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MILLETS SECTOR IN INDIA: TRENDS, ROLE, CHALLENGES, AND WAY AHEAD

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ABSTRACT

This paper examines the millets sector in India, emphasizing its potential to address contemporary agricultural challenges and enhance food security. As traditional irrigated lands reach their limits, millets offer a viable alternative due to their resilience to climate change and adaptability to harsh conditions. India, a leading producer and advocate of the International Year of Millets (IYoM-23), is actively promoting the cultivation of millets. Through growth rate analysis and comparative net output return studies, the author identifies critical gaps in current practices, revealing that significant advancements in area expansion, production, productivity, and profitability are needed. The paper proposes comprehensive strategies to overcome these challenges, focusing on research and development, policy support, and the establishment of a robust value chain to fully integrate millets into the agricultural landscape.

Keywords: Climate change, Dietary diversity, Food security, Nutrition, Sustainability

The term "millet" is derived from the Latin word "milum," meaning grain. Millets encompass a diverse group of small-seeded coarse cereals belonging to the Poaceae family. These ancient food grains were among the first plants domesticated for human consumption, cultivated across 131 countries, primarily on marginal lands in dry regions of temperate, subtropical, and tropical climates, spanning over 78 million hectares. Millets serve as a traditional food source for approximately 590 million people in Asia and Africa (FAO, 2022; NAAS, 2022). Millets are classified into three categories: major, minor, and pseudo millets. Major millets produced in India include sorghum, pearl millet, and finger millet. Minor millets consist of foxtail millet, little millet, barnyard millet, proso millet, and brown top millet. Pseudo millets include amaranth and buckwheat.

Millets, referred to as "Shree Anna" by India's Finance Minister during the Budget 2023-24 speech, are increasingly recognized as future foods in light of the adverse effects of global warming, climate change, and growing concerns regarding nutrition and health security. This crop plays a crucial role in addressing the welfare of marginal farmers, mitigating the water crisis, improving soil health, and combating all three forms of malnutrition: undernutrition, protein deficiency, and the hidden hunger associated with micronutrient deficiencies. Moreover, millets contribute to achieving the United Nations Sustainable Development Goals (SDGs) for 2030, specifically SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 8 (Decent Work and Economic Growth), SDG 12 (Sustainable Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). Millets require minimal inputs for cultivation and are particularly well-suited for natural farming practices. For instance, the cultivation of finger millet in Karnataka using natural farming techniques, combined with moderate applications of farmyard manure, has demonstrated reduced cultivation costs, alongside increased yields, achieving a 1.4-fold increase in profitability (Kumar *et al.,* 2020).

Multiple factors have contributed to a 67% decline in the area cultivated with millets since the onset of the Green Revolution (estimate based on data from DES 2023b). These include a bias in agricultural policy favouring staple cereals such as rice and wheat, increasing urbanization, dietary diversification, high labour intensity in millet farming, insufficient alternatives to farm gate prices (which heightens price risk), increased yield risk, and a lack of investment, technology, and market support for small and medium-sized millet farmers (DES 2023b). However, there is a growing interest in reviving millet cultivation in India, driven by considerations of nutrition, health, and climate resilience. Currently, approximately 233.9 million people, or 16.6% of the total population, are hungry or undernourished in India (FAO *et al.*, 2023). Over the past 15 years, the prevalence of obesity has doubled, increasing from 12.6% in 2005-06 to 24% in 2020-21, while the percentage of individuals with a body mass index (BMI) below normal has decreased significantly, from 35.5% to 18.7%. Additionally, in the last five years, anemia among children has sharply risen from 58.6% in 2015-16 to 67.1% in 2020-21, and there has been a slight increase among pregnant women, from 50.4%

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to 52.2%. Furthermore, 36% of children in India are stunted, and 32% are underweight (National Family Health Survey NFHS-3, 2005-06; NFHS-4, 2015-16; NFHS-5, 2019-21) (IIPS, 2022).

Millets are highly nutritious grains rich in macronutrients, such as proteins (including essential amino acids), carbohydrates, and dietary fiber, and micronutrients, including vitamins and minerals like folic acid, vitamin B6, β-carotene, niacin, calcium, iron, zinc, phosphorus, magnesium, manganese, and potassium. These super foods are gluten-free, non-allergenic, non-acid forming, and easily digestible. Regular consumption of these low glycemic index grains can effectively combat malnutrition, hidden hunger, and deficiencies in calcium and vitamins A, B, and B-complex. They also help reduce anemia, obesity, diabetes mellitus, and cardiovascular diseases, while promoting healthy growth and development in children and strengthening the nervous system (Dayakar Rao *et al.*, 2017, 2018b, 2021; Nithiyanantham *et al.*, 2019; Kumar *et al.*, 2018). As C4 plants, millets are less input-intensive, with a global warming potential of only 230-250 kg CO_2 per hectare. They require minimal water, averaging 350-400 mm, and low fertilizer application, around 60-80 kg per hectare (Ullah *et al.*, 2017; Pathak *et al.*, 2014). These sustainable food sources necessitate low investment and hold significant potential to improve the livelihoods of smallholder farmers by providing a stable source of income (Tiwari *et al.*, 2022). Therefore, there is a strong case for promoting dietary diversity through the gradual replacement of wheat and rice with millets.

