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RESEARCH NOTE

Analysing Regional Patterns and Factors Affecting Acreage under Major Millets in India

Pardeep Singh[1,2], Kiran Kumara T.M.[1], Kalu Naik[1], and Diksha Bali[1]

ABSTRACT

Despite having nutritional attributes and climate resilience characteristics, the cultivation of millets in India is experiencing a concerning decline. Using panel data from Indian states and employing a random-effect model, this paper investigates spatio-temporal changes in millet cultivation and explores factors influencing their area allocation. Findings revealed that although the overall area under millets has decreased, there is a rise in millet production attributed mainly to increased yields. The state-wise and crop-wise trends in area and production of millet showed that the decline in area of millet was sharper in sorghum, mainly in Maharashtra and small millets in Madhya Pradesh and Andhra Pradesh. Madhya Pradesh, Andhra Pradesh, and Gujarat exhibit the potential for increased millet production, necessitating targeted efforts. The study reveals that relative returns, particularly those from competing crops like rice and maize, influence millet area allocation. The climatic variables, particularly temperature, dry spells and pre-monsoon rainfall, significantly affect acreage allocation under sorghum and pearl millets. Price support, which helps farmers realise better returns, affects area allocation. Cost of cultivation also emerged as critical determinants affecting area allocation, therefore highlights the need for reducing cost of cultivation. Although there has been a commendable increase in MSPs, actual procurement has only recently gained momentum which need to be sustained.

Keywords: Climate Resilient Crops, Sustainable Agriculture, Crop Diversification, Arid Agriculture

JEL Code: C01, C33, O13, O11, Q54, C54

I
INTRODUCTION

The global goal of Sustainable Development Goals (SDGs), zero hunger, may not be achieved by 2030 due to multiple factors, including COVID-19 (UN, 2023; Filho et al., 2024). More than 700 million people are still facing hunger, primarily in Africa, where it is on the rise; however, conditions are also dire in Asia (FAO, 2024). Climate change is increasing the frequency of extreme weather events such as droughts, heatwaves and floods, which stress our ecosystems and have further consequences for global food and nutritional security. Obesity is also on the rise. In 2020, 14% of adults above the age of five were obese (BMI $\geq$30 kg/m^2), and by 2035, that number is expected to rise to 24% (WOF, 2023).

India, being the most populous country in the continent and the world, also suffers from the burden of malnutrition. Though the latest statistics show that the health outcome indicators, when compared with 4th National Family Health Survey, have improved, still more than one-third of children under 5 years are stunted, 19% are wasted, 32% are underweight and 3% are overweight (GoI, 2022). The number of

[1]ICAR - National Institute of Agricultural Economics and Policy Research (NIAP), Pusa, New Delhi
[2]College of Agribusiness Management, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar-385506, Gujarat, India

people with obesity and diabetes are increasing. As per a study, the number of people with diabetes in India during 1990 to 2016 has increased by 2.5 times reached to 65 million (Tandon et al., 2018).

The cropping pattern and diet centred around cereals, mainly rice and wheat, to a great extent, are responsible not only for widespread issues malnutrition but also degradation of natural resources such as water, soil and biodiversity (Choudhary at al., 2018). Therefore, the agricultural production system needs a paradigm shift for its long-term sustainability and the cropping patterns need to be more diversified.

Reviving millets in the cropping pattern can foster ecological balance, reduce environmental impact, and support the long-term health of agricultural ecosystems. Millets can adapt and thrive under challenging growing conditions, including low rainfall, high temperatures, and poor soil fertility due to multiple reasons, including short growing cycle of 70-90 days (Sharma and Gupta, 2021; Ravi et al., 2022). Millets require less water for cultivation, making them suitable for regions experiencing water scarcity. For instance, pearl millet requires around 350-500 mm of water during the growing season compared to 1,200-1,500 mm of paddy (FAO, 2023). By reducing the reliance on synthetic fertilizers and pesticides, the cultivation of millets can contribute to promoting sustainable agriculture practices (Satyavathi et al., 2021). The cultivation of different millet species and varieties helps preserve traditional knowledge, local seed systems, and genetic resources, which in turn enhance the resilience of agricultural ecosystems and reduce the risk of crop failures due to pests, diseases, and climate variability (Nelson et al., 2019). Furthermore, millets are versatile, with applications ranging from traditional foods to modern snacks, increasing their market value and consumer demand.

Despite their nutritional benefits and climate-resilient characteristics, the consumption of millets has been on a declining trend globally, except in Africa. Globally, millets are cultivated in over 90 countries, with significant production in Asia and Africa. According to the latest data from the US Department of Agriculture (2023), global millet production in 2023-24 was 29.62 million tonnes (mt), reflecting an 8% decrease from the previous year. However, between 2014 and 2023, production increased by 0.70% (USDA, 2023).

India leads global millet production, contributing 41% of the global output with 12.2 million tons (MT) in 2023-24, followed by Niger (11%), China (9%), Mali (7%), and Nigeria (5%). While the per capita consumption of millets in Africa has increased from 11 kg/year in 1982 to around 14 kg/year in 2009 (Rao and Basavaraj, 2015), in India it has declined drastically from 32.9 kg to less than 5 kg from 1962 to 2011-12. Consumption of millets has almost halved just within the period of less than a decade, 2004/05 to 2011/12. The area under millets has also declined dramatically from around 37 million hectare (m ha) in 1966/67 to 13.63 m ha in 2020-21. Small millets saw the sharpest decline and are grown only in one-tenth of the area covered in 1966. Sorghum also recorded a sharp decline from 18 m ha to 4.38 m ha during the corresponding period. There are a number of factors that might have affected the acreage under these crops. Keeping the decline in view, this study attempted to understand the spatio-temporal patterns in area, production and yield, to explore the factors affecting area under millets.

II

MATERIALS AND METHODS

2.1 Data

The study used panel data, with an equal number of observations in each state from 1990-91 to 2020-21. The states selected for sorghum crop were Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Tamil Nadu on the basis of maximum area proportion, while Gujarat, Haryana, Maharashtra, Rajasthan, and Uttar Pradesh selected for pearl millet. Total 1260 and 1050 data points were used for sorghum and pearl millet, respectively. The data were collected from secondary sources, mainly the Directorate of Economics and Statistics, and National Statistical Office. The returns from various crops were estimated indirectly by dividing value of output by area under the crop. The prices (FHP and MSP) were taken in real terms arrived by deflating current prices by the wholesale price index at the base year 2011-12.

