



RESEARCH ARTICLE

Growth and instability in millet cultivation in Odisha (1981–82 to 2021–22): Trends, varietal and agro-climatic perspectives

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Abstract

Agriculture in Odisha is predominantly rain-fed and smallholder-based, with millets historically serving as staple food crops and livelihood crops for tribal and marginal farmers. Despite renewed national interest in millets as climate-resilient, nutritious crops, the cultivation of ragi, jowar, bajra and small millets in Odisha has experienced a sustained decline that remains insufficiently documented. This study examines the long-term growth and instability in area, production and productivity of these four millet crops in Odisha over four decades (1981–82 to 2021–22), using secondary time-series data from the Directorate of Agriculture and Farmers' Empowerment, Government of Odisha. Growth trends were analysed using compound annual growth rate (CAGR), while variability and instability were assessed using the coefficient of variation (CV) and the Cuddy-Della Valle Instability Index (CDVI). Cultivated area and production declined consistently across all four crops. Ragi area contracted at -3.53 % per annum ($p < 0.001$) and production at -5.87 % per annum ($p < 0.001$). Small millets showed comparable area and production declines (-5.51 and -5.54 % respectively) accompanied by stagnant productivity. Jowar recorded the steepest area contraction (-6.11 % per annum), representing an approximately 84 % reduction in cultivated area over four decades, while bajra registered the sharpest production decline (-6.91 % per annum). Uniformly low CDVI values indicate that these declines are structurally rather than climate-driven. The findings point to a durable structural decline rather than a transient downturn, shaped jointly by policy incentives favouring paddy and the uneven geographic reach of national millet breeding programmes. Reversing this trend will require rationalised minimum support prices, expanded procurement infrastructure and breeding investments targeted at Odisha's specific agro-climatic conditions.

Keywords: agricultural policy; compound annual growth rate; crop diversification; millet decline; Odisha

Introduction

Millets are a group of small-seeded cereal crops cultivated as staple food crops for thousands of years, for subsistence farming communities in Asia and Africa. Millets are rich in protein, dietary fibre, iron (Fe), calcium (Ca) and essential amino acids and have been shown to have antioxidant properties (1). Their nutritional composition contributes to improved food and nutritional security. These attributes also make millets important for sustainable agriculture and public health (2). In addition to their nutritional properties, millets are naturally resilient crops that can withstand drought, low soil fertility and high temperature variability, which are increasingly limiting the cultivation of major cereals like wheat and rice, as the world becomes more aware of the threats of climate change, accelerating land degradation and fragility of food systems (3–5). India is one of the largest millet-producing countries in the world, where cultivation occurs in arid, semi-arid and humid agro-ecologies. For decades, millets have been sustaining millions of small and marginal dryland farmers in peninsular and central India.

However, since the Green Revolution era of the 1960s, the Government policies in India have focused primarily on promoting high-yielding wheat and rice varieties through subsidies in input use, guaranteed procurement and increased irrigation. Such a shift gradually led to the displacement of millets due to the attractive prices offered for irrigated cereals (6). As a result, there has been a continuous decrease in millet acreage and production during these years despite a rising concern for millets as a more nutritious and climate-resilient alternative crop for consumers (7). The recent International Year of Millets declared for 2023 has also contributed significantly towards raising attention to reviving the millets-based agri-food system in India (8, 9).

In this context, Odisha occupies a distinctive position in terms of its distinct role in millet agriculture, where a significant part of the tribal population depends on ragi, bajra, jowar and other small millets like kodo, kutki and sanwa due to dietary and cultural importance (10). In Odisha, millet farming occurs mostly in tribal-dominated uplands of Koraput, Rayagada, Kalahandi and

Sundargarh districts, providing sustenance to small and marginal farmers in these areas (10, 11). The soil characteristics, rainfall pattern and lack of irrigation facilities in upland areas make them suitable for cultivating millets. However, despite this, the agriculture of millets in Odisha has faced consistent decline regarding area, production and productivity due to structural neglect in favour of paddy (12, 13).

Several studies have examined the growth and instability of millet cultivation at the national level (14–16). However, with regard to Odisha, only limited studies have examined long-term trends, but none has comprehensively assessed long-term in Odisha for all four major millet crops over four decades while integrating quantitative trend analysis with varietal and agro-climatic context (13–17). A comprehensive four-decade study on all the four major millets has not been yet comprehensively investigated.

This study addresses this gap by analysing of the long-term growth and volatility of bajra, jowar, ragi and small millets production in Odisha from 1981–82 to 2021–22, using the compound annual growth rate (CAGR) and the Cuddy-Della Valle Instability Index (CDVI), a widely used measure that adjusts for underlying trend components, unlike the raw coefficient of variation (18). The findings aim to generate actionable empirical insights for policymakers and agricultural planners engaged in revitalising millet cultivation and tribal food security in the region.

