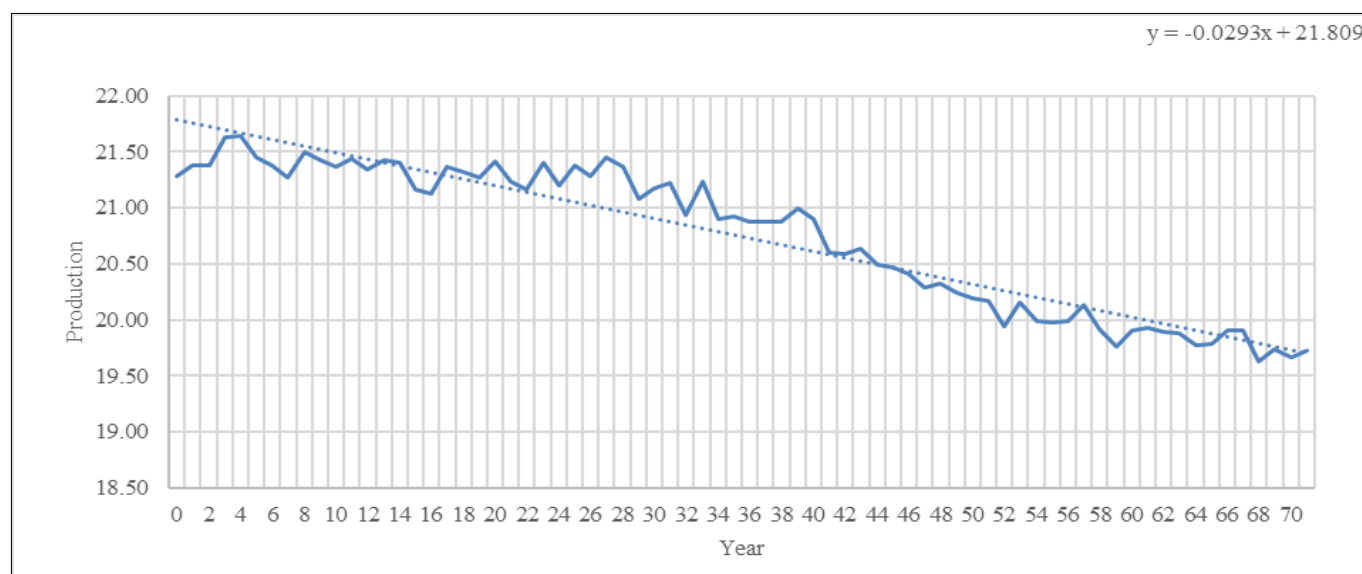


Fig. 11. Small millet production (log).