2.2 Econometric Tool

We used a panel data technique and built a random effect model (REM) to investigate the linkages between the area under cultivation of the main crop and selected parameters that may affect the millet acreage. The REM assumes that the individual-specific coefficient β_{1i} is fixed for each time-in-variant, and it is a random variable with a mean value of β_1. Dummy variables are used to designate a particular state's impacts on millet crops. It allows for heterogeneity among states as each state is allowed to have its intercept value due to varying agro-climatic conditions for growing millets (Svanidze and Götz, 2019). The functional form of the random effect model for panel data can be written as:

$$y_{it} = \beta_0 + \sum_{i=1}^{n} \beta_i \sum x_{it-1} + \sum_{i=1}^{n} \beta_i \sum D_{it} + \epsilon_{it}$$

Where,

y_{it} is the area allocated by ith state under a millet crop in tth year; x_{it-1} is a set of explanatory variables at lag, D_{it} = 1 for the state heterogeneity effect during the period 1990-91 to 2020-21; otherwise, it is 0, β_i is the coefficient of an estimable model, β_0 is an intercept; n is number of cross-sectional units (states in this case), and ϵ_{it} is an error term in the estimable model. Separate models were run for pearl millet and sorghum.

2.2.1 Explanatory Variables

The area allocation of millet crops by farmers can depend on various factors (Shinoj et al., 2014). Some of the key factors influencing the decision to allocate land for millet cultivation include prices, returns from the crop and the competing crops, cost of cultivation and risk involved. The explanatory variable considered for the model with a-priory hypothesis are discussed below.

Return from main crop (Rs./ha): Return is the biggest factor influencing allocation of area under different crops. When farmers allocate the area under crops, they keep in mind previous year's returns from the crops (Kahan, 2008). Therefore, the change in return from a crop in the previous year was taken as an explanatory variable. In other words, area allocation for a crop in the year, ‘t’, depends on relative changes in returns from the crop in previous year (t-1) compared to ‘t-2’. It was assumed that positive and higher differences in returns compared to the previous year motivated farmers to allocate more area under the crop.

Return from the competing cereal crop (Rs./ha): Millets are mainly grown in rainy season, except in few pockets of Karnataka, Gujarat and Tamil Nadu where pearl millet is also grown in the rabi season. Paddy and maize are two major competing crops to millets in the same season (Andrews and Bramel-Cox, 1993; Soler et al., 2008). The difference in returns from the crop (RMC_{t-1}) compared to the competing crops (RCC_{t-1}) was considered to be negatively associated with the area allocation under millets.

Return from the pulses crop (Rs./ha): Pulses, namely black gram and pigeon pea were considered as complementary crops. The consideration of pulses as a complementary crop to millet was on two grounds: first, that these crops fix nitrogen, helping improve the productivity of the millets, and second, that millets and pulses grown in a mixed cropping pattern enhances income of the farmers (Ram and Meena, 2014; Chapke et al., 2018). Traditionally, these crops were grown as mixed crops. Millets are low fertilizer-consuming crops, therefore, the differences in returns from pulses (RPC_{t-1}) compared to the main crop (RMC_{t-1}) was computed and used as an explanatory variable. Area allocation under millet was assumed to be affected positively by a higher value.

Return from the oilseeds crop (Rs./ha): Groundnut, sesame and soybean crop are major oilseed crops grown in the kharif season and compete with millets. As in the case of competing cereal crops, it was assumed that returns from competing oilseed will adversely affect the area allocation under the millet crop (Sairam et al., 2023). The profitability of oilseeds such as groundnut and soybean can attract farmers, especially in rainfed regions where both millets and oilseeds are viable options.

Return from the other millet crops (Rs./ha): Millet crops that are grown in the kharif season also compete with the other millet crops grown in the same season. Farmers are profit-oriented and allocate the area under high-return millet crops. Therefore, we assumed that millets grown in the same season will compete with each other. It was assumed that the increase in return from a millet crop would adversely affect the area under other millet crops.

Cost of cultivation of main crop (Rs./ha): The cost of cultivation of the crop is an important determinant for allocating area under it. By considering the cost of cultivation, farmers can evaluate the profitability and viability of cultivating a particular crop. They can compare the cost of cultivation with the expected returns from the crop to make informed decisions regarding the allocation of land area and resource allocation for different crops (Sreedhar et al., 2021). The cost of cultivation was assumed to have an inverse relation with area allocation under the crop.

Price support: Price support by the Government, such as minimum support price (MSP) plays a crucial role in encouraging farmers to allocate more land for a particular crop. This creates a favorable economic environment for farmers and incentivizes them to increase their production of the supported crop. As a result, farmers are more likely to allocate a larger area of their land to cultivate the crop, as they can expect better returns and reduced financial risks (Sreedhar et al., 2021). This variable was captured as ratios of lagged farm gate harvest prices (FHP) to MSP. A higher ratio implies that farmers are getting more than MSP, which will encourage them to allocate more area under the crop.

Percent of irrigated land: Increased irrigation water availability encourages farmers to produce more profitable crops like rice, maize, sugarcane, and fruits, which have better market value and production potential compared to millet crops (Birthal and Hazrana, 2019). When the irrigated area grows, the area under drought-resistant crops like sorghum and millet decreases.

Rainfall during sowing time: In the semi-arid region, rainfall during crop cultivation time has a favourable impact on the area expansion and cultivation of sorghum and pearl millet by providing required soil moisture for germination and early growth of the crop (Marteau et al., 2011). The farmers in rainfed regions increasingly favor millets and pulses over paddy, maize and oilseeds when faced with uncertain rainfall, as these crops provide stable yields and returns under water-limited conditions, thus ensuring better food security and income stability (Ram and Meena, 2014). Therefore, rainfall from June 1st to 15th June, 16th to 30th June, and 1st to 15th July was considered to ascertain whether area allocation under these crops increases in the event of delayed monsoon or not.

Rainfall during growing period: When rainfall exceeds average levels, farmers are compelled to shift their emphasis to higher-value crops such as oilseeds in the next year, which are more profitable in favorable rainfall conditions (Maracchi et al., 1993). In above-average rainfall years, farmers often choose for oilseed crops over sorghum and millet crops due to higher profits. Therefore, the rainfall during the previous growing season of these crops (June to October) was taken as an explanatory variable.