Materials and Methods

Data source and nature

The study was conducted in the eastern coastal region of India, Odisha, which has a wide range of agro-ecological zones from coastal plains to upland tribal plateaus. The secondary data on area (ha), production (tonnes) and productivity (kg ha⁻¹) of ragi, jowar, bajra and small millets for 1981–82 to 2021–22 were obtained from the Directorate of Agriculture and Farmers' Empowerment, Government of Odisha annually and data were processed using International Business Machines Statistical Package for the Social Sciences (IBM SPSS) Statistics version 16.0.

Statistical framework

Growth trends of the area sown, total production and productivity per hectare of bajra, jowar, ragi and small millets in Odisha were analysed using the CAGR approach from 1981–82 to 2021–22. The CAGR was used to estimate long-term growth trends, CV measured overall variability and CDVI quantified instability after removing the trend component (18). Although substantial structural declines were observed in area and production in the area and production, there existed differences in the productivity and instability trends among the four crops.

Compound annual growth rate (CAGR)

Compound annual growth rate was estimated by fitting an exponential (log-linear) trend model to the time-series data (18):

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

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.

The model was estimated using ordinary least squares (OLS) linear regression of $\ln(Y_t)$ on the time index (t) in IBM SPSS

Statistics v16.0. The significance of the trend coefficient (b) was assessed using the two-tailed t -test ($H_0: b = 0$), with 39 degrees of freedom ($n = 41$). Statistical significance was denoted as $p < 0.10$, $p < 0.05$ and $p < 0.01$.

Coefficient of variation (CV)

The coefficient of variation was computed to measure relative variability in the time series.

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

Cuddy-Della Valle instability index (CDVI)

To measure true instability after accounting for the trend component, the CDVI was computed as (18):

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

Where, R^2 is the coefficient of determination from the exponential trend regression. A CDVI < 15 denotes low instability, 15–30 moderate instability and > 30 high instabilities. The CDVI is preferred over the raw CV because it adjusts for the trend component, isolating fluctuations not attributable to the underlying growth trajectory.

Results and Discussion

Ragi: Area, production and productivity trends and variability

In terms of area under cultivation and production, ragi showed significant decreases in both parameters, area and production values of -3.53 and -5.87 % respectively (Table 1, Fig. 1a–c). Given the greater percentage decrease in production (-5.87 %) compared to the area under cultivation (-3.53 %), productivity gains have not been enough to compensate for the loss in production, which could be caused by the continuous loss of area devoted to cultivating this grain. The difference between the two variables is indicative of a multiplicative effect whereby the reduction in cultivated area has led to stagnant or poor yield performance. The production decline rate has been found to outpace the loss of area cultivated with millet crops in many national-level studies (12, 14).

Despite the cultural significance of ragi within tribal populations in Odisha and the fact that it plays a key role in the tribal food systems, as well as ceremonies and festivals, its cultivation area has progressively declined over the last four-decades. As shown by stability analysis, ragi cultivation has displayed relatively stable dynamics over this period (CDVI of area = 4.52 and CDVI of production = 7.38) and thus can be interpreted as a gradual process, while productivity proved to show moderate instability (CDVI of productivity = 17.75) and thus fell into the category of moderately unstable crops, defined by a CDVI range of 15–30 (18). It is believed that productivity is highly susceptible to climatic changes because of

Table 1. Growth and instability in area, production and productivity of ragi in Odisha

Particulars		Area (log)	Production (log)	Productivity (log)
Growth	CAGR (%)	-3.53***	-5.87***	-3.70**
	p value	0.001	0.001	0.030
Instability	CV	6.519	8.621	18.858
	CDVI	4.518	7.380	17.747

* Significant at 10 % level ($p < 0.10$); ** Significant at 5 % level ($p < 0.05$); *** Significant at 1 % level ($p < 0.01$); CAGR: compound annual growth rate; CV: coefficient of variation; CDVI: Cuddy-Della Valle Instability Index.

