Millets and Food Security in India: State-wise Analysis of Sustainable Agriculture

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Abstract

India occupies the most strategic position in the millet production globally. It has been able to retain the leadership because of various initiatives undertaken at national and state-level such as product diversification, giving subsidies and tax incentives, quality assurance, especially after declaration of 2023 as International Year of Millets. This study examines the production of millets in the top ten states of India from 2019 to 2024, in order to explore the impact of state-specific factors on production levels. Panel data analysis finds that the Fixed-Effects (FE) model is more suitable over the Random-Effects (RE) model supporting the crucial role of state-specific effects in influencing millet production. The Hausman test value indicates that state-specific elements account for a considerable amount of production variance. Thus, it emphasizes the need for adapting and recommending variations in state-level agricultural policies and practices to improve the productivity of millets. Moreover, significant positive coefficient of area under cultivation suggests that, particularly in states where production has been declining, emphasis should be on improving the area under millet farming. These results underline the need of focused state-specific strategies to increase millet production, which aligns with sustainability objectives and guarantees food security. Policymakers by coordinating national and state-level efforts can help to meet the Sustainable Development Goals of the United Nations by addressing the state-specific challenges and using the resilience of millets, so contributing to a more sustainable and secure food system.

Keywords: Millets, Food Security, Economic Analysis, Panel Regression, Sustainability

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1. Introduction

Millets often referred to as "nutri-cereals" or "dryland cereal", have become popular as these are quite resistant to heat and highly productive in arid areas, supporting sustainable agriculture. Rain-fed farming systems (Priya et al., 2023; Tripathi & Vyas, 2023) would find these small-seeded grasses ideal as being highly nutritious and drought-tolerant. Since millets can thrive in harsh environments and adapt to poor soil conditions, these crops have become crucial for addressing world food security challenges (Mohod et al., 2023; Nanda & Sharma 2022). These can be broadly classified into two groups: major (pearl millet, sorghum, and finger millet) and minor (proso, tiny millet, kodo, foxtail, and barnyard millet). India has a long tradition of growing and consuming millets and is the largest producer of the millets in the world primarily focussing on pearl millet (bajra), sorghum (jowar) and finger millet (ragi).

Millets are also gaining popularity in the consumer market, particularly for being gluten-free and high-fibre food products. Millet-based food items such as flour, biscuits, and flakes are becoming popular among health-conscious consumers in countries including the United States, Europe, and Asia-Pacific. Vegetarians and vegans opt for these grains because of their high protein content. In Africa and Asia, millet-based breakfast cereals and traditional recipes are gaining popularity, contributing to a global millet-based breakfast food market that generated over USD 2 billion in revenue in 2018. This is expected to grow at more than 4.5% as the demand for fibrous, gluten-free foods rises in the next 6-7 years (Global Market Insights, 2019). Products based on millet, including porridge for newborns, are becoming significant dietary interventions to avoid malnutrition in developing nations. Additionally, millet beer, a traditional beverage in Africa, is making inroads into the global beverage market, particularly in Asia-Pacific, North America and Europe. Millets are also commonly utilized as animal feed in the United States, which adds to their economic importance (The Agricultural and Processed Food Products Export Development Authority (APEDA) and Yes Bank Report, 2022).

Given the global significance of millets and India's prominent role in their production, the objective of the study is (i) to examine the driving force behind the growing demand for Indian millets; (ii) to analyse the millet production and consumption trends in India for top ten states from 2019 to 2024; and (iii) using panel regression analysis to examine the

state-specific effects influencing millet production. Addressing the disparities through targeted research and interventions can enhance overall productivity, strengthen India's contribution to global millet supply, and promote sustainable agricultural practices.

The paper is divided into seven sections with Section 2 discussing India's position in the global context, comparing its production and consumption trends with top five countries. It then explores the driving forces behind the increasing global demand for Indian millet in Section 3 followed by a review of relevant literature in Section 4. The data sources and methodology are discussed in Section 5. The results Section 6 presents trends at both national and state levels, with a closer look at productivity factors across regions. The paper concludes with policy recommendations in Section 7, aiming to enhance India's position as a major millet producer and exporter while supporting sustainable agricultural practices.