Average temperature: Sorghum and pearl millet are recognized for their heat tolerance, and rising temperatures may raise their relative competitiveness compared to less heat-tolerant crops. These crops are well-adapted to high-temperature conditions, making them more tolerant to climate change. As temperatures rise, farmers in semi-arid regions may come to rely more on these resistant crops for food security and stable income (Soler et al., 2008). Therefore, temperature during the previous year was also included in the model.

Dry-spells during the growing season: Another climatic variable included in the model was continuous dry spells of two weeks. This variable was included to empirically establish whether millets are used as an adaptation option when there is a continuous dry-spell.

While panel data offers numerous advantages in terms of efficiency, increased variation, and control for unobserved heterogeneity, the power of such estimators depends critically on the compatibility of the assumptions of statistical tools with the data-generating process (Hsiao, 2007). Hence, to test the suitability of the model and ensure the robustness of the results, different tests, namely slope homogeneity test, cross-sectional dependency tests, second-generation unit root test to find the stationarity in the data, panel co-integration, and Hausman test, were performed on the data. The Hausman test was found non-significant indicating that random effect model shall be selected for the present study.

Slope homogeneity test: The slope homogeneity test finds whether the slope coefficients of the cointegration equation are homogeneous or not (Swamy, 1970). The test was further improved by Pesaran and Yamagata (2008) who proposed two delta test statistics $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ (Pesaran and Yamagata, 2008).

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{\sqrt{2k}}\right) \sim X_k^2$$

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{v(T,k)}\right) \sim N(0,1)$$

Where N represents the number of cross-section units, S denotes the Swamy test statistic, and k denotes independent variables. $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ are suitable for large and small samples, respectively, where $\tilde{\Delta}_{adj}$ is the "mean-variance bias adjusted" version $\tilde{\Delta}$. Therefore, the standard delta test $\tilde{\Delta}$ requires error should be free from the problem of autocorrelation. By relaxing the assumptions of homoscedasticity and serial independence, Pesaran and Yamagata (2008) and Blomquist and Westerlund (2013), developed a Heteroscedasticity and Autocorrelation Consistent (HAC) robust version of slope homogeneity test (Pesaran and Yamagata, 2008; Blomquist and Westerlund, 2013); Δ_{HAC} and $(\Delta_{HAC})_{adj}$

$$\Delta_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC} - k_2}{\sqrt{2k_2}}\right)$$

$$(\Delta_{HAC})_{adj} = \sqrt{N}\left(\frac{N^{-1}\bar{S}_{HAC} - k_2}{v(T,k)}\right) \sim N(0,1)$$

The slope homogeneity test was performed and indicated that the slope coefficients are not heterogeneous meaning that homogeneity exists across sample states.

Cross-sectional dependence tests: The cross-sectional dependency (CD) tests were estimated to examine the presence of cross-sectional dependence in residuals (Chudik and Pesaran, 2015; Bailey et al., 2019). Below equation represents the cross-sectional dependence in the variables:

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum_{J=i+1}^{N} \rho_{ij}$$

Where, N represents the number of cross-section units, T represents the years, ρ denotes correlation among the residuals. The tests results found to be statistically significant and supporting the assumption of cross-sectional dependence in the residuals of the estimable model.

Second-generation unit root test: As the CD test performed above proved the cross-sectional dependence in panel, we performed the further test, i.e. second-generation unit root test or the presence of stationarity in the data set. To test for stationarity in the data, the study has used Pesaran Panel Unit Root tests, as the first generation of unit root tests do not account for cross-sectional dependence in testing for stationarity (Levin et al., 2002; Pesaran, 2007). The results of unit root test confirm that the data was stationary.

III

RESULTS AND DISCUSSION

3.1 Global Scenario of Millets

Over the past six decades, the global landscape of millet production has undergone significant transformations. Initially, Asia and Africa stood as the primary producers of millets worldwide. However, the introduction of Green Revolution technologies and the promotion of high-yielding cereal crops such as rice and wheat led to a decline in millet cultivation in various regions. Farmers shifted their focus towards crops that offered higher yields and were more convenient to process. Consequently, the millet-growing areas experienced a steady decline over the last 60 years. Between 1961 and 2021, the global area under millet cultivation decreased from 89.41 million hectares to 71.86 million hectares, marking a reduction of approximately 20% (Table 1 and Figure 1). The decline was predominantly observed in Asia, particularly in India and China. Within Asia, the area under millet cultivation decreased by 37.28 million hectares, with India accounting for 22.9 million hectares and China for 12.67 million hectares. Conversely, in Africa, the area allocated to millet cultivation increased from 24.64 million hectares to 46.73 million hectares during the same period. Consequently, the relative share of millet cultivation shifted from Asia to Africa. In 1961, Asia accounted for 61% of the world's total millet-growing area, with India contributing 41.28% and China contributing 16%. However, by 2021, Africa claimed 65% of the total global millet-growing area.

TABLE 1. AREA, PRODUCTION AND YIELD OF MILLETS IN INDIA AND THE WORLD

Particulars	1961	1971	1981	1991	2001	2011	2021
Area (Million ha)							
Africa	27.56	30.65	30.02	45.54	53.85	61.53	65.03
Asia	61.00	54.45	52.76	40.38	34.02	28.31	24.03
China	15.88	13.04	7.81	4.38	2.46	1.64	2.13
India	41.28	37.86	41.78	33.37	28.34	23.71	19.49
Rest of the world	11.43	14.9	17.22	14.07	12.14	10.16	10.94
World	89.41	93.64	83.25	79.73	78.62	76.18	71.86
Production (Million t)							
Africa	25.93	21.25	21.61	33.47	38.48	40.81	41.97
Asia	47.32	41.27	36.59	32.59	28.89	30.41	28.09
China	27.07	20.2	12.4	10.52	5.28	4.32	6.24
India	23.64	18.46	22.25	20.14	21.19	23.45	19.7
Rest of the world	26.75	37.48	41.8	33.94	32.63	28.78	29.94
World	66.65	91.64	100.24	80.59	88.69	83.86	91.45
Yield (t/ha)							
Africa	0.70	0.68	0.87	0.74	0.81	0.73	0.82
Asia	0.58	0.74	0.84	0.82	0.96	1.18	1.49
China	0.95	1.52	1.91	2.43	2.42	2.90	3.72
India	0.43	0.48	0.64	0.61	0.84	1.09	1.29
Rest of the world	1.74	2.46	2.92	2.44	3.03	3.12	3.48
World	0.75	0.98	1.20	1.01	1.13	1.10	1.27