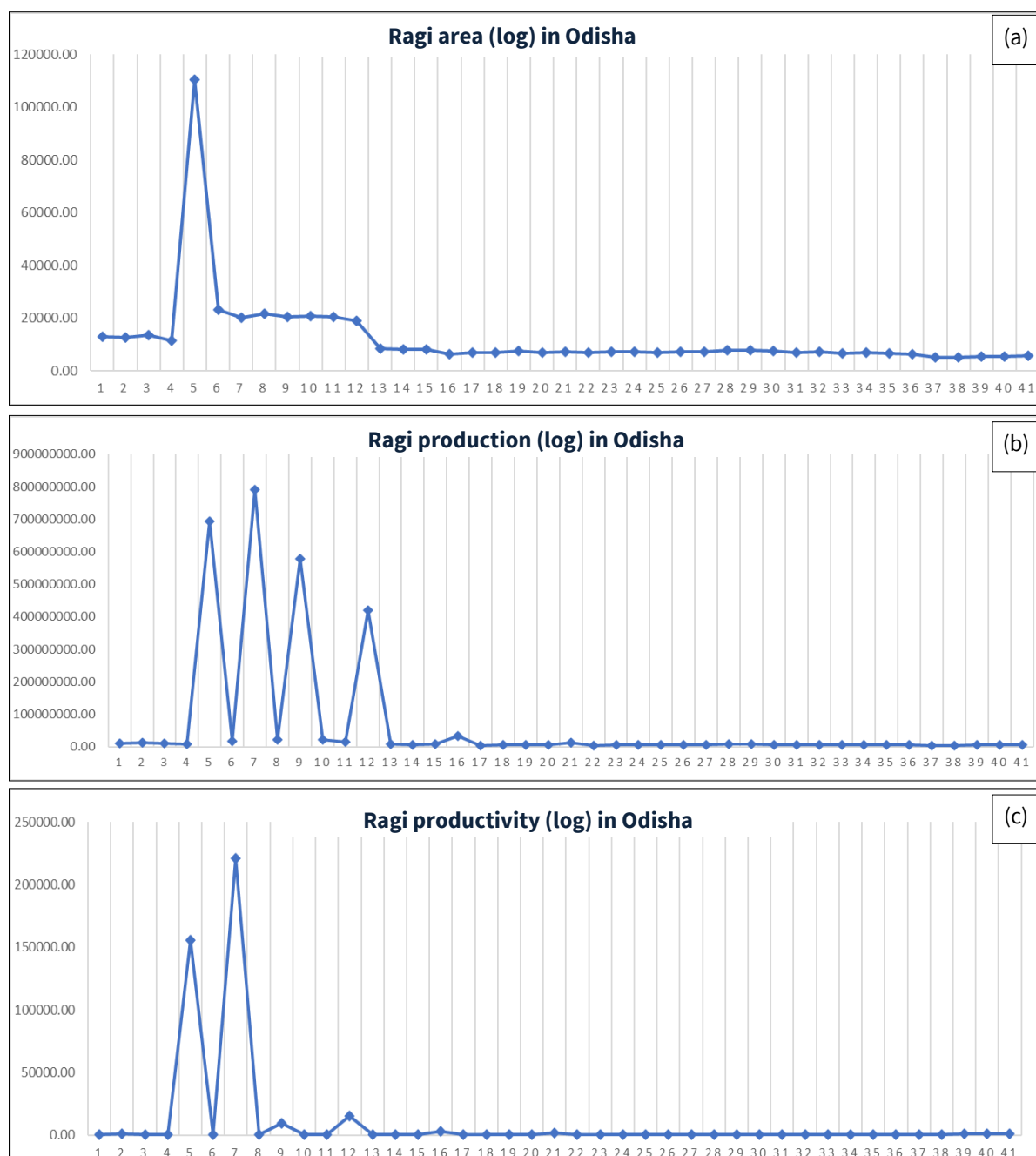


Fig. 1. Area, production and productivity of ragi in Odisha.

rain-fed agriculture (4). Ragi farmers are unable to engage in various techniques that could contribute to increased productivity, namely line sowing, improved soil fertility and better seed varieties due to unfavourable monsoon weather conditions and their lack of knowledge in these matters. Lack of governmental support regarding seed development, extension programs and marketing facilities in Odisha has left the local farmers with little chance to enhance productivity of ragi (16). In summary, the findings of this study indicate the presence of a long-lasting structural decline in the cultivation of ragi that has mainly occurred due to area reduction and inability to increase productivity due to yield instability.

Small millets: Area, production and productivity trends and variability

Area and production of small millets decreased significantly over the four-decade study period, with CAGR values of -5.51 and -5.54 % respectively (Table 2, Fig. 2a–c). Small millets consist of several minor grains, including kodo millet (*Paspalum scrobiculatum* L.), little millet or kutki (*Panicum sumatrense* Roth ex Roem. & Schult.), barnyard millet or sanwa (*Echinochloa frumentacea* Link) and others. These

were traditionally grown by tribals in Odisha's upland areas in subsistence farming systems (10). Even after considering their significant adaptability to nutrient-poor soils and moisture stress conditions, these millets have shown a relatively fast decline in cultivated area. Productivity of small millets grew marginally over the past four-decades with an annual growth rate of only 0.27 % ($p = 0.358$). This implies a relative stagnation in productivity improvements during this period. Since the magnitudes of area decline (-5.51 %) and production decline (-5.54 %) are nearly identical, the results indicate that total output losses were primarily attributable to the decline in the area under cultivation rather than to a deterioration in yield per hectare. In other words, the crop maintains its yield capacity on land still under cultivation; however, the cultivated area has been declining. The CDVI of productivity is 8.79, meaning that yield stability remained high despite decades of stagnation. This indicates that there haven't been any dramatic changes in climate or agriculture leading to productivity losses. Moreover, CDVI values for the area and production indicators (10.428 and 5.620 respectively) lie within the threshold of low instability. The