2. India in Global Context: Production and Consumption

Globally, millet cultivation covered an area of 71.70 million hectares in 2022, showing minimal change from 71.88 million hectares in 2012. Despite this, millet production has slightly increased over the decade, reaching 90.65 million metric tons with a compounded yearly growth rate of 0.3% from 2012 to 2022. India dominates global millet production, contributing 19% of the total output in 2022 as evident in Table 1. Its leadership role is evident as millet occupies as a key staple in agriculture policy across all states and ensures its role in food security. Nigeria follows closely with a 10.01% share while other major contributors are Sudan, the United States, and China with between 6% and 7% of global production (APEDA, and Yes Bank Report, 2022).

Table 1: Millet Production in Top 5 Countries (2022)

Rank	Country	Share (%) of World Production	Millet Output ('000 MT)
1	India	19	17,600
2	Nigeria	10.01	9,000
3	Sudan	7.23	6,500
4	United States	6.91	6,212
5	China	6.34	5,700

Source: APEDA and Yes Bank Report, 2022

This production data underscores the potential for economic and food security benefits in these nations. No doubt India's leadership is positive but excessive reliance on millets for climate resilience and food security may also face challenges such as water management, sustainable land use, which could strain agricultural resources in dry areas. However, countries like the U.S. and China which have diversified agriculture system and lower share of millet production may have enough scope to integrate millet as part of broader sustainability strategy without altering the agricultural balance. Thus, it requires a balanced support from other crops, careful resource management to meet the long term goal of sustainable agriculture and food security.

Table 2 demonstrates except for sorghum consumption, consumption of all other millet in India displayed a modest decadal growth of 2% for 2012-2022, suggesting a diversification in millet consumption. Rising consumption trends in India, China, Nigeria, and Sudan show the importance of millets in both human diets and animal feed as per the agricultural practices of the nations (Paschapur et al., 2021).

There is no doubt that millet can offer sustainable solution to the global food insecurity and climate change challenge. It's their ability to withstand harsh conditions and nutritional benefits that promotes them as a crucial crop for both human consumption and economic growth. By promoting millet-based products and expanding their presence in global food systems, we can enhance food security while fostering sustainable agricultural practices across countries.

Table 2: Millet Consumption and its Growth Rate in Top 5 Countries

S. No.	Country	Sorghum Consumption ('000 MT)	CAGR (2012-2022) (%)	Other Millets Consumption ('000 MT)	CAGR (2012-2022) (%)
1	India	4,450	-1	13,300	2
2	China	11,000	16	2,700	4
3	Nigeria	6,800	4	2,000	5
4	Sudan	4,950	6	1,500	15
5	Ethiopia	4,600	2	1,100	4

Source: APEDA and Yes Bank Report, 2022

3. Driving Forces behind the Global Demand for Indian Millet

With the declaration of 2023 as the International Year of Millets, India made substantial efforts to improve its visibility in the global arena. Special efforts were made to create awareness about nutritional and environmental benefits of millets. Some key factors drive this increasing demand for Indian millets in national and international markets:

(i) Market Research and Consumer Preferences: Market research plays a very important role in identifying export markets and assessing consumer preferences. Indian exporters have managed to cater to the unique demands, tastes, and nutritional preferences of international consumers by aligning their products with these insights. For example, the rising interest in gluten-free, organic, and sustainable food options in Europe and North America has created a niche market for millet-based products that meet these criteria (Global Market Insights, 2018).

(ii) Product Diversification: Increasing the variety of any good is essential for improving its reach to customers. Indian producers have tried to diversify their basket by including products such as millet flour, snacks, cereals, and beverages; which creates more opportunities for them in the international market. It satisfies the needs of consumers who are health-conscious and also caters to the increasing trend toward plant-based and whole-grain diets (FAO, 2023).

(iii) Government Initiatives: Several initiatives by the Indian government have promoted millet exports such as collaborations with government trade promotion agencies and the provision of subsidies and tax benefits. For instance, by lowering taxes and giving freight subsidies on millet-processing machinery lowered their production and transportation costs, thus, making Indian millets more competitive in the global market (APEDA, 2022, 2023).

(iv) Certification and Traceability: The trust of any food item increases if it is certified by an agency of repute and one can track its organic contents, and follow fair trade, or sustainable production practices. These validations by the Indian government helped in gaining the confidence of customers, particularly in Europe

and North America. These consumers are willing to pay a premium for ethically sourced and sustainably produced goods (Willer et al., 2023).