Source: Authors estimation from FAOSTAT, 2023

Despite a decline in the global millet-growing area, the total production of millets has actually seen a significant increase of 25 million tonnes, reaching a record high of 91.45 million tonnes in 2021 (Table 1 and Figure 1). This remarkable growth can be primarily attributed to the substantial increase in millet production in African countries, where it has more than doubled from 26 million tonnes to an impressive 42 million tonnes. Additionally, India has experienced a noteworthy 14% increase, with millet production reaching 20 million tonnes in 2021. The surge in millet production can be largely credited to advancements in agricultural technology and subsequent improvements in millet productivity. These technological innovations have empowered farmers to maximize their yields even with reduced cultivation areas. The positive trend is not limited to specific regions; it is being observed worldwide. Over the past six decades, the global yield of millets has witnessed a remarkable growth of over 70%, underscoring the substantial advancements in millet cultivation technologies and practices.

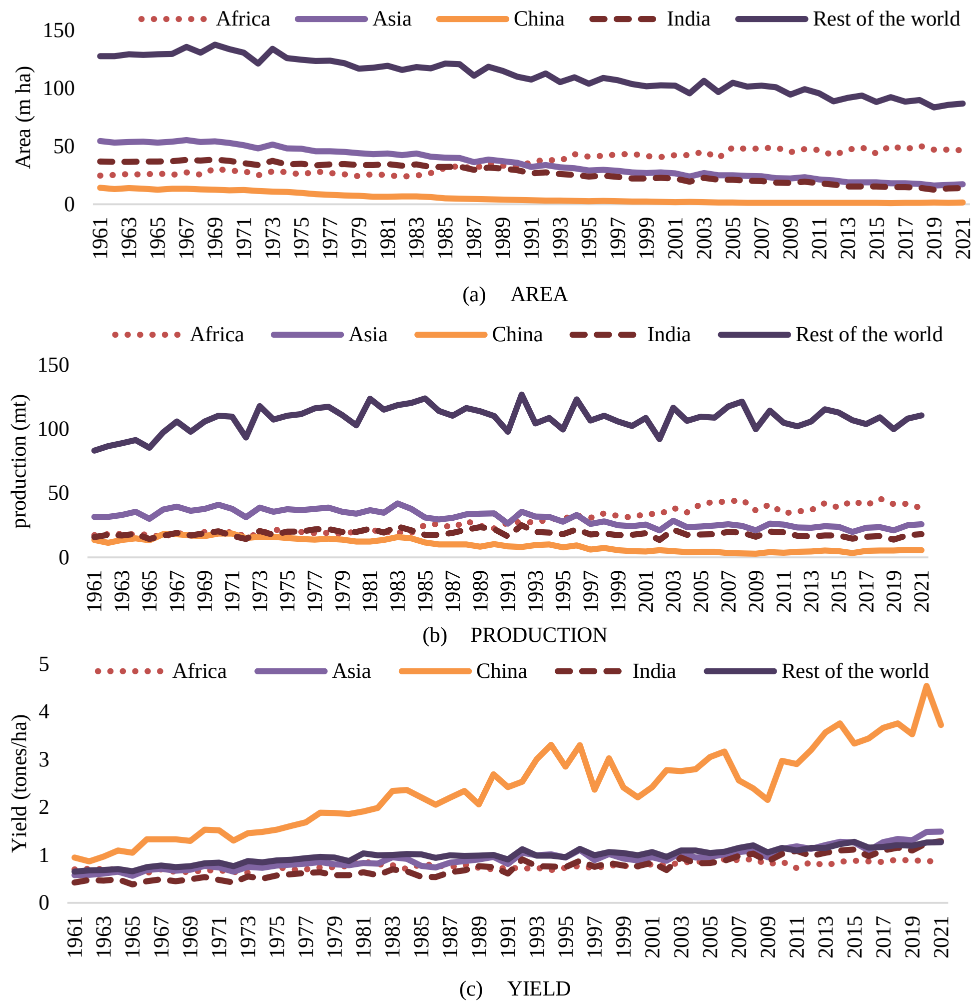


FIGURE 1. AREA, PRODUCTION AND YIELD TREND OF MILLETS IN INDIA AND THE WORLD

However, it is important to acknowledge that there are still significant gaps in millet yields, particularly when comparing different regions. Notably, the yield of millets in India and Africa lags behind, with yield levels only reaching one-third and one-fourth respectively, when compared to China. In India, particularly, the increase in millet productivity has been remarkable. The yield has tripled, rising from 0.43 tonnes per hectare in 1961 to an impressive 1.3 tonnes per hectare (Table 1 and Figure 1). This substantial improvement in yield demonstrates the successful implementation of advanced agricultural technologies, such as improved seeds, efficient irrigation methods, better crop management practices, and enhanced knowledge transfer to farmers.

3.2 Growth in Area, Yield and Prices of Millet vis-à-vis Other Cereal Crops

Table 2 presents a comparison of the growth in area, yield, and prices of millets in contrast to other cereals over the last four decades. The findings reveal some critical trends and challenges that deserve attention. Firstly, millets have experienced a concerning negative growth rate of 2.27% per annum in terms of cultivation area. In contrast, other cereals, notably maize and wheat, have seen significant area increases, with maize exhibiting the highest growth at 1.56% per annum, followed by wheat at 0.85% per annum. The decline in the area under small millet cultivation has been particularly alarming, exceeding 3.23% per annum. This sharp decline, especially in the last decade, demands immediate attention and concern. On the issue of prices, millets have seen a much faster increase (7%/annum) compared to rice, wheat, and maize. While the rise in millet prices is an encouraging sign given the reviving demand, it remains insufficient to bridge the economic gap with competing cereals. Encouragingly, the increase in millet yield has been relatively comparable to major cereals, ranging from 1.5% to 1.8% per annum, except for maize, which boasts a higher growth rate of 2.5% per annum (Table 2). However, the growth in millet yield has been more inconsistent than that of major cereals, with varying decadal growth rates. This inconsistency is attributed to the fact that millets are predominantly rainfed crops, with only a small fraction of the area under sorghum, finger millet, and pearl millet being under irrigation (11% and 15%, respectively), compared to 96% for wheat and 65% for paddy.