The Government of India is actively extending policy support to promote the inclusion of millets in daily diets. In 2018, millets such as jowar (sorghum), bajra (pearl millet), and *ragi* (finger millet) were officially rebranded as "Nutri Cereals," replacing the previous term "coarse cereals" or "Mota anaj." This shift has contributed to a notable increase in millet production, rising from 43.06 million tonnes in 2018 to 50.90 million tonnes in 2021-22 (Saini *et al.*, 2021; DES 2023a). The year 2018 was also designated as the National Year of Millets to promote awareness and demand for these grains. Since then, a sub-mission focused on nutri-cereals has been implemented under the National Food Security Mission across 212 districts in 14 states. Additionally, millets have been identified as a key product under the One District One Product (ODOP) initiative by the Ministry of Food Processing Industries (MoFPI) in 19 districts across 10 states. The government has selected 30 applications under the Production Linked Incentive scheme for millet-based products, with an allocation of ₹800 crores. Furthermore, more than 500 startups are already engaged in the millet value chain, with around 250 of these startups incubated by the Indian Institute of Millets Research under the Rashtriya Krishi Vikas Yojana - Remunerative Approaches for Agriculture and Allied Sectors Rejuvenation (RKVY-RAFTAAR) (MoF 2023). As the leading producer of millets and the proponent of the International Year of Millets-2023, India is taking a proactive role in raising awareness and boosting the consumption and production of millets. This is achieved through a multi-stakeholder engagement approach that involves various ministries, state and union territories, farmers, startups, exporters, retail businesses, hotel chains, and Indian embassies (FAO, 2022; Dayakar Rao *et al.*, 2021).

This paper aims to do a trend analysis of the area, production, and yield of various types of millets, utilizing secondary data across four sub-time periods that align with the agricultural growth phases identified by Chand and Singh (2023). By calculating the growth rates of millet area, production, and yield, the study aims to establish the declining position of millets within India's crop production system, while also highlighting a recent, albeit minor, revival attributed to several government initiatives aimed at mainstreaming millets. The author further computes relative return ratios for *kharif* crops, demonstrating that major millet crops yield lower returns compared to alternative *kharif* crops, which contributes to farmers' preferences for these alternatives. To foster a more conducive policy environment for millet mainstreaming in the country, six policy initiatives are proposed across the millet value chain. These include: (i) Inclusion of millets in social safety nets, (ii) Extension of Minimum Support Price (MSP) to all varieties of millets, (iii) Promotion of millet consumption, (iv) Strengthening the processing ecosystem for millets in India, (v) Implementation of organic certification for millets, and (vi) Encouragement of private sector engagement in the millet value chain, particularly for value-added millet products.

Millets sector scenario

India's contribution to world millet production

According to the Food and Agriculture Organization (FAO) of the United Nations, Asia and Africa are the primary regions for millet cultivation, with China, Ethiopia, Russia, and India being the top four high-yielding countries[1]. India has the largest area dedicated to millets, covering 9.76 million hectares, followed by Niger (6.15 million hectares), Sudan (2.80 million hectares), and Mali (2.08 million hectares). Sorghum is the most widely produced millet globally, accounting for 66% of millet production, followed by pearl millet. India leads the world in millet production, contributing approximately 40% of the global total, with China at

[1]High yields in some countries are explained by small production quantities and intensive high input production (Source: FAOSTAT, 2022).

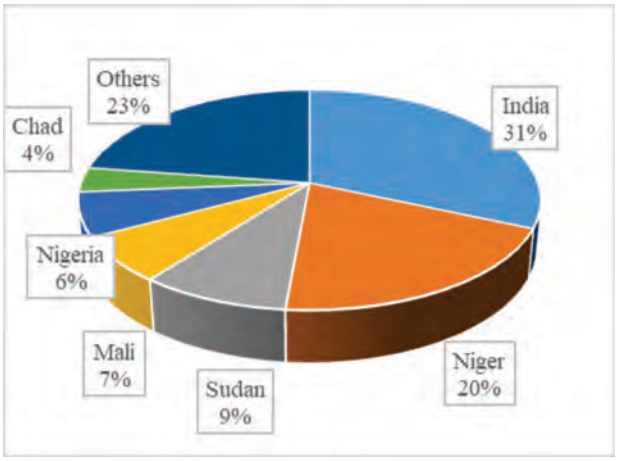


Fig. 1. Share of world millet area by major countries (2021-22)