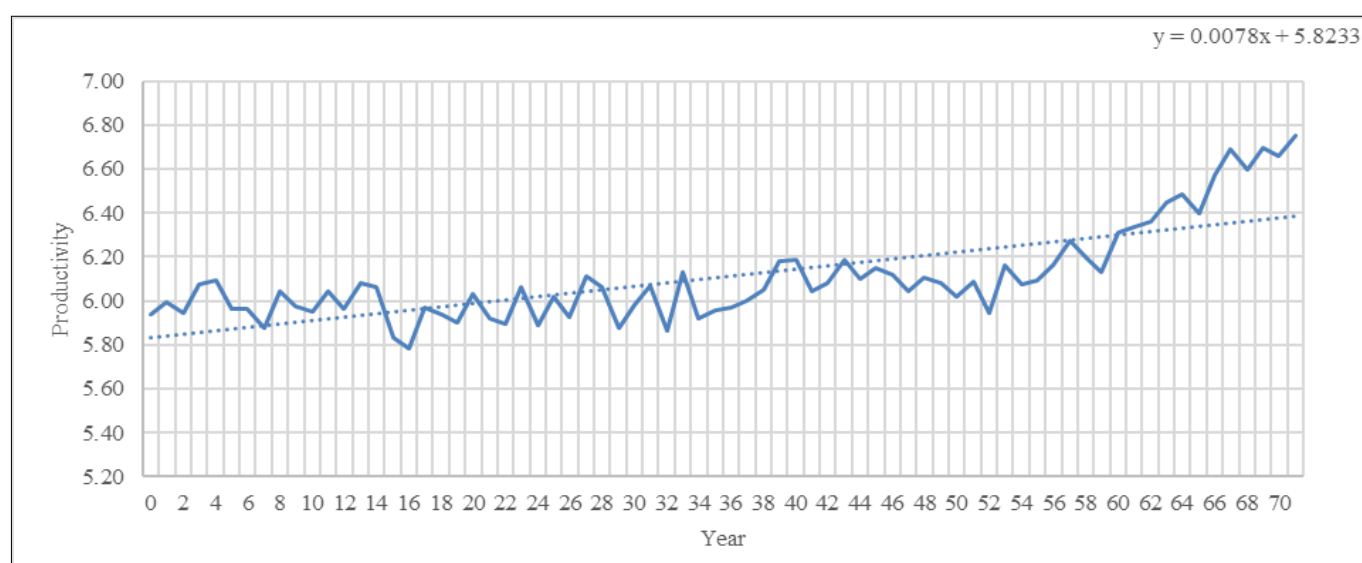


Fig. 12. Small millet productivity (log).

Table 4. Growth and instability in area, production and productivity of small millet in India

Particulars		Area (log)	Production (log)	Productivity (log)
Growth	T value	26.524	26.03	9.548
	CAGR (%)	-3.64**	-2.88**	0.79**
	p value	0.001	0.001	0.001
Instability	CV	5.564	3.100	3.572
	CDVI	1.673	0.948	2.354

*Significant at 10 % level ($p < 0.10$), ** Significant at 5 % level ($p < 0.05$), *** Significant at 1 % level ($p < 0.001$). Growth rates (CAGR) and associated statistics are estimated using log-transformed series.

Conclusion

This study systematically examined seven decades of trend and variability data for bajra, jowar, ragi and small Millets. Cultivated area declined for all these crops, while productivity improved across all, confirming that incremental technological progress has reached even policy-neglected crops. Bajra alone achieved gains in both production and yield efficiency, driven by hybrid seed adoption and sustained breeding investment. Jowar and Ragi exhibit intensification under contraction, while small millets face the most severe structural erosion, concentrated among

smallholder and tribal communities with limited market access (18). The uniformly low instability values confirm these trends are structural rather than weather-driven, demanding equally structural responses: strengthening minimum support price (MSP) and procurement mechanisms for non-bajra millets, accelerating breeding investment and integrating millets into public food distribution. Given increasing projected aridity across Indian drylands, the resilience of millets makes their revival both agronomically and nutritionally imperative (19). Future research should examine sub-regional disaggregation of millet trends, assess the impact of price policy on acreage decisions and explore the potential of underutilised small millet species as climate-adaptive crops in an era of intensifying environmental stress.

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Authors' contributions

BS, SNM, BM, CN, KKS and AD contributed to conceptualisation, methodology design, data validation, statistical analysis, interpretation of results, visualisation and manuscript refinement. BS additionally undertook the research methodology and drafted the manuscript. KKS and AD ensured coherence in the discussion and critically revised the manuscript. SNM also provided guidance and collaboration. BKM, BPN and PPT contributed to study design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

The authors would like to declare that OpenAI's ChatGPT and Claude AI were used during the preparation of this manuscript solely for language refinement and improving clarity. The intellectual content, ideas and conclusions presented are entirely the original work of the authors. The manuscript was carefully reviewed and edited after using the AI tool and the authors take full responsibility for the content of the publication.