The state-wise and crop-wise trends in area and production of millet showed that the decline in area under millet was sharper in sorghum and small millets compared to pearl millet and finger millet (Table 3). The area under sorghum has declined by 73.3% to 4.82 m ha in 2019/20 from 18.05 m ha in 1966/67 of which 29% is in Maharashtra alone (Table 3). Similarly, area under small millets lost by 90% since 1966/67 of which 55% is from Madhya Pradesh and Andhra Pradesh declining at the rate of -3.90% and -8.05%, respectively. Similar is the trend in production. The production of sorghum has come down to 4.77 mt in 2019/20 from 9.22 mt in 1966/67 and that of small millets by 75% from 1.49 mt in 1966/67. The production of pearl millet has increase by 131%, mainly due to genetic improvement during last few decades (Yadav and Rai 2013; Yadav et al., 2021).

TABLE 2. GROWTH RATES OF AREA, YIELD AND PRICES OF FOODGRAINS AND MILLETS IN INDIA

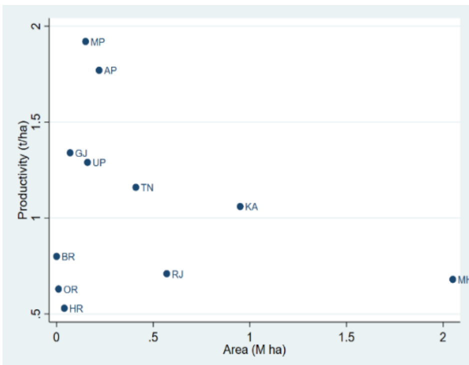
Particulars		1981-1990	1991-2000	2001-2010	2011-2020	1981-2020
Rice	Area	0.47	0.58**	-0.13	0.17	0.29**
	Price	-0.81	1.14*	2.13	3.53**	0.73**
	Yield	3.19**	1.39**	1.62*	1.68**	1.70**
Wheat	Area	0.45	1.72**	0.93**	0.29	0.85**
	Price	-1.89**	1.19	2.99**	3.18**	0.94**
	Yield	3.09**	1.75**	0.68	1.54*	1.62**
Maize	Area	-0.29	0.99*	2.94**	1.05**	1.56**
	Price	-1.39	0.12	1.13	4.14**	0.55**
	Yield	2.07	2.23**	2.10	2.36**	2.49**
Small	Area	-3.44**	-2.13**	-3.66**	-4.06**	-3.23**
Millet	Price	2.00*	8.44**	5.79**	10.39**	6.63**
	Yield	1.37	1.46*	2.02	1.12	1.50**
Millet	Area	-1.25**	-2.66**	-1.78*	-3.23**	-2.27**
	Price	4.42**	8.51**	8.28**	5.56**	7.03**
	Yield	1.24	1.27	2.17	1.23	1.79**

*** and * indicate the level of significance at 0.01 & 0.05, respectively; Prices are the real prices at the base year 2011-12*

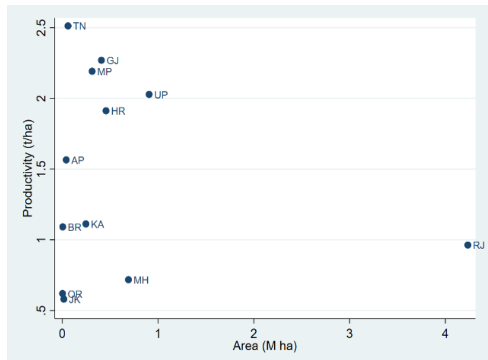
When plotted the major millet area occupying states based on the yield (Figure 2), a very interesting pattern was observed. It is evident that the yield in most of these states falls below the national average millet yield, with the exception of finger millet, which demonstrated a slightly higher yield in Karnataka than the national average. However, there is a tremendous opportunity to enhance production by focusing on increasing the cultivation area in states that have proven to be high-yield regions. Notably, states like Madhya Pradesh and Andhra Pradesh showcased impressive yields of sorghum, exceeding 1.5 tonnes (Figure 2). In fact, traditionally sorghum has been one of the major crops in these states occupying area of 2.54 m ha in Andhra Pradesh and 2.29 m ha in Madhya Pradesh (Table 3). Gujarat is another state with relatively high yield potential in sorghum with area declining at very fast rate of more than 6% perannum. The state also has high yield potential in pearl millet and small millets. Likewise, Tamil Nadu holds significant potential for increasing millet production, given its substantially higher yields in finger millet (>3t/ha), pearl millet (2.5t/ha), and small millets (1.4t/ha). This gives opportunity; (1) for other regions to learn from their practices and emulate their strategies to boost production, and (2) increasing area under these high potential regions.

3.3 Competitiveness of Millets

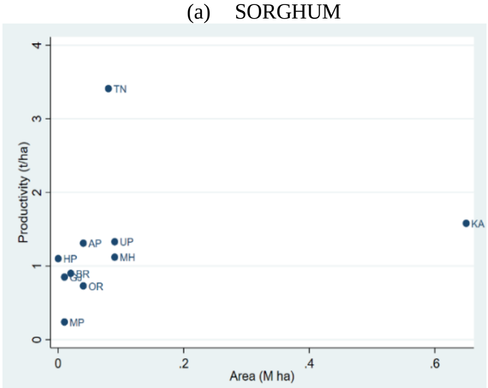
The cultivation of millets is often associated with low profitability discouraging farmers from growing them. To assess the competitiveness of millets in comparison to alternative crops, the per-hectare profitability was examined. The profitability analysis using plot-level data collected under the Cost of Cultivation Scheme of the Commission for Agricultural Costs and Prices (CACP). The data spanned the triennium ending in 2021-22 (https://eands.dacnet.nic.in/Cost_of_Cultivation.htm). The analysis revealed significant variations in economic margins among different crops, with millets