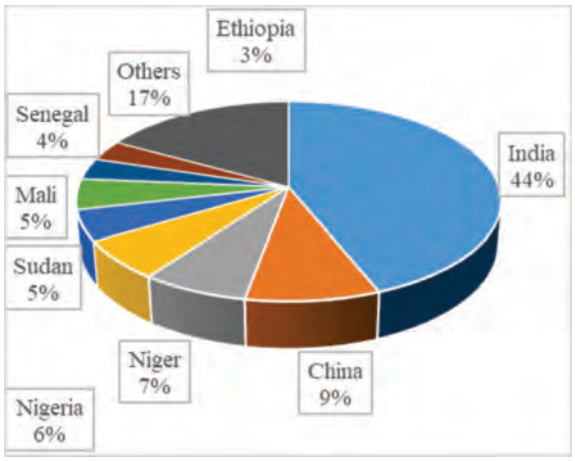
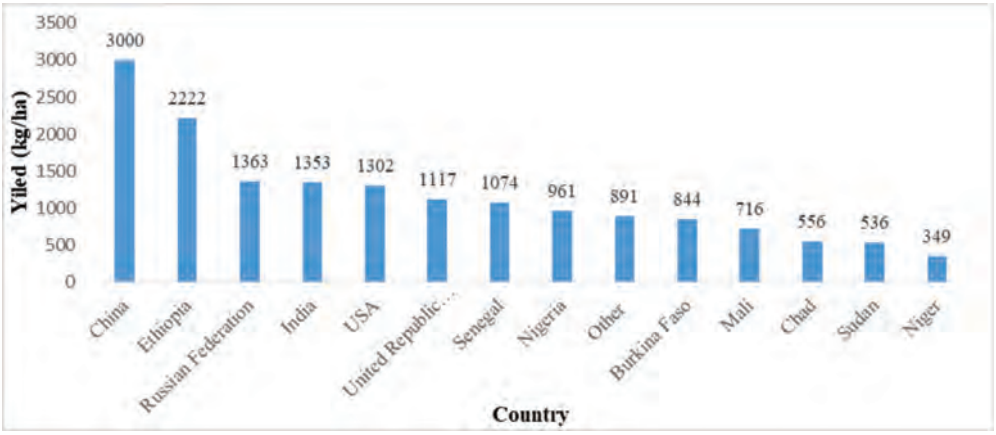


Fig. 2. Share of world millet production by major countries (2021-22)

Source: FAOSTAT (2022)



Source: FAOSTAT (2022)

Fig. 3. Millet yields in major countries (2021-22)

9%, Niger at 7%, and Nigeria at 6%. Furthermore, India is the largest producer of several specific millet types, including kodo millet (100%), little millet (100%), barnyard millet (99.9%), finger millet (53.3%), and pearl millet (44.5%) (ASSOCHAM, 2022).

The production and market for millets are expected to receive a significant boost following the United Nations' declaration of 2023 as the International Year of Millets. The global millet market is projected to grow from USD 11.02 billion to USD 13.80 billion, representing a compound annual growth rate (CAGR) of 4.6% from 2023 to 2028 (Mordor Intelligence, 2024).

Status and trends in millet sector in India

According to the Directorate of Economics and Statistics, millets are cultivated across 23 states in India, covering an area of 12.29 million hectares, with a total production of 16.00 million tons and an average yield of 1,302 kg per hectare. Among millets, pearl millet ranks as the fourth most important food grain in India, following rice, wheat, and maize, with an area of 6.84 million hectares and a production of 9.79 million tons. This accounts for 56% of the total millet area and 61% of total millet production in the country. Pearl millet also boasts the highest yield among millets at 1,430 kg per hectare, closely followed by finger millet at 1,396 kg per hectare.

State-wise trends in millets

According to the Directorate of Economics and Statistics, the major states cultivating millets in India include Rajasthan (4,363 thousand hectares), Maharashtra (2,457 thousand hectares), Karnataka (1,638 thousand hectares), Uttar Pradesh (1,083 thousand hectares), and Madhya Pradesh (555 thousand hectares), all exhibiting high density of millet cultivation. However, Rajasthan (981 kg/ha) and Maharashtra (938 kg/ha) demonstrate relatively low yields, highlighting the urgent need for technological innovations to enhance productivity. Despite its significant area

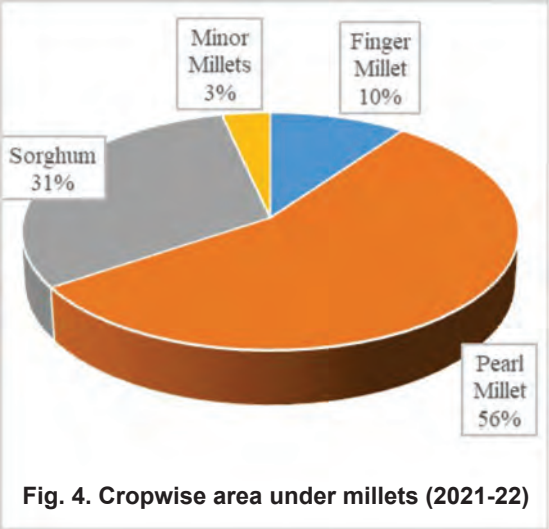


Fig. 4. Cropwise area under millets (2021-22)