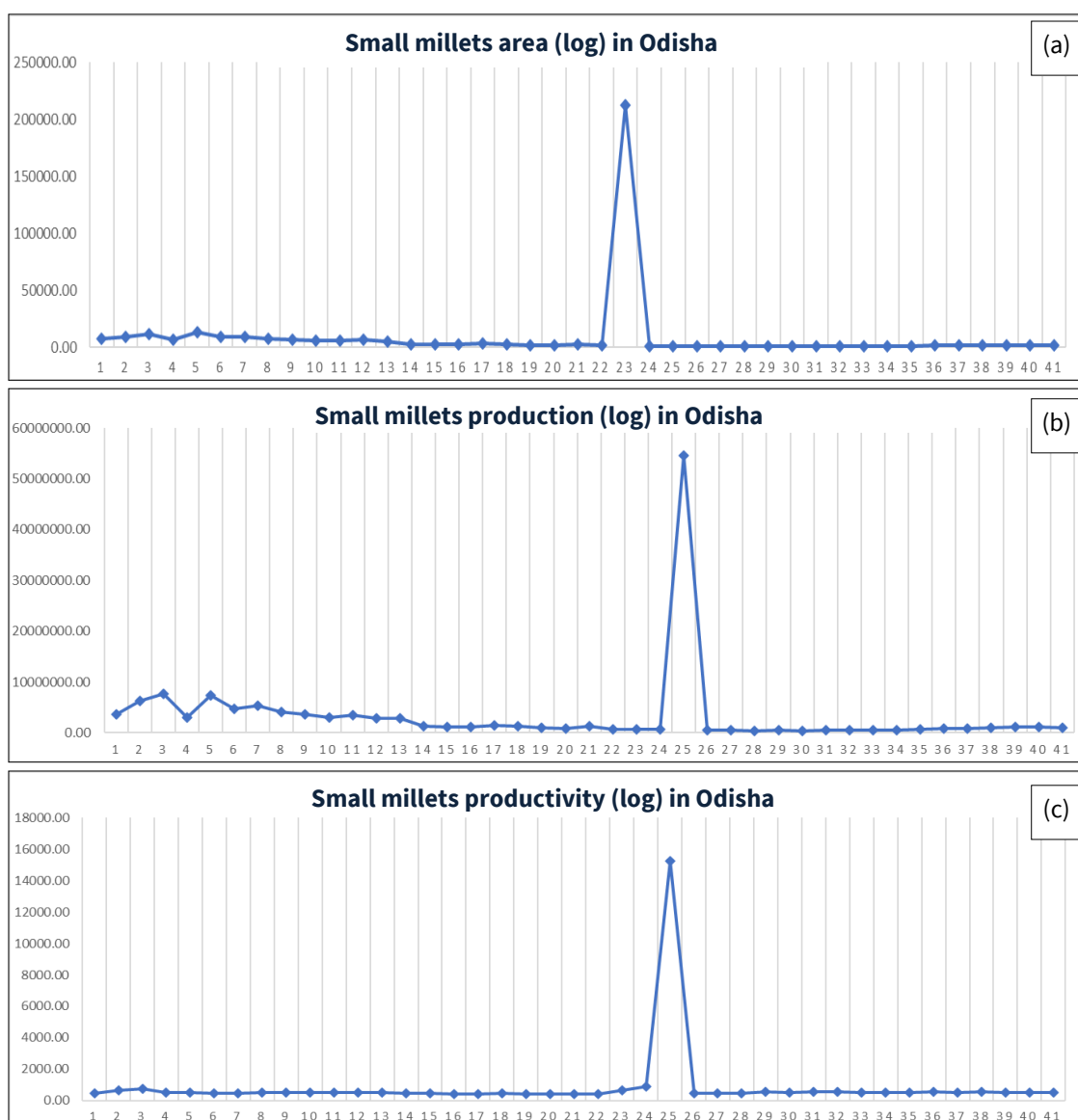


Fig. 2. Area, production and productivity of small millets in Odisha.

Table 2. Growth and instability in area, production and productivity of small millet in Odisha

Particulars		Area (log)	Production (log)	Productivity (log)
Growth	CAGR (%)	-5.51***	-5.54***	0.27
	<i>p</i> value	0.001	0.001	0.358
Instability	CV	13.441	7.395	8.800
	CDVI	10.428	5.620	8.786

* Significant at 10 % level ($p < 0.10$); ** Significant at 5 % level ($p < 0.05$); *** Significant at 1 % level ($p < 0.01$); CAGR: compound annual growth rate; CV: coefficient of variation; CDVI: Cuddy-Della Valle Instability Index.

results indicate that the decline has been a consistent trend over the four-decades rather than being characterised by substantial fluctuations. This conclusion is supported by the results of nationwide observation of small millets' marginalisation, which took place after the Green Revolution due to policy support cessation, paddy expansion and absence of remunerative pricing. These factors resulted in a gradual loss of incentives for farmers to cultivate nutritionally valuable grain crops such as millets (6, 19). Our results confirm national-level findings and indicate that a long-term trend of small millets' decline has taken place. The observed stagnation in productivity highlights the need for targeted interventions to improve the long-term sustainability of small millet cultivation.