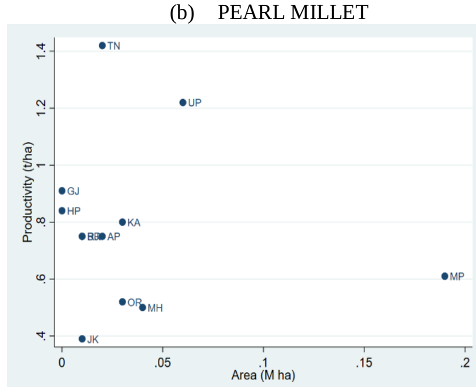
(a) SORGHUM



(b) PEARL MILLET



(c) FINGER MILLET



(d) SMALL MILLET

FIGURE 2. AREA AND YIELD OF MILLETS IN MAJOR PRODUCING STATES OF INDIA (TE 2020-21)

generally exhibiting lower returns compared to competing crops. The specific findings are summarized in Table 4. Across different states and crops, the returns from millets varied considerably. For instance, sorghum in Telangana generated less than a thousand rupees per hectare, while pearl millet in Gujarat yielded approximately 41.5 thousand rupees per hectare. Among the different millet varieties, finger millet showed lower net economic margins, while pearl millet demonstrated relatively higher margins. Finger millet generated only marginal returns (<Rs. 7 thousand/ha) in most states, except for Karnataka and Uttarakhand, which accounted for 75% of the total area and production of finger millet in the country. These differences may be largely attributable to differences in yield as one can observe from Figure 2. Prices, mainly of by-products, also makes significant differences in the returns. While the fodder prices are higher in Rajasthan and Gujarat, these are considerably low in the states like Haryana and Rajasthan due to fodder demand-supply mismatch in the two former states (Chand et al., 2015).

TABLE 3. STATE-WISE CHANGES IN AREA UNDER MILLETS IN INDIA

States	Pearl millet						Sorghum					
	Area (m ha)			Production (mt)			Area (m ha)			Production (mt)		
	1966/67	2019/20	CAGR	1966/67	2019/20	CAGR	1966/67	2019/20	CAGR	1966/67	2019/20	CAGR
Andhra Pradesh	0.66	0.03	-5.95	0.37	0.07	-3.73	2.54	0.24	-5.96	1.55	0.51	-3.43
Gujarat	1.58	0.44	-2.48	0.76	0.91	-0.30	1.29	0.05	-6.16	0.32	0.07	-3.22
Haryana	0.89	0.49	-1.49	0.37	1.02	1.80	0.27	0.03	-2.77	0.05	0.02	-0.96
Karnataka	0.41	0.32	-1.67	0.11	0.37	0.46	2.72	0.83	-2.73	1.43	0.99	-1.60
Madhya Pradesh@	0.25	0.30	0.01	0.19	0.66	2.83	2.29	0.11	-5.12	1.38	0.17	-3.27
Maharashtra	1.73	0.67	-1.59	0.40	0.51	0.71	6.13	2.29	-2.44	3.21	1.81	-1.35
Rajasthan	5.01	4.29	-0.10	1.23	4.69	3.29	1.13	0.64	-1.26	0.35	0.46	-0.07
Tamil Nadu	0.47	0.07	-4.92	0.34	0.19	-2.66	0.74	0.45	-2.41	0.56	0.52	-1.92
Uttar Pradesh*	1.01	0.92	-0.32	0.52	1.94	2.39	0.90	0.17	-3.45	0.36	0.23	-1.97
All India	*12.24*	*7.54*	*-0.98*	*4.47*	*10.36*	*1.47*	*18.05*	*4.82*	*-2.52*	*9.22*	*4.77*	*-1.44*
States	Finger millet						Small millets					
	Area (m ha)			Production (mt)			Area (m ha)			Production (mt)		
	1966/67	2019/20	CAGR	1966/67	2019/20	CAGR	1966/67	2019/20	CAGR	1966/67	2019/20	CAGR
Andhra Pradesh	0.34	0.04	-4.82	0.26	0.05	-4.30	0.92	0.02	-8.05	0.25	0.02	-6.28
Bihar$	0.17	0.02	-5.02	0.08	0.01	-3.98	0.20	0.00	-7.86	0.08	0.00	-6.62
Gujarat	0.06	0.01	-3.05	0.03	0.01	-2.53	0.13	0.00	-5.61	0.06	0.00	-5.01
Karnataka	0.85	0.64	-0.83	0.53	1.16	0.77	0.36	0.05	-6.46	0.09	0.04	-5.26
Madhya Pradesh	0.02	0.01	-2.16	0.00	0.00	-2.06	1.53	0.15	-3.93	0.19	0.09	-2.63
Maharashtra	0.22	0.08	-1.75	0.15	0.09	-1.07	0.21	0.04	-2.90	0.07	0.02	-2.54
Orissa	0.13	0.04	-3.42	0.11	0.03	-3.96	0.10	0.03	-5.22	0.05	0.02	-5.03
Tamil Nadu	0.30	0.08	-2.97	0.34	0.27	-1.19	0.48	0.03	-6.48	0.37	0.04	-5.47
Uttar Pradesh*	0.16	0.08	-1.35	0.11	0.12	-0.22	0.53	0.06	-4.57	0.29	0.08	-2.86
All India	*1.98*	*1.00*	*-1.84*	*1.63*	*1.76*	*-0.49*	*4.58*	*0.46*	*-4.61*	*1.49*	*0.37*	*-3.57*

Note: @Including Chhattisgarh; *Including Uttarakhand; $Including Jharkhand; *Source:* Based on data from Directorate of Economics and Statistics, Government of India.

TABLE 4. STATE-WISE NET RETURN FROM MILLET AND DIFFERENCE IN NET PROFIT FROM ALTERNATIVE CROPS (RS/HA OVER COST A2) (TE 2021-22)