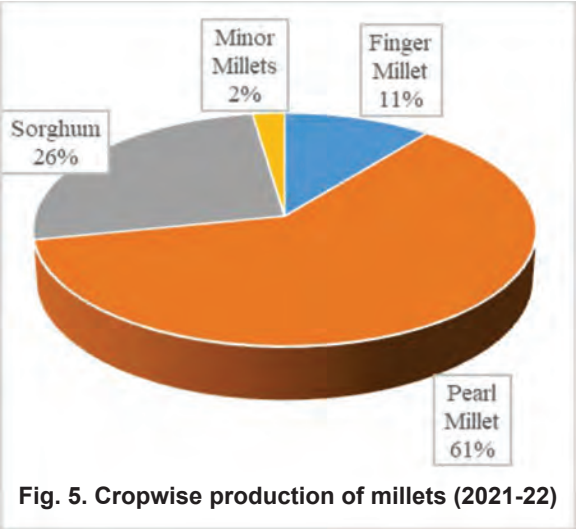
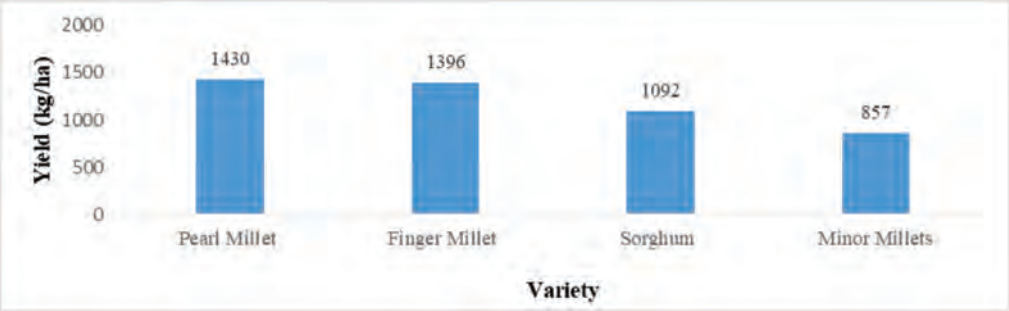


Fig. 5. Cropwise production of millets (2021-22)

Source: Directorate of Economics and Statistics (2023)



Source: Directorate of Economics and Statistics (2023)

Fig. 6. Cropwise yield of millets (2021-22)

under millet cultivation, Haryana produces only 1,132 thousand tonnes of millets due to its smaller size. The leading millet producers by percentage share include Rajasthan (27%), Maharashtra (14%), Uttar Pradesh (14%), Karnataka (13%), Madhya Pradesh (7%), and Gujarat (7%). Figures 7-9 illustrate the state-wise distribution of area, production, and yield of millets. Singh *et al.* (2013) argue that factors such as cultural diversity, agro-ecology, food habits, and the availability of natural resources significantly influence the regional variations in millet cultivation, including area allocation, production levels, and average yields.

Diminishing status of millets

The quinquennial mean area, production, and yield of millets in India, as depicted in Figure 10, illustrate a significant decline in the area dedicated to millets since the onset of the Green Revolution. Despite this reduction in area, millet productivity has increased by nearly 185% during the same period, primarily due to the widespread adoption of high-yielding varieties and hybrids. The share of millets in the overall cereal production has diminished markedly, with their contribution declining from 25.5% to 5.5%, and the area under millet cultivation decreasing from 39.6% to 12.4% over this timeframe (Figure 11). Additionally, per capita production of millets has also fallen, dropping from 34.0% to 11.7% (Figure 12).

The objective of this study is to conduct a comprehensive trend analysis of the area, production, and yield of various types of millets in India, assessing their evolving position within the agricultural landscape. The study aims to identify key factors contributing to the decline in millet cultivation and production, while also highlighting recent governmental initiatives that have spurred a minor revival in the sector. Additionally, the research seeks to evaluate the economic viability of millets in comparison to alternative crops, propose strategic policy interventions to enhance the millet value chain, and promote the integration of millets into public distribution systems and nutrition programs. By leveraging insights from agricultural research, market trends, and policy frameworks, the study aspires to provide actionable recommendations for boosting millet