Jowar: Area, production and productivity trends and variability

Of all four millets evaluated in this paper, jowar demonstrated the greatest reduction in both its area, with CAGR of (-6.11 %) being statistically significant at 1 % level and total production (-6.36 %) respectively (Table 3, Fig. 3a–c). Of note is that the degree of decline in both measures is remarkable, cultivated area dropped down from more than 2766 ha in the early 1980s to only about 440 hectares in 2021–22 season and hence implies that the extent of reduction is nearly 84 %. This represents the complete withdrawal of jowar from agricultural production in Odisha and can be considered one of the most dramatic cases of millet marginalisation in this state. Moreover, such a sharp reduction in cultivation of jowar means that there was a major shift in cropping practices in regions, where jowar used to play the role of a significant rainfed crop in the past. Being a highly drought-resistant and versatile crop, which can serve to produce both grain and straw (which is widely used as fodder), the complete disappearance of jowar from Odisha's agricultural practice affects not only food and nutritional security but also the entire system of animal husbandry in tribal farms. Of interest is the fact that despite having relatively high coefficient of variation of area (15.23 %), CV for production in jowar is lower (7.23 %). However, the level of CDVI is still relatively low for both metrics (10.50 for area and 4.12 for production), hence

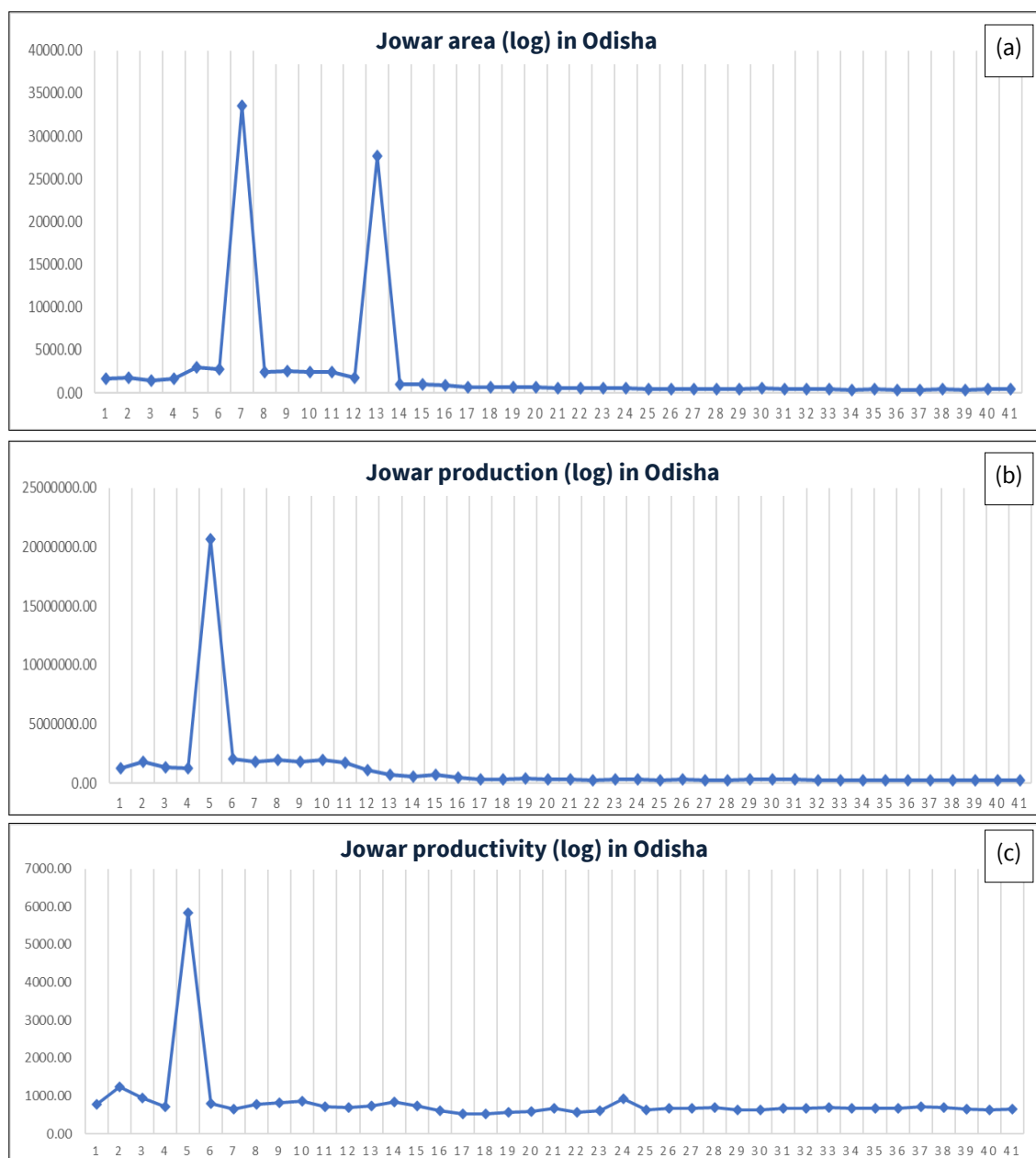


Fig. 3. Area, production and productivity of jowar in Odisha.