Millet	State	Net Returns (Rs./ha)	Competing cereal crops	Competing crops other than cereals
Sorghum	Andhra Pradesh	6217	Paddy (44036) & maize (40266),	Black gram (19905), cotton (14497), pigeon pea (14393) & groundnut (5795)
Pearl millet	Gujarat	41509	Paddy (-819) & maize (-34530)	Cotton (125), groundnut (-974), sesame (-2928) & pigeon pea (-25905)
Pearl millet	Haryana	19346	Paddy (73868)	Cotton (25154)
Ragi	Karnataka	18031	Paddy (24910), sorghum (1747) & maize (358)	Cotton (21011), pigeon pea (1694), soybean (-4656), groundnut (-8396), black gram (-13273) & sesame (-22876)
Sorghum	Karnataka	19778	Paddy (23163), maize (-1389) & ragi (-1747)	Cotton (19263), pigeon pea (-53), soybean (-6403), groundnut (-10143), black gram (-15020) & sesame (-24623)
Sorghum	Madhya Pradesh	18030	Paddy (7429) & maize (-486)	Sesame (-345), pigeon pea (-546), soybean (-10530) & black gram (-13848)
Pearl millet	Maharashtra	20219	Maize (17435), sorghum (234), ragi (-18998) & paddy (-32263)	Pigeon pea (22011), cotton (1959), soybean (-7587) & black gram (-15829)
Ragi	Maharashtra	1221	Maize (36433), sorghum (19233), pearl millet (18998) & paddy (-13265)	Pigeon pea (41010), cotton (20958), soybean (11412) & black gram (3169)
Sorghum	Maharashtra	20454	Maize (17201), pearl millet (-234), ragi (-19233) & paddy (-32498)	Pigeon pea (21777), cotton (1725), soybean (-7821) & black gram (-16063)
Ragi	Odisha	2444	Paddy (25931) & maize (19459)	Black gram (11548), cotton (25924), groundnut (19843), pigeon pea (15779) & sesame (6855)
Pearl millet	Rajasthan	19696	-	Groundnut (29495), black gram (-10155), green gram (-6162), sesame (-6931) & soybean (-1389)
Sorghum	Rajasthan	12948	Pearl millet (6748)	Groundnut (36243), soybean (5359), green gram (586), sesame (-183) & black gram (-3406)
Ragi	Tamil Nadu	6684	Maize (32035), paddy (26799) & sorghum (12528)	Sesame (24861), groundnut (14248) & pigeon pea (2259)
Sorghum	Tamil Nadu	19212	Maize (19507), paddy (14271) & ragi (-12528)	Sesame (12333), groundnut (1720) & pigeon pea (-10269)
Sorghum	Telangana	864	Paddy (44632) & maize (41600)	Groundnut (30207), soybean (27499), cotton (22178), pigeon pea (3031) & sesame (9118)
Pearl millet	Uttar Pradesh	22558	Paddy (1294) & maize (-2306)	Pigeon pea (11161), sesame (-9970) & black gram (-17182)
Ragi	Uttarakhand	24567	Paddy (8860)	

Note: Figures in the parentheses indicate differences in net returns from alternative crops; '+'means returns from the crop are higher by the amount indicated in the parenthesis and vice a versa.

Source: Authors estimation based on data from plot-level data of Commission for Agricultural Costs and Prices, Government of India.

The differences in the returns are clearly reflected in the area allocation under those crops, although paddy typically serves as the primary competing cereal crop against millets, there are exceptions in the western dry states of Gujarat, Maharashtra, and Rajasthan. In Gujarat and Rajasthan, millets, particularly pearl millet, prove to be more profitable than paddy. Similarly, in Maharashtra, both sorghum and pearl millet demonstrate higher economic margins compared to paddy. In Tamil Nadu, maize outperforms other millets in terms of returns. On a comparative basis, paddy is more profitable than millets by approximately Rs. 1200/ha in Uttar Pradesh and as much as Rs. 73,868/ha in Haryana.

It is worth noting that the returns from millets are generally lower than those from major pulses, oilseeds, and commercial crops grown in the states. For example, sorghum and pearl millet in Rajasthan yield lower returns by 36 thousand and 30 thousand/ha respectively, compared to groundnut. Similarly, the profitability from cotton in Karnataka is more than double the profitability from sorghum and finger millet. In Maharashtra, net returns from pigeon pea are twice as high as those from pearl millet and finger millet.

3.4 Determinants of Area Allocation under Millets

The area allocation under millet cultivation is primarily influenced by relative rather than absolute returns. The changes in area allocation for millets are responsive to changes in returns from competing crops like rice or maize. For instance, a one per cent increase in returns from the competing crops corresponds with decrease in the area under sorghum in the country by 3.58% (Table 5). Similarly, a one per cent increase in returns from oilseeds corresponds to 0.56% and 1.26% decrease in the area under sorghum and pearl millet, respectively. A direct relationship was observed between an increase in returns from pulses and the area under millets. Similar was the case within different millets. This phenomenon may be attributed to the fact that both millet and pulse crops can escape stresses, particularly the delayed monsoon and dry-spells, and don’t compete with each other.

Despite being less input-intensive, the cost of cultivation emerges as a crucial factor influencing area allocation under millets. A one percent increase in cost of cultivation discourages farmers, leading to a substantial decrease of 8.76% of area under sorghum and a 2.77% reduction in area under pearl millet cultivation. Thus, there is a pressing need to minimize cultivation costs for millets (Sreedhar et al., 2021).

Findings further revealed that prices impact the area allocation under millets significantly. Here we take the ratio of farm gate prices to minimum support prices and found that with a per cent increase in the ratio, there is likelihood to 3.46 % increase in area under sorghum and a 7.73% increase in area under pearl millet, indicating that favorable market prices encourage farmers to allocate more land to these crops. The yield also plays a pivotal role in determining the area coverage under millets. This underscores the importance of technological advancements, particularly high-yielding varieties, in influencing cultivation decisions, recognizing the potential cost implications of input-led increases. The importance of both price signals and yield improvements in shaping farmers' decisions, aligning with previous studies that highlight the positive impact of improved crop varieties and favorable prices on area expansion under crops (Padulosi et al., 2009).