(v) Quality Assurance: Indian millets must guarantee quality assurance all along the supply chain if they are to meet global standards. The strict testing and following food safety rules have strengthened customer confidence and presents Indian millets as a reputable, premium-quality product on a worldwide scene (FSSAI, 2020).

4. Review of Literature

While there are many studies available on millet production and its significance, this section reviews only a few recent ones that highlight the key aspects of millet cultivation and its significance.

Tripathi and Vyas (2023) have explored the significance of millets in the historical context, tracing back thousands of years to ancient civilizations such as China and India. It gives an extensive overview of millets' global relevance, highlighting their adaptability across diverse regions, including Africa, Europe, and the Americas. Historically, millets have been a staple food in areas with challenging agroclimatic conditions due to their high levels of protein, fibre, and antioxidants. Further they concluded, because of modern agricultural practices, shifting dietary preferences, and climate change, there has been a decline in millet cultivation.

Kheya et al. (2023) emphasize that millets have been overlooked to a great extent in agricultural research, and policies even though these have nutritional and environmental benefits. Realizing this gap, several tropical countries, including India and Bangladesh, have started to focus on improvements in millet cultivation practices and marketing. Various factors such as barriers to millet adoption, inadequate infrastructure, and weak market linkages are responsible for its sluggish response. Thus, it suggests an increase in investment in research and extension services, strong market linkages, and integrating millets into national policies.

Kumar et al. (2022) underscore the importance of focusing on drylands to boost grain production, as most irrigated agricultural lands are nearing exhaustion. Drylands often present challenges due to low soil fertility, but millets offer a solution owing to their adaptability to poor growing conditions and higher nutritional value compared to traditional staples like wheat and rice. By shifting agricultural focus toward millets and other coarse cereals, there can be a significant increase in nutrient supply, with potential enhancements of 1-5% in protein and 5-49% in iron. Additionally, millets contribute to climate resilience by reducing greenhouse gas emissions, irrigation water demand, and energy use. Their ability to thrive in diverse ecological conditions with minimal need for artificial fertilizers and water has earned them the label of "Miracle Grains". It also emphasizes the need for integrating climate-smart technologies in millet cultivation to ensure sustainability and meet future demands.

Ceasar and Maharajan (2022) argue that promoting millets is crucial for meeting the United Nations' Sustainable Development Goals (SDGs), particularly those related to food and nutritional security. Millets' low input requirements for fertilizers and pesticides make them suitable for low- and middle-income countries, especially in Asia and Africa. Enhancing millet production and consumption aligns with global efforts to strengthen food security and develop climate-resilient agricultural systems.

Paschapur et al. (2021) endorse that minerals like iron, calcium, and magnesium, as well as proteins and fibre, can be found in large amounts in millets. Further, consuming millets can also lower the risk of getting diseases like cancer and heart disease that are linked to modern eating and sedentary lifestyle choices. The promotion of millets as ready-to-eat and ready-to-cook products can increase income of the farmers, enhance production, and stimulate market demand. This not only supports food and nutritional security but also contributes to economic growth and job creation in developing regions.

Maitra (2020) emphasise that millet-based intercropping systems offer a sustainable agricultural practice, particularly in drylands where conventional farming faces challenges. It advocates that intercropping cereals and legumes with small millets can improve resource efficiency, prevent soil nutrient loss, and enhance soil health. This system increases resilience against extreme weather conditions, improves productivity,

and provides higher economic returns, making it a viable strategy for sustainable agriculture in resource-constrained areas.

In summary, the literature emphasizes the historical and contemporary significance of millets as a staple food crop with exceptional nutritional value and climate resilience. Despite modern challenges, the promotion of millets through climate-smart agricultural practices and market innovations presents a promising pathway to enhance food and nutritional security. Integrating millets into global and local food systems is essential for attaining long-term sustainability and guaranteeing food security for subsequent generations.

5. Data & Methodology

5.1. Data Used and its Source

The information is drawn from the various reports of Agricultural and Processed Food Products Export Development Authority (APEDA) regarding area, yield, and production of millets at the state and national level. Its basic source is US Department of Agriculture and Department of Agriculture and Farmer's Welfare, Government of India. To understand India's progress and position in global context, the data is analysed for the latest decade 2012-2022. Within India, state-level dynamics are examined using data for the latest five fiscal years for top ten states (i.e. from the year 2019-20 to 2023-24 for the ten states which have highest production in 2022-23). The estimates of 2023-24 are based on projections than actual estimates. The research uses relative percentages, ratios, and growth rates over the relevant period to explore the trends in millet output, area, and yield. Further, to delve deeper into state-level differences, we use panel regression. This method allows us to analyze the relationship between millet production and other influencing factor, area, over time across different states (Wooldridge, 2010).