Table 3. Growth and instability in area, production and productivity of jowar in Odisha

Particulars		Area (log)	Production (log)	Productivity (log)
Growth	CAGR (%)	-6.11***	-6.36***	-1.15**
	p value	0.001	0.001	0.015
Instability	CV	15.234	7.226	5.597
	CDVI	10.503	4.115	5.187

* Significant at 10 % level ($p < 0.10$); ** Significant at 5 % level ($p < 0.05$); *** Significant at 1 % level ($p < 0.01$); CAGR: compound annual growth rate; CV: coefficient of variation; CDVI: Cuddy-Della Valle Instability Index.

implying that the process of area decline and production reduction were systematic and structural, rather than transient adjustments associated with climatic shocks (18). The low instability values suggest that long-term structural factors may have contributed more substantially than short-term fluctuations. Another reason for a consistent decline in area under jowar is that the productivity itself was on a slight decline during the analysed period (CAGR: -1.15 %; $p < 0.05$). Hence, the collapse in production of jowar is a result of two

interrelated phenomena, namely, reduction in area under this crop and gradually falling yield per hectare. It is interesting that neither bajra nor ragi showed such a tendency in the last metric, thus indicating even greater level of marginalisation of this crop in Odisha. As in case with other millets in eastern India, marginalisation of jowar can be explained by government policies-driven input subsidies and assured procurement mechanisms that overwhelmingly favour irrigated rice cultivation, leaving jowar farmers without comparable institutional support (6, 13).

Bajra: Area, production and productivity trends and variability

Bajra exhibited the greatest decline in production (CAGR = -6.91 %), accompanied by a significant reduction in cultivated area (CAGR = -6.00 %, $p < 0.001$) (Table 4; Fig. 4a-c). Given that production decline (-6.91 %) was higher than the area decline (-6.00 %), it can be inferred that the performance of yield per hectare also suffered, although the difference between the two declines is not significant. Interestingly, no significant trend in productivity over the study period emerged, with the observed decline being statistically insignificant (CAGR: -0.51 %, $p = 0.501$). This result is especially important because it reveals that the yield of