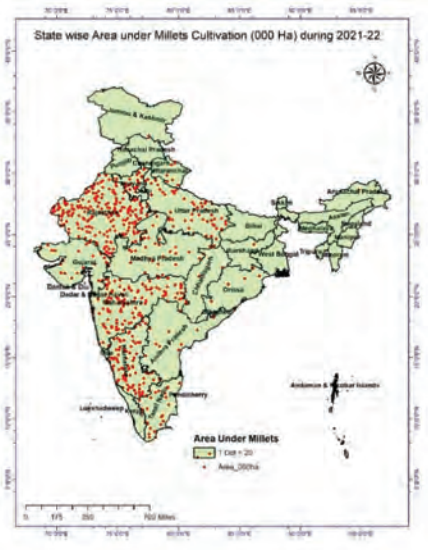


Fig. 7. Statewise area under millet cultivation

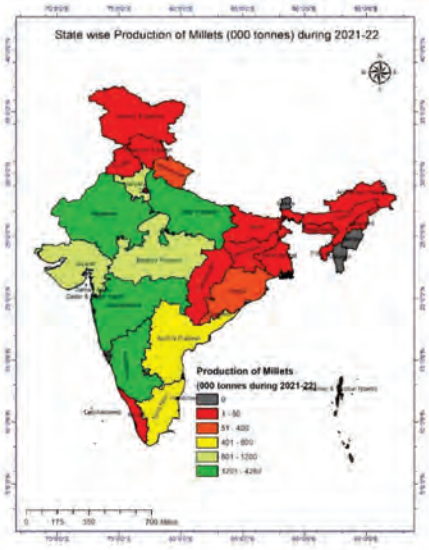


Fig. 8. Statewise production of millets

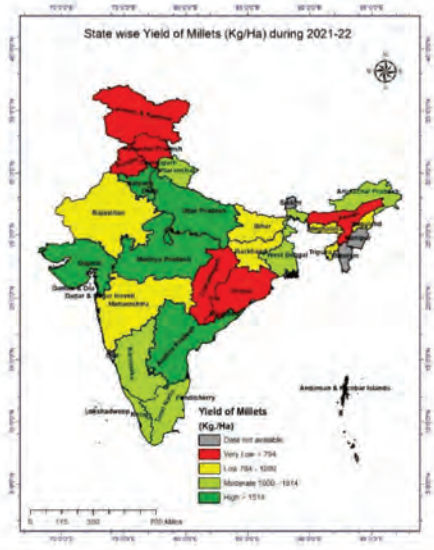


Fig. 9. Statewise yield of millets

Source: Authors creation using Directorate of Economics and Statistics Data

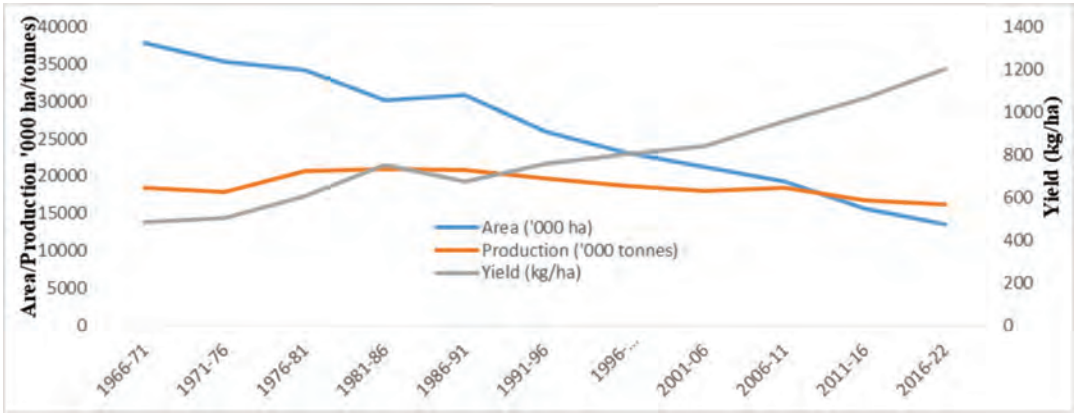


Fig. 10. Quinquennial mean area, production and yield of millets in India

Source: Directorate of Economics and Statistics

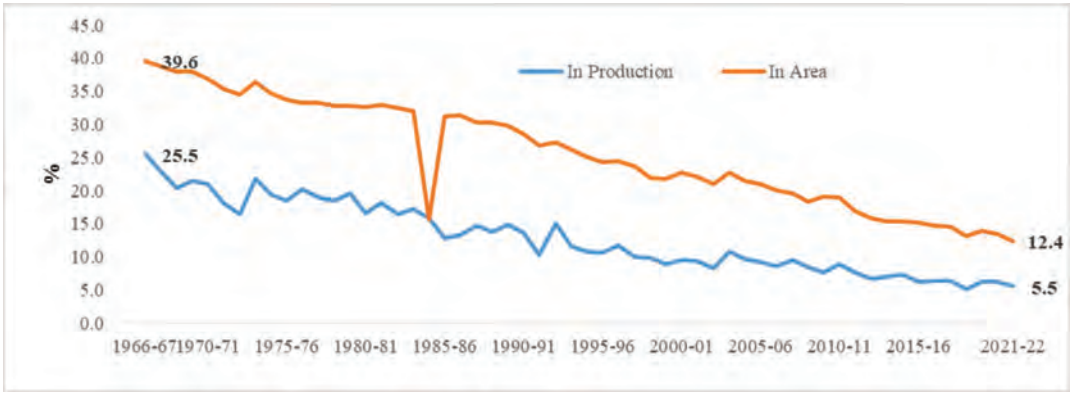


Fig. 11. Share of millets in cereals

Source: Authors estimates based on Directorate of Economics and Statistics

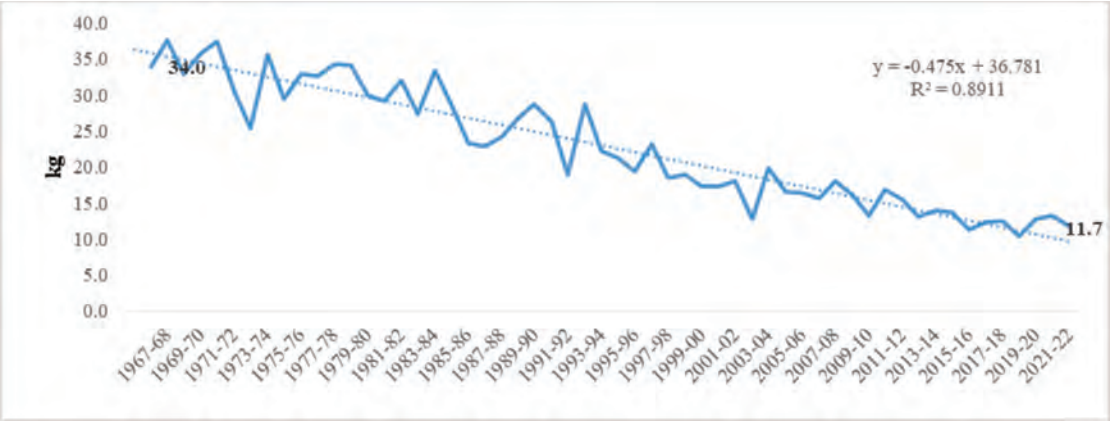


Fig. 12. Per capita production of millets

Source: Authors estimates based on Directorate of Economics and Statistics and CSO

production, consumption, and market acceptance, thereby contributing to food security and improved nutritional outcomes in India.

MATERIALS AND METHODS

Growth rate analysis

The compound growth rates for area, production, and yield of different types of millets have been estimated for selected periods using secondary data. Time series data covering the period from 1975-76 to 2021-22 was sourced from the Directorate of Economics and Statistics. This timeframe has been divided into four sub-periods based on the agricultural growth phases identified by Chand and Singh (2023). The millet wise compound growth rates are estimated to study the growth with the following exponential model.

$Y = ab^t$

Log Y= log a + t log b

CGR = (Antilog b-1) * 100

where,

t = time period in years

Y = area/production/yield

a & b = Regression parameters and

CGR = Compound growth rate

Comparative net output return ratio

The net return ratio is estimated using the same methodology as given in Singh *et al.* (2021). Net value of crop output is taken for the year 2021-22 TE from the *kharif* Marketing Season Report, 2023-24, Commission for Agricultural Costs and Prices. It is calculated by subtracting cost of cultivation (Cost A_2) from gross value of output and is used to estimate the output return of the different crops. Detailed procedure of estimation of net return ratio is given below:

$$Crop\ Output_{Net\ return} = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ \vdots \\ a_n \end{bmatrix}_{nX1}$$

Here, a_1 to a_n = value of output (net) from a_1^{th} to a_n^{th} crop. The construction procedure of net return ratio matrix for competitive crops is given below:

$$Net\ Return\ Ratio = \begin{bmatrix} a_1/a_1 & a_1/a_2 & .. & .. & a_1/a_n \\ a_2/a_1 & a_2/a_2 & .. & .. & a_2/a_n \\ \vdots & \vdots & .. & .. & \vdots \\ \vdots & \vdots & .. & .. & \vdots \\ a_n/a_1 & a_n/a_2 & .. & .. & a_n/a_n \end{bmatrix}_{nXn}$$

Here, diagonal element of the matrix shows the comparative return for same crop and first column shows the comparative return ratio of crop 1 to n^{th} with respect to crop 1. First row shows the crop return ratio of crop 1 with respect to 1 to n^{th} crop.

RESULTS AND DISCUSSION

Growth rate analysis

A trend analysis of the area, production, and yield of millets was conducted to assess their deteriorating position within India's crop production system. It is evident that both the area under millets and their overall output have experienced a negative growth rate during the study period (Table 1). Additionally, growth in millet productivity has been minimal, indicating stagnation in yields. As illustrated in Table 1, millet production-which is influenced by both productivity and the area under cultivation-began to decline notably from the 1990s, with the sharpest decline observed in minor millets.

During the study period, the area cultivated with bajra (pearl millet), which is the most widely grown millet crop, consistently exhibited a negative growth rate. However, the yield of bajra demonstrated positive

growth, contributing to an overall increase in total production. Notable improvements in the status of bajra have been observed since the 2015-16 period, largely attributed to the promotional measures implemented by the current government. Specifically, production growth has been reported at 3.33%, with yield growth at 2.84%. Additionally, the rate of area reduction has slowed to -0.23% compared to previous periods.