Panel regression is particularly effective in this context as it accounts for both temporal effects (changes over time) and individual heterogeneity (differences between states) (Khari & Jain, 2023; Li et al., 2021). It improves the accuracy of estimates by reducing omitted variable bias and allows for better understanding of dynamic relationships in the

data. In scenarios like state-wise agricultural production analysis, panel regression helps in identifying state-specific trends and time-dependent factors affecting overall production outcomes.

5.2. Model Specification

Given the limitation of data, the basic structural model of production is considered. The millet production is a function of area cultivated, state-specific characteristics, and year. This model would enable us to estimate the contributions of each variable (area, state, year) to millet production, taking into account individual differences across states and over time (Fuss, & McFadden, 1978).

$$Production_{it} = \alpha + \beta_1 Year_t + \beta_2 State_i + \beta_3 Area_{it} + U_{it} \quad (1)$$

where: $Production_{it}$ is the millet production in state i at time t; $Year_t$ is the time variable 2019-24; $State_i$ is the fixed effect for each state; $Area_{it}$ is the area under cultivation in each state i at time t; U_{it} is the error term.

Fixed effects (FE) model would control for time-invariant characteristics of each state and identify the effects of years on production while accounting for unobserved heterogeneity. This model will help in comprehending the influence of each state while accounting for fluctuations over time. While random effects (RE) model would enable to determine whether the state-specific effects are randomised and uncorrelated with the variables that are considered independent.

Given the characteristics of the data pertaining to agricultural production, selecting between FE and RE models is of the utmost importance. In this study, the Hausman test was utilised to ascertain whether or not the FE model was more appropriate than the RE model. This was done to guarantee that the selected approach accurately captured the fundamental dynamics of millet production across states over the specified period.

6. Result and Analysis

6.1. Area, Production, and Productivity of Millets: All India

Table 3 shows data on millets in India, highlighting both challenges and achievement in terms of its land area, output, and productivity. Millet area cultivation has fallen from 15.40 million hectares in 2012-13 to 14.00 million hectares in 2022-23, with a compound annual growth rate (CAGR) of -0.95% over the decade. This decline can be attributed to a shift in agricultural focus towards crops that require more water, such as rice and wheat, which are often preferred due to their higher economic returns.

Table 3: Millets Production and Sustainability Data in India (2012-13 to 2022-23)

Indicator	2012-13	2022-23	CAGR (2012-23)	Plausible explanation
Area under Cultivation (Mn Ha)	15.4	14	-0.95%	Decrease in area due to shift towards more water-intensive crops.
Production Volume (Mn MT)	16.03	17.6	0.94%	Modest growth in production despite reduced area.
Productivity (MT/ha)	1.04	1.26	2.00%	Increase in productivity due to improved practices and hybrid varieties.

Source: APDEA and Yes Bank Report, 2022

Despite the reduction in the area under millet cultivation, millet production has shown a modest increase, growing from 16.03 million MT in 2012 to 17.60 million MT in 2022-23, with a CAGR of 0.94%. This growth is particularly significant given the shrinking land allocated to millets because of improved agricultural practices; use of high-yielding and hybrid varieties of millets. These changes have allowed farmers to achieve higher production levels on reduced acreage, showcasing the resilience and adaptability of millet cultivation (Tripathi & Vyas, 2023; Kumar et al., 2022).

Furthermore, productivity has increased from 1.04 metric tonnes per hectare in 2012-13 to 1.26 metric tonnes per hectare in 2022-23, reflecting a CAGR of 2.00%. This boost in productivity indicates the success of modern farming techniques and the introduction of improved millet varieties, which have contributed to sustaining and even enhancing production levels despite a decrease in the cultivated area (Paschapur et al., 2021).

Overall, while the reduction in the acreage under millet presents challenges, improvements in productivity and output demonstrate the crop's adaptability and potential as a sustainable option (Chakrabarti & Mittal, 2023). Millets' low requirements of water and their ability to survive in less fertile soils make them particularly valuable in

promoting sustainability and food security, especially in drought-prone regions. These characteristics underscore the importance of millets in diversifying crops and enhancing resilience against climate change and water scarcity (Ceasar & Maharajan, 2022; Maitra, 2020).