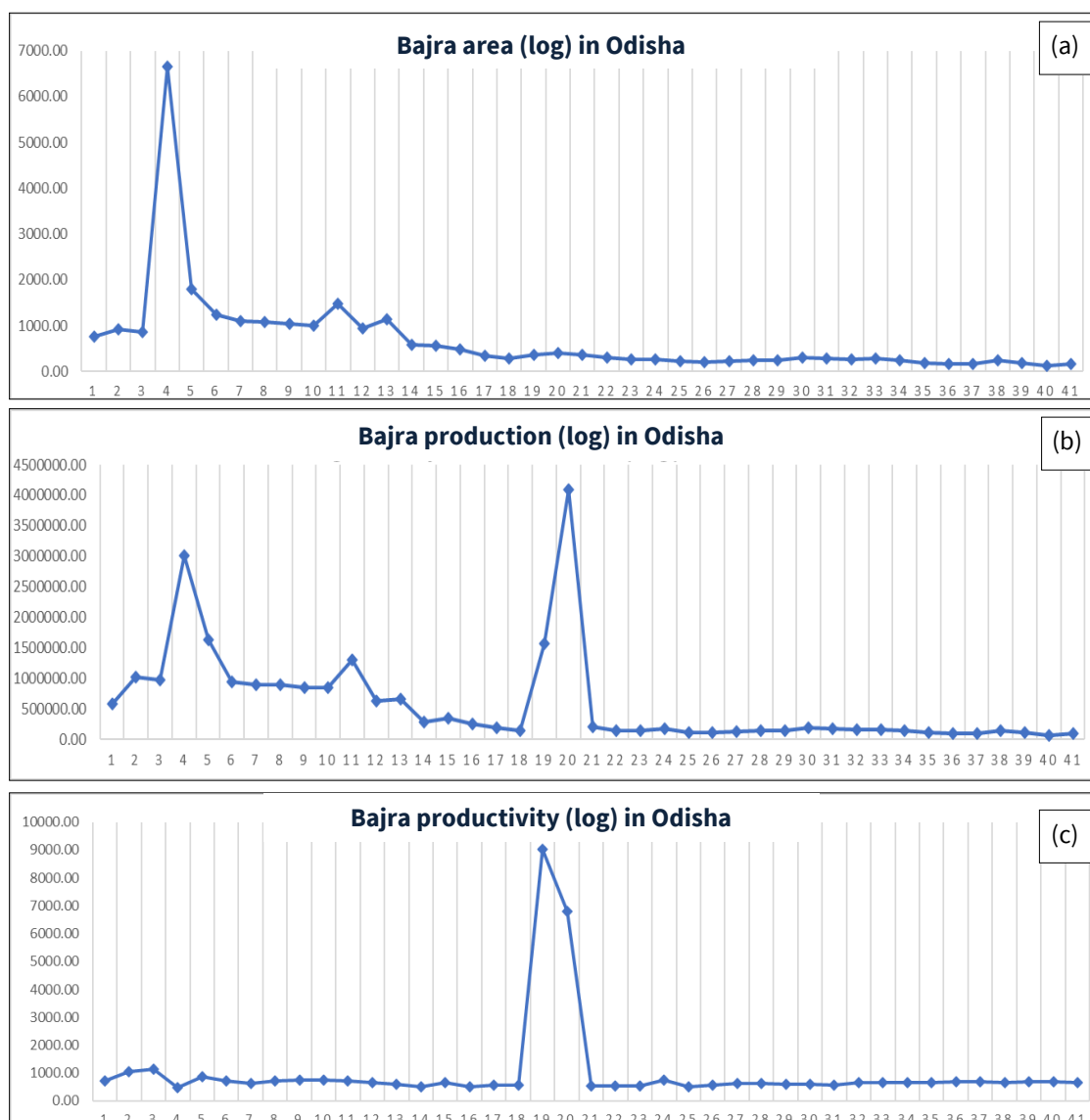


Fig. 4. Area, production and productivity of bajra in Odisha.

Table 4. Growth and instability in area, production and productivity of bajra in Odisha

Particulars		Area (log)	Production (log)	Productivity (log)
Growth	CAGR (%)	-6.00***	-6.91***	-0.51
	<i>p</i> value	0.001	0.001	0.501
Instability	CV	13.944	8.417	8.667
	CDVI	6.719	4.998	8.617

* Significant at 10 % level ($p < 0.10$); ** Significant at 5 % level ($p < 0.05$); *** Significant at 1 % level ($p < 0.01$); CAGR: compound annual growth rate; CV: coefficient of variation; CDVI: Cuddy-Della Valle Instability Index.

bajra remained largely stable over the long-term period, despite significant area reductions in cultivation. From a policy interpretation perspective, these results suggest that bajra production declined due to withdrawal from less-productive areas as farmers increasingly shifted to more subsidised and assured-purchase crops, such as paddy and wheat (17). This pattern may indicate a gradual reduction in cultivated area while productivity remained relatively stable in the remaining production zones while the observed pattern is consistent with farmers shifting towards more remunerative crops. This view is supported by very low values for the coefficients of variation of area (6.72) and production (5.00) for bajra, which indicates consistency and gradualness of the decline process with a consistent negative slope and low instabilities

between years. No erratic year-to-year changes that could signal the existence of climate or pests' disturbances were found. Such findings confirm the existing national trends showing the shift of bajra cultivation from the dry-land and semiarid agricultural systems to areas suitable for irrigation with rice and wheat taking advantage of guaranteed purchase and subsidy policies (12, 13). The absence of yield improvements despite significant area highlights the need for policy interventions aimed at improving market incentives, seed systems and varietal development.

Framework for qualitative interpretation

In addition to the CAGR, CV and CDVI analysis of area, production and productivity, this study also examines how varietal-development history and agro-climatic factors relate to the observed growth and instability patterns for each crop. This component of the analysis is descriptive and qualitative in nature, drawing on secondary literature, Indian Council of Agricultural Research-Indian Institute of Millets Research/All India Coordinated Research Project reports (ICAR-IIMR/AICRP) reports and published records of varietal releases and is not derived from a separate statistical model (e.g., a regression of yield on climate or varietal-adoption variables). It is intended to contextualise and offer plausible explanations for the quantitative trends reported above, rather than to independently test the strength of these linkages.

Varietal and agro-climatic perspectives of millet yield in Odisha

The growth and instability patterns observed in this study cannot be fully explained by policy or market incentives alone, as millet yield trends in Odisha have also been strongly influenced by varietal development and agro-climatic suitability. Crop improvement for sorghum, pearl millet, finger millet, foxtail millet, little millet, barnyard millet, kodo millet and proso millet is coordinated by ICAR-IIMR, Hyderabad, through the AICRP, comprising 13 centres across 10 states for pearl millet and 31 centres across 15 states for sorghum and small millets (20). Differences in the pace and regional reach of varietal replacement across crops are likely to have contributed to the contrasting trends observed in Odisha.