Sorghum, another significant millet crop accounting for 26% of total millet production, has experienced a continuous negative growth rate in area cultivation throughout the study period. However, periods of high positive growth in yield, particularly from 1975-76 to 1990-91 and again from 2015-16 to 2021-22, resulted in a positive overall growth rate for production. Despite these yield improvements, sorghum is losing its significance in the agricultural landscape, primarily due to its relatively low per hectare income and decreasing demand for food consumption. Consequently, it is increasingly cultivated for fodder in agriculturally advanced states such as Punjab, Haryana, and Western Uttar Pradesh.

Ragi (finger millet), predominantly cultivated in Karnataka and Tamil Nadu, experienced a continuous negative growth rate in both area and production until 2015-16. However, between 2015-16 and 2021-22, there has been a notable shift toward positive growth in both area and production, despite the crop's yield reporting a marginal negative growth rate attributed to two consecutive years of drought.

Minor millets, which are integral to the geography, tradition, and culture of India, have exhibited the sharpest and most consistent declines in both area and production throughout the study period. This trend is particularly concerning given that minor millets offer significantly higher nutritional and health benefits compared to other millets. This trend highlights the urgent need to promote the cultivation of minor millets as mixed crops, enhance research and development (R&D) efforts, establish a minimum support price (MSP), and generate harmonized system (HS) codes to unlock their export potential. These initiatives could help revitalize the minor millet sector and improve its visibility in the agricultural landscape. These results align with the studies conducted by Yadav *et al.* (2024) and Kumar *et al.* (2023), highlighting a growing consensus on the need for targeted interventions in this area.

Comparative net output return ratio

Table 2 presents the relative return ratios for *kharif* crops, illustrating that the return ratios for major millets are consistently less than one. This indicates that the returns from major millet crops are lower compared to those from alternative *kharif* crops. Specifically, the returns from bajra were 63%, 39%, 48%, 51%, and 47% lower than those from paddy, maize, arhar (tur), groundnut, and cotton, respectively. Consequently, it is not feasible for bajra to replace these crops; however, it could be more readily substituted by other crops such as jowar, *ragi*, moong, urad, soyabean, sunflower,

Table 1. Growth rate of millets (%)

Crop	Particular	1975-76 to 1990-91	1990-91 to 2005-06	2005-06 to 2015-16	2015-16 to 2021-22	1975-76 to 2021-22
Finger Millet	Area	-1.11	-2.05	-2.08	1.06	-2.27
	Production	-0.53	-1.30	-0.54	1.45	-1.14
	Yield	0.59	0.77	1.57	-0.20	1.13
Pearl Millet	Area	-0.45	-0.77	-3.14	-0.23	-1.03
	Production	0.70	1.87	0.72	3.33	1.69
	Yield	1.15	2.66	3.99	2.84	2.72
Sorghum	Area	-0.60	-2.94	-4.04	-6.73	-3.09
	Production	0.38	-3.22	-5.17	0.13	-2.28
	Yield	0.97	-0.28	-1.19	5.77	0.79
Minor Millets	Area	-4.31	-5.04	-5.23	-7.18	-5.23
	Production	-3.53	-5.49	-1.84	-2.95	-3.92
	Yield	0.81	-0.48	3.58	4.30	1.38
Millets	Area	-1.29	-2.13	-3.53	-2.75	-2.20
	Production	0.12	-1.14	-1.67	2.03	-0.63
	Yield	1.42	1.01	1.92	4.91	1.61

Source: Authors estimates based on Directorate of Economics and Statistics

sesame, and nigerseed. Similarly, the returns from *ragi* were 100%, 23%, 71%, 82%, 86%, 2%, 11%, and 81% lower than those from paddy, bajra, maize, arhar (tur), groundnut, sunflower, sesame, and cotton, respectively. This further emphasizes the unfeasibility of *ragi* replacing these crops, although it could be substituted by crops like jowar, moong, urad, soyabean, and nigerseed. For jowar, the returns were 110%, 29%, 80%, 5%, 91%, 96%, 7%, 17%, and 91% lower than those from paddy, bajra, maize, *ragi*, arhar (tur), groundnut, sunflower, sesame, and cotton, respectively. Therefore, jowar is also not a viable replacement for these crops, though it could potentially replace moong, urad, soyabean, and nigerseed. The consistently low financial returns from millet crops compared to alternative crops clearly contribute to the low preference among farmers for cultivating these varieties.

The Government of India has implemented a significantly higher Minimum Support Price (MSP) for millets compared to other crops to enhance their production. From 2017-18 to 2023-24, the absolute increases in MSP for finger millet (102%), sorghum (hybrid) (87%), and pearl millet (75%) outpaced those for paddy (41%) and wheat (31%). Additionally, the average year-on-year change in MSP was markedly higher for finger millet (13.6%), sorghum (hybrid) (11.8%), and pearl millet (10.4%) compared to paddy (5.9%) and wheat (4.6%) (authors' estimates based on DES 2023b). However, an increasing reliance on MSP by farmers presents an unsustainable solution with significant financial implications for government budgets. To promote the profitability of millets, alternative reforms are necessary, including market diversification, the development of alternative income streams for millet farmers, and value-chain integration. Examples of progressive initiatives, such as Haryana's Bhavantar Bharpai Yojana and Madhya Pradesh's Bhavantar Bhugtan Yojana, which implement the Price Deficiency Payment Scheme, represent excellent steps toward reducing dependence on MSP and fostering greater self-reliance among farmers.

Genetic innovations, hybrid development, and the introduction of high-yielding, water-responsive varieties, along with improved agronomic practices, have the potential to significantly enhance productivity in millet cultivation. To effectively compete with other crops, it is crucial to implement measures such as water conservation strategies, the adoption of the latest high-yield crop cultivars, and integrated nutrient management alongside integrated pest and disease management. These approaches can help bridge existing yield gaps. Moreover, expanding millet cultivation, particularly small millets with short growth cycles and minimal water requirements, into wastelands and post-*kharif* fallow lands can increase cropping intensity and

Table 2. Comparative Net Output Return Ratio (NORR) from crops in *kharif* season during 2021-22 (TE)

Crop	Paddy	Jowar	Bajra	Maize	*Ragi*	Arhar (Tur)	Moong	Urad	Groundnut	Soybean	Sunflower	Sesame	Nigerseed	Cotton
Paddy	1.00	2.10	1.63	1.17	2.00	1.10	2.28	2.71	1.08	2.37	1.97	1.80	3.14	1.10
Jowar	0.48	1.00	0.77	0.56	0.95	0.52	1.08	1.29	0.51	1.13	0.93	0.86	1.49	0.52
Bajra	0.61	1.29	1.00	0.72	1.23	0.68	1.40	1.66	0.66	1.46	1.21	1.11	1.93	0.68
Maize	0.86	1.80	1.39	1.00	1.71	0.94	1.95	2.32	0.92	2.03	1.68	1.54	2.69	0.94
Ragi	0.50	1.05	0.81	0.58	1.00	0.55	1.14	1.35	0.54	1.19	0.98	0.90	1.57	0.55
Arhar (Tur)	0.91	1.91	1.48	1.06	1.82	1.00	2.07	2.46	0.98	2.15	1.79	1.64	2.85	1.00
Moong	0.44	0.92	0.72	0.51	0.88	0.48	1.00	1.19	0.47	1.04	0.86	0.79	1.38	0.48
Urad	0.37	0.78	0.60	0.43	0.74	0.41	0.84	1.00	0.40	0.88	0.73	0.67	1.16	0.41
Groundnut	0.93	1.96	1.51	1.09	1.86	1.02	2.12	2.52	1.00	2.20	1.83	1.67	2.92	1.03
Soybean	0.42	0.89	0.69	0.49	0.84	0.46	0.96	1.14	0.45	1.00	0.83	0.76	1.32	0.47
Sunflower	0.51	1.07	0.83	0.59	1.02	0.56	1.16	1.38	0.55	1.21	1.00	0.92	1.60	0.56
Sesame	0.56	1.17	0.90	0.65	1.11	0.61	1.26	1.50	0.60	1.32	1.09	1.00	1.74	0.61
Nigerseed	0.32	0.67	0.52	0.37	0.64	0.35	0.72	0.86	0.34	0.76	0.63	0.57	1.00	0.35
Cotton	0.91	1.91	1.47	1.06	1.81	1.00	2.06	2.45	0.97	2.15	1.78	1.63	2.85	1.00

Source: Authors estimates based on *kharif* marketing season report, 2023-24, Commission for Agricultural Costs and Prices

provide farmers in dryland agriculture with year-round income. Organic certification for millets can also elevate their market value. To facilitate this, central and state governments could offer financial assistance, including low-cost loans and infrastructure development to cover certification costs. Additionally, organically produced millets could be insured against price and yield risks and listed on the government's GEM portal to enhance market access.

Challenges in India's millet ecosystem

The status of millets has been diminishing over-time and they have become orphan crops, un-favoured by policy, investments, technology, and market; the situation is worse for minor millets, despite their higher health and nutritive value. Various states such as Maharashtra, Karnataka, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Tamil Nadu, Rajasthan, Uttarakhand, Haryana and Gujarat have lost major share of area under millets to more remunerative and water-intensive crops like maize, cotton, soybean, etc.

The millet ecosystem faces numerous challenges pertaining to production, processing, value addition, marketing, and consumption, hindering the process of advocating millets as the staple foods. Multiple supply side and demand side factors as well as regulatory and policy constraints such as low yield, technology, and profitability, lack of commercialization, product-specific cultivars and seed hubs for breeding and seed production, changing consumer taste and preferences, limited recipe options, lack of consumer awareness and slow pace of outreach, efficient processing machinery and diversification of processing technologies, favour of Government's policy towards finer cereals in terms of input subsidies and availability at incentivized prices through Public Distribution System, Mid-Day Meal, Women and Child Development and other public- funded feeding programs