6.2. Area, Production, and Productivity of Millets: State-wise

A deeper look into India's millet production in 2022-23 reveals notable state-level variations which need to be appreciated as depicted in Figure 1. Referring to Table 4, one finds Rajasthan dominantly leads in both area and production, cultivating 52.12 lakh hectares and producing 56.7 lakh tonnes, but its yield is moderate at 1088 kg per hectare. States like Uttar Pradesh and Haryana, though smaller in area, show impressive productivity with yields of 2051 kg and 2195 kg per hectare, respectively. These figures suggest effective farming practices or more favourable growing conditions in these regions. In contrast, Maharashtra, despite its large cultivation area of 18.99 lakh hectares, reports a lower yield of 933 kg per hectare, indicating potential areas for improvement in productivity.

Andhra Pradesh stands out with the highest yield of 2826 kg per hectare, signaling highly efficient cultivation practices or optimal environmental conditions. Meanwhile, Gujarat and Madhya Pradesh also demonstrate strong performance, with yields exceeding 2000 kg per hectare. In contrast, Tamil Nadu and Uttarakhand present middle-level yields of 1287 kg and 1528 kg per hectare, respectively.

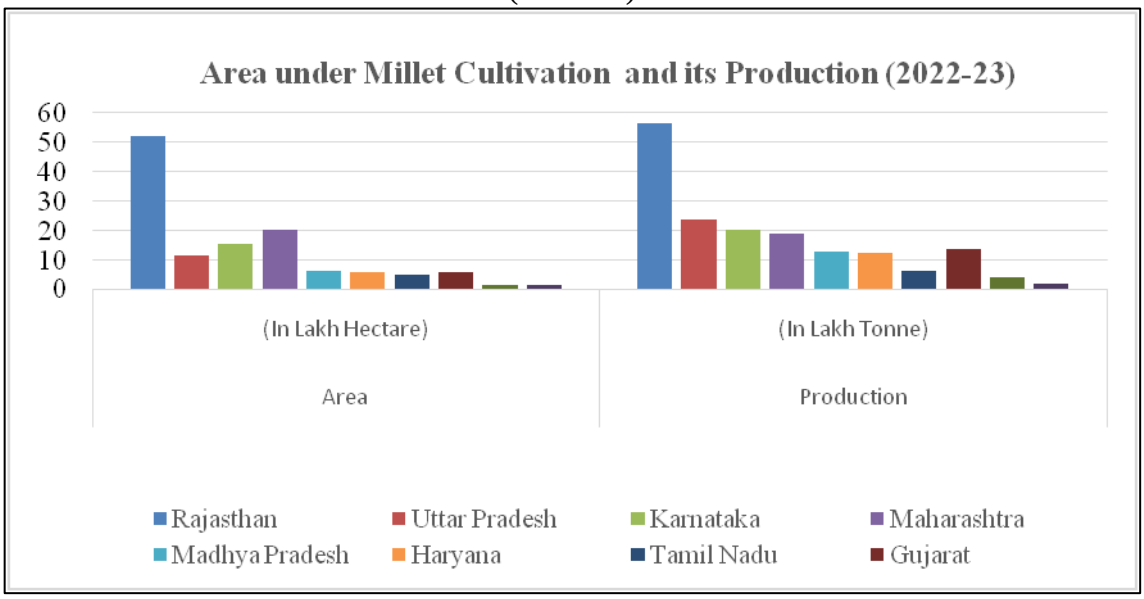
This analysis reveals both positive growth in certain states and challenges in others, reflecting varying agricultural conditions and efforts across India in millet production. While the decline in cultivation area may pose challenges, particularly in expanding millet’s role in food security, the rising productivity offers hope for sustainable growth (Chakrabarti & Mittal, 2023).