References

1. Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare. Agricultural statistics at a glance 2021. New Delhi: Government of India; 2022. <https://eands.dacnet.nic.in/>
2. Chand R, Srivastava SK, Singh J. Changing structure of rural economy of India: implications for employment and growth. New Delhi: NITI Aayog; 2017. <https://niti.gov.in>
3. Gollin D. Agricultural productivity and economic growth. In: Pingali P, Evenson R, editors. Handbook of agricultural economics. Vol. 4. Amsterdam: Elsevier; 2010. p. 3825–3866. [https://doi.org/10.1016/S1574-0072\(09\)04073-0](https://doi.org/10.1016/S1574-0072(09)04073-0)
4. Kumar A, Tomer V, Kaur A, Kumar V, Gupta K. Millets: a solution to agrarian and nutritional challenges. Agric Food Secur. 2018;7:31. <https://doi.org/10.1186/s40066-018-0183-3>
5. Food and Agriculture Organisation of the United Nations. FAOSTAT: food and agriculture organisation statistical database. Rome: FAO; 2023. <https://www.fao.org/faostat/en/>
6. Kane-Potaka J, Anitha S, Tsusaka TW, Botha R, Budumuru M, Upadhyay S, et al. Assessing millets and sorghum consumption behaviour in urban India: a large-scale survey. Front Sustain Food Syst. 2021;5:1–12. <https://doi.org/10.3389/fsufs.2021.680777>
7. Abinaya K, Natarajan S, Ganapathy M, Arivazhagan K. Studies on intercropping in finger millet (*Eleusine coracana* L.) under SRI principles. Mysore J Agric Sci. 2020;54(3):73–79.
8. Gowda HRC, Amrutha T, Raghavendra KJ, Kumar CS. Millets production and prospects in India: an economic overview. Green Farming. 2019;10(3):300–305.

9. Chaitra GB, Patil C, Yeledhalli RA. Attracting and retaining youth in agriculture: a case of agriclincs and agribusiness centres (ACABC) scheme in India. Int J Curr Microbiol Appl Sci. 2020;9(2):1109–1115. <https://doi.org/10.20546/ijcmas.2020.902.130>
10. Saleh SMA, Zhang Q, Chen J, Shen Q. Millet grains: nutritional quality, processing and potential health benefits. Compr Rev Food Sci Food Saf. 2013;12(3):281–295. <https://doi.org/10.1111/1541-4337.12012>
11. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. 4th ed. New Delhi: Indian Council of Agricultural Research; 1985.
12. Cuddy JDA, Della Valle PA. Measuring the instability of time series data. Oxford Bull Econ Stat. 1978;40(1):79–84. <https://doi.org/10.1111/j.1468-0084.1978.mp40001006.x>
13. Yadav OP, Bidinger FR. Dual-purpose landraces of pearl millet (*Pennisetum glaucum*) as sources of high stover and grain yield for arid zone environments. Plant Genet Resour. 2008;6(2):73–78. <https://doi.org/10.1017/S1479262108993084>
14. Yamuna N, Kolekar DV, Rakesh N. Trend and instability analysis of area, production, productivity of millets in India. J Sci Res Rep. 2024;30(8):686–699. <https://doi.org/10.9734/jsrr/2024/v30i82290>
15. Bhagavatula S, Rao PP, Basavaraj G, Nagaraj N. Sorghum and millet economies in Asia: facts, trends and outlook. Patancheru: International Crops Research Institute for the Semi-Arid Tropics; 2013.
16. Chaitra G, Jeyavel S. A study on the growth and instability in area, production, productivity and minimum support price of major millets in India. Mysore J Agric Sci. 2024;58(3).
17. Shobana S, Krishnaswamy K, Sudha V, Malleshi NG, Anjana RM, Palaniappan L, et al. Finger millet (Ragi, *Eleusine coracana* L.): a review of its nutritional properties, processing and plausible health benefits. Adv Food Nutr Res. 2013;69:1–39. <https://doi.org/10.1016/B978-0-12-410540-9.00001-6>
18. Padulosi S, Mal B, King OI, Gotor E. Minor millets as a central element for sustainably enhanced incomes, empowerment and nutrition in rural India. Sustainability. 2015;7(7):8904–8933. <https://doi.org/10.3390/su7078904>
19. Intergovernmental Panel on Climate Change. Climate change 2022: impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report. Cambridge: Cambridge University Press; 2022. <https://doi.org/10.1017/9781009325844>

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