TABLE 5. DETERMINANTS OF AREA UNDER MILLETS CROP USING PANEL CORRECTED ROBUST STANDARD ERROR MODEL

Crop Acreage	Sorghum	Pearl millet
ΔReturn from the main crop$_{(t-1)}$	0.0045**	0.0064**
	(0.0017)	(0.0026)
ΔReturn from the competing foodgrains crop$_{(t-1)}$	-0.0358**	-0.0036
	(0.0142)	(0.0121)
ΔReturn from the supplementary pulses crop$_{(t-1)}$	0.0079**	0.0098*
	(0.0028)	(0.0057)
ΔReturns from the complementary oilseeds$_{(t-1)}$	-0.0056*	-0.0126*
	(0.0034)	(0.0077)
ΔReturn from the other millet crop$_{(t-1)}$	0.0076	0.0019**
	(0.0084)	(0.0008)
Cost of cultivation of main crop$_{(t-1)}$	-0.0876**	-0.0277**
	(0.0166)	(0.0045)
Price support$_{(t-1)}$	0.0346**	0.0773**
	(0.0167)	(0.0115)
Yield$_{(t-1)}$	0.00012**	0.0182*
	(0.00007)	(0.0107)
Percent of irrigated land$_{(t-1)}$	-0.0449*	-0.0242*
	(0.0264)	(0.0147)
Number of dry-spells$_{(t-1)}$	-0.0075*	0.0051*
	(0.0046)	(0.0031)
Rainfall (mm)$_{(t-1)}$	-0.0137	-0.0129*
	(0.0151)	(0.0073)
Average temperature (°C)$_{(t-1)}$	0.4176**	0.0116**
	(0.1551)	(0.0052)
Rainfall (mm, June 1 to 15)	0.0157**	0.0397**
	(0.0077)	(0.0044)
Rainfall (mm, June 16 to 30)	-0.0049	0.0059**
	(0.0087)	(0.0034)
Rainfall (mm, July 1 to 15)	-0.0014	-0.0012
	(0.0081)	(0.0052)
State Dummy	Yes	Yes
R^2	0.756	0.792
Wald test statistics	1342.38**	3060.11***

*Note: Figure in parenthesis are t-statistics; ** and * indicates the level of significance at 0.05 and 0.10 respectively; Source: Authors' estimation*

An increase in irrigated land leads to a reduction in the cultivation of sorghum and pearl millet by 4.49% and 2.42%, respectively, as farmers shift towards more profitable crops like paddy, maize and oilseeds. Irrigation availability drives farmers to prioritize high-value crops that thrive with water access, decreasing the area allocated to traditional, drought-resistant crops (Birthal and Hazrana, 2019). Results further showed that farmers opt to cultivate millets if there is sufficient rainfall up to 15th June. They still increase allocating area under pearl millet when sufficient rainfall occurs up to 30th June. Area allocation under sorghum and pearl millet decreases, though non significantly, if the monsoon delays beyond 30th June. A 1% rise in rainfall during this period leads to a 1.57% and 3.97% increase in the sown areas of sorghum and pearl millet, respectively. Pearl millet area expands by 0.59% with a 1% increase in rainfall from June 15 to 30. Sorghum and pearl millet are well-adapted to semi-arid regions and respond positively to early rainfall, which provides critical soil moisture for germination and early growth. These findings underscore the importance of timely rainfall in supporting the cultivation of these crops in semi-arid areas (Marteau et al., 2011).

As expected, millets are used as contingency or adaptation strategy against dry-spells. An increase of one dry-spell of continuous two weeks during the monsoon season leads to a 0.59% increase in the area allocated to pearl millet, as it is well-suited to arid environments. While pearl millet requires some soil moisture during its early growth stages, its resilience enables farmers to cultivate it successfully even in areas with extended dry periods, providing an opportunity for expansion in regions prone to drought (Marteau et al., 2011). In case of sorghum crop, an additional dry-spell lead to a decrease in the area under the crop by 0.75%. Additionally, excessive rainfall can result in 1.29% reduction in the area under pearl millet, as farmers shift to more profitable oilseeds like groundnut and soybean (Soler et al., 2008). Rising average temperatures, on the other hand, is supporting the expansion of sorghum and pearl millet, as these heat-tolerant crops are well-suited to high-temperature conditions, making them crucial for food security in the face of climate change (Soler et al., 2008).

IV

CONCLUSION AND POLICY IMPLICATIONS

Besides their climate resilience characteristics, millets have potential to mitigate the problem of malnourishment, combat hidden hunger and micronutrient deficiencies, and minimizing the risk of diabetes. Despite their nutritional qualities and climate resilience characteristics, the area under millets in the country is on the declining trend. This study attempted to understand the spatio-temporal changes in area, production and yield of millets and to explore the factors affecting area under millets. We used panel data of Indian states and applied random effect model to analyse the factors affecting. The findings showed that though the area under millets has declined in the country, there has been increase in production of millets primarily attributed to increase in the yield. However, there are still significant gaps in millet yields, particularly when comparing different regions. Also, the growth in millet yield has been more inconsistent than that of major cereals highlighting the need for genetic improvement, particularly stress tolerant varieties (Saxena et al., 2018; Padulosi et al., 2009). States like Madhya Pradesh, Andhra Pradesh and Gujarat showcased impressive yields of sorghum, which have high potential of increasing production by reviving sorghum in these states. Gujarat and Tamil Nadu also have high yield potential and the production of millets can be increased by area intensification in these states, particularly under finger millet in Tamil Nadu and pearl millet and small millets in both the states. A wider gap in the yield potential between states highlight to promote knowledge exchange, learning from best practices and emulate their strategies to boost production. Lessons from high-yielding regions should be shared with states struggling to meet the national average, enabling them to implement successful millet cultivation practices and policies. Additionally, targeted investments in research and infrastructure can further support the growth of millet cultivation and improve yields across the country.

The area allocation under millet cultivation is primarily influenced by relative rather than absolute returns. The changes in area allocation for millets are responsive to changes in returns from competing crops like rice or maize. The differences in the returns are largely attributed to differences in yield but also due to prices, mainly of by-products, also makes significant differences in the returns. Therefore, there is need to create level playing field for millets by adopting crop-neutral price policy. This can be done by incentivising millet cultivation, may be in the form of payments for ecosystem services (PES) as these crops require less water and chemical inputs. The International Year of Millets has definitely been able to create awareness about health and environmental benefits of millets and focus direct policy attention, but the more important is to monitor the progress in creating enabling policy environment for millets at various levels. There is also a need to develop cost effective technologies for processing of fodder and compressing the fodder for logistic ease in transportation so that the fodder demand-supply mismatch across regions may be minimised.

The climatic variable significantly influences area allocation under millets. These crops are being cultivated as climate adaptation strategies. The credit disbursed through Kisan Credit Cards for these crops can be considered as climate funds. While millets are less input-intensive, the cost of cultivation still emerged as a crucial factor influencing area allocation under these crops. Findings further revealed that prices impact the area allocation under millets significantly. Therefore, to ensure that the farmers realise better farm-harvest prices, it is imperative to boost the procurement of millets at MSP. Despite a noteworthy increase in minimum support prices for millets, actual procurement has only recently gained momentum, increased from 0.21 mt in 2018/19 to 0.72 mt in 2022/2023. Sustaining this positive momentum is crucial for the agricultural sector.

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