Table 4: State-wise Area, Production and Productivity of Millets in India (2022-23)

States	Area (in lakh hectare)	Production (in lakh tonnes)	Productivity (in kg/hectare)
Rajasthan	52.12	56.7	1088
Uttar Pradesh	11.55	23.69	2051
Karnataka	15.27	20.33	1331
Maharashtra	20.35	18.99	933
Madhya Pradesh	6.05	12.54	2072
Haryana	5.53	12.14	2195
Tamil Nadu	4.9	6.3	1287
Gujarat	5.52	13.64	2473
Andhra Pradesh	1.33	3.76	2826
Uttarakhand	1.15	1.61	1528
All India	**126.98**	**17.32**	**1364**

Source: APEDA Report (2023)
https://apeda.gov.in/milletportal/files/Statewise_Millet_Production.pdf

Figure 1: Graphical Presentation of State-wise Area and Production of Millets in India (2022-23)



Source: APEDA Report (2023)
https://apeda.gov.in/milletportal/files/Statewise_Millet_Production.pdf

6.3. Trend in Millet Cultivation and Production in India: State-wise

Table 5 presents data on millet production across the top ten states in India from 2019-20 to 2023-24, highlighting both growth and challenges in this sector. Rajasthan consistently

leads as the top millet producer, although its production has fluctuated, peaking at 56.74 lakh tonnes in 2022-23 before declining to 48.09 lakh tonnes in 2023-24, which may be attributed to changing weather patterns and shifts in cultivation practices (Tripathi & Vyas, 2023). Uttar Pradesh shows a steady increase in millet production over the years, rising from 21.72 lakh tonnes in 2019-20 to 26.98 lakh tonnes in 2023-24, likely due to successful agricultural strategies and better resource access (Kumar et al., 2022).

In contrast, Karnataka exhibits a gradual decline in production, decreasing from 25.56 lakh tonnes in 2019-20 to 17.49 lakh tonnes in 2023-24, possibly indicating challenges in sustaining output due to climatic conditions or a shift towards other crops (Ceasar & Maharajan, 2022). Similarly, Maharashtra shows a downward trend with production dropping from 24.29 lakh tonnes to 17.15 lakh tonnes for the same period, reflecting a possible shift in agricultural focus or external factors affecting millet cultivation (Paschapur et al., 2021).

Conversely, Madhya Pradesh stands out with a consistent increase in millet production, growing from 8.96 lakh tonnes in 2019-20 to 12.68 lakh tonnes in 2023-24, signaling successful agricultural practices and possibly the adoption of high-yielding varieties (Maitra, 2020). Haryana experienced fluctuations, peaking at 13.67 lakh tonnes in 2020-21 before stabilizing at 11.94 lakh tonnes in 2023-24, which may be due to variations in weather conditions or input use (Khari & Jain, 2023).

Other states show varying trends; Tamil Nadu witnessed a steady decline in production, falling from 10.17 lakh tonnes in 2019-20 to 6.23 lakh tonnes in 2023-24, potentially due to a shift towards other crops or environmental challenges (Li et al., 2021). Gujarat experienced a mixed trend, with a sharp increase from 9.9 lakh tonnes in 2019-20 to 13.64 lakh tonnes in 2022-23, followed by a significant drop to 4.51 lakh tonnes in 2023-24, indicating the influence of market demand and weather conditions (Khari & Jain, 2023). Andhra Pradesh faced a decline in production, decreasing from 5.14 lakh tonnes in 2019-20 to 3.9 lakh tonnes in 2023-24, which may reflect a shift in agricultural focus or challenges in productivity (Ceasar & Maharajan, 2022). Uttarakhand maintained relatively low levels of millet production, with a slight decrease from 1.91 lakh tonnes in 2019-20 to 1.61 lakh tonnes in 2023-24, likely due to its specific climatic and geographical constraints limiting large-scale cultivation (Tripathi & Vyas, 2023).

This analysis reveals a complex landscape of millet production across India, with some states showing positive growth and others facing challenges in maintaining or increasing their production levels. These variations highlight the impact of differing agricultural conditions, resource availability, and policy measures on millet cultivation across the country. Understanding these state-wise trends is crucial for formulating focused plans to augment millet production and long-term sustainability in India's agricultural sector.