Among the four crops studied, finger millet has received the strongest region-specific breeding support relevant to Odisha. Odisha University of Agriculture and Technology (OUAT) has released several locally adapted varieties, including OEB 10, OUAT-2 (Suvra), BM 9-1 (Bhairabi), OEB 526 and OEB 532, the latter developed from a GPU-26 × L-5 cross, moderately blast-resistant and recommended for Odisha, Bihar, Chhattisgarh, Karnataka and Tamil Nadu (21, 22). This sustained breeding effort likely contributed to ragi recording the smallest decline in cultivated areas (-3.53 % per annum). The Shree Anna Abhiyan (Odisha millet mission) has further promoted improved varieties such as GPU-28 and CSV-27 while strengthening seed systems and extension. Nevertheless, many tribal farmers continue cultivating traditional landraces such as jam mandia and kalia mandia because of their superior adaptation to acidic upland soils, staggered maturity and resilience to erratic monsoon conditions. The coexistence of improved varieties and indigenous landraces likely explains the moderate productivity instability observed for ragi (CDVI = 17.75).

In contrast, breeding efforts for kodo, little and barnyard millet have progressed more slowly. Recent ICAR-IIMR germplasm characterisation reports only a few hundred evaluated accessions for these species, considerably fewer than for sorghum or finger millet (23). This limited breeding pipeline is consistent with the insignificant productivity growth recorded for small millets (CAGR = 0.27 %, $p = 0.358$), suggesting that continued reliance on traditional landraces reflects a varietal improvement gap rather than management or extension deficiencies. Given Odisha's importance as one of the major small-millet-growing states alongside Madhya Pradesh, Chhattisgarh and Jharkhand, strengthening breeding efforts for these crops should be a national priority (24).

Although sorghum breeding has advanced nationally, with recent AICRP trials reporting genotypes outperforming the long-established check variety CSV-27 by 5–10 % (25), these gains have largely benefited Maharashtra and Karnataka, where sorghum is well adapted to dry, clayey soils (26). Odisha's humid, high-rainfall environment favours fungal diseases such as grain mold and limits the performance of dryland hybrids, restricting the successful adoption of high-yielding sorghum varieties and contributing to the crop's near-complete disappearance from the state.

A similar agro-climatic mismatch is evident for pearl millet. National hybrids such as the ICRISAT-ICAR RHB 273 were developed primarily for A1 dryland regions receiving less than 400 mm annual rainfall (27), whereas Odisha's sub-humid climate exposes the crop to greater pest and disease pressure. This mismatch is consistent with the sharp decline in bajra area (CAGR = -6.00 %, $p < 0.001$) despite the absence of a significant productivity trend (CAGR = -0.51 %, $p = 0.501$),

indicating that farmers largely withdrew the crop from less suitable environments rather than experiencing widespread yield failure.

Overall, the observed decline in millet cultivation in Odisha appears to reflect the combined effects of policy support favouring rice and wheat and the uneven distribution of ICAR-IIMR/AICRP breeding gains across India's agro-climatic regions. The OUAT's sustained breeding programme demonstrates the benefits of targeted varietal development for ragi, whereas the decline of sorghum and pearl millet and the stagnant productivity of small millets highlight the consequences of limited adaptation to Odisha's humid, rainfed tribal landscapes. These findings suggest that reversing millet decline will require not only improved price and procurement policies but also greater investment in breeding programmes that develop genotypes specifically adapted to Odisha's upland agro-climatic conditions.

Conclusion

The four-decade analysis revealed a significant long-term decline in millet cultivation across Odisha, characterised by substantial reductions in area and production. Low Cuddy-Della Valle Instability Index (CDVI) values across all crops confirm that this is not a transient climate-induced downturn but a durable structural contraction suggesting that structural factors, including policy-related influences, have contributed to the long-term decline. Critically, this decline is compounded by a geographic and agro-climatic mismatch in national breeding investment. Policy initiatives to revive millets should move beyond generic price support and strengthen location-specific varietal improvement. Greater collaboration among Indian Council of Agricultural Research-Indian Institute of Millets Research, All India Coordinated Research Project reports (ICAR-IIMR, AICRP) on small millets, Odisha University of Agriculture and Technology (OUAT) and the Odisha Department of Agriculture is needed to develop and evaluate millet varieties under Odisha's humid tribal upland conditions. Priority should be given to the conservation and genetic improvement of indigenous landraces such as jam mandia and kalia mandia, which possess valuable adaptive traits for acidic soils and high-rainfall environments. Such targeted breeding efforts can improve varietal suitability, productivity and climate resilience in the region.

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Authors' contributions

SNM provided guidance and supervision of the research methodology. BS, SNM, BM, KKS and AD contributed to the conceptualisation, methodology development, data validation, statistical analysis, interpretation of results, visualisation and manuscript refinement. BS drafted the manuscript. SNM and BM

contributed to methodology development, data validation and manuscript refinement, while KKS and AD contributed to the organisation of the discussion and critical revision of the manuscript. BKM, BPN and GN contributed to the study design and coordination. All authors have 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

During the preparation of this work the authors used OpenAI's ChatGPT and Claude AI in order to language refinement and improving clarity as per journal guidelines. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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