Table 5: State-wise, Production of Millets in India during last five years (2019-20 to 2023-24)

State	2019-20	2020-21	2021-22	2022-23	2023-24
Rajasthan	51.47	51.56	42.8	56.74	48.09
Uttar Pradesh	21.72	22.98	22.26	23.69	26.98
Karnataka	25.56	25.69	20.54	20.33	17.49
Maharashtra	24.29	25.14	23.05	18.99	17.15
Madhya Pradesh	8.96	10.24	11.81	12.54	12.68
Haryana	10.35	13.67	11.32	12.14	11.94
Tamil Nadu	10.17	9.05	7.65	6.3	6.23
Gujarat	9.9	10.92	11.79	13.64	4.51
Andhra Pradesh	5.14	5.41	3.59	3.76	3.9
Uttarakhand	1.91	2.01	2	1.76	1.61

Source: APEDA Report (2023)
https://apeda.gov.in/milletportal/files/Statewise_Millet_Production.pdf

6.4. Panel Regression Analysis

The findings of the panel regression are summarized in Table 6, contrasting the fixed-effects and random-effects models to assess millet production across the top ten states in India. Both models utilize 50 observations across 10 groups, representing the state-level panel data.

The analysis of millet production using FE and RE models provides insights into the impact of time and area on production levels across different states. Both models are statistically significant; with the FE model showing an F-statistic of 48.43 and the RE model a Wald chi-squared of 179.31, both with p-values of 0. However, the year coefficient is not significant in either model, suggesting that changes over time do not have a substantial impact on millet production, In contrast, the area under cultivation is highly significant in both models, indicating that increasing the area significantly boosts

millet production, a result that is consistent with previous research highlighting the direct relationship between cultivated area and crop output.

Table 6: Results of Panel Regression

	Fixed-Effects (FE)	**Random-Effects (RE)**
Number of Observations	50	50
Number of Groups	10	10
F-statistic/Wald chi2	F(2,38) = 48.43	Wald chi2(1)=179.31
Prob > F / Prob > chi2	0	0
Year Coefficient	0.0446 (p = 0.780)	-0.0275 (p = 0.860)
Area Coefficient	1.1955 (p = 0.000)	1.0198 (p = 0.000)
Constant	1.3	3.7265
Sigma_u (Variance due to u_i)	5.6154477	4.1249583
Sigma_e (Error term variance)	1.4937149	1.4937149
Rho (Fraction of variance due to u_i)	0.9339	0.8841
F test that all u_i = 0	F(9, 38) = 35.29 , Prob > F = 0.0000	

Source: Author's calculation

The variance components reveal that a large portion of the variability in millet production is due to differences across states rather than random variation, as indicated by the high rho values in both models. The Hausman test result (p = 0.0914) suggests a preference for FE model, indicating state-specific characteristics may be associated with the independent variables.

Given these findings, FE model is considered more apt for this dataset, as it effectively captures the state-specific variations that influence millet production. It highlights the critical role of state-level factors, suggesting that policies and interventions aimed at enhancing millet production should consider these unique state-specific characteristics.

7. Conclusions and Policy implications

The analysis of millet production in India from 2019-20 to 2023-24 reveals important trends and regional variations that have important suggestions for food security and agricultural policy. While the overall area under millet cultivation has declined but a positive trend in production underscores the crucial role of rising productivity. The

increase in yield suggests adoption of better farming practices, use of high yielding varieties, demonstrating its resilience and potential for sustainable agriculture. Analysis of top ten states highlights some states like Uttar Pradesh, Madhya Pradesh show an increase in millet production while others such as Karnataka, Maharashtra experienced decline. These variations underline the importance of regional factors, including climatic conditions, agricultural practices, and state-specific production policies.

The regression analysis shows that the area under cultivation has a significant positive impact on millet production. This result underscores the direct relationship between the extent of cultivated land and production output, emphasizing the need for optimal utilization and potential expansion of millet cultivation areas to boost overall production. Policies should focus on enhancing the area under cultivation for millet, especially in states where production has been declining.

The comparative analysis of the FE model, preferred over the RE model underscores the significance of state-specific factors in influencing millet production suggesting that state-level policies and conditions are crucial in understanding and improving millet production.

The cultivation of millets should be encouraged to achieve the objective of sustainable agriculture as these have ability to thrive in low water and less fertile conditions, harsh climate conditions. There is a need for state-specific strategies to promote millet production that address the unique problems and opportunities associated with each state. Every state should have targeted support and incentives, and training on best agricultural practices, especially those which have witnessed a decline in production of millets.By strengthening market linkages, developing value chains, putting efforts in research and development of high yielding disease resistant varieties, millet cultivation can become economically more viable for farmers and achieve the broader sustainability goals. In conclusion, an integrated policy framework that coordinates national and state-level efforts will be crucial for tapping the full potential of millets, contributing to a secure and sustainable food system in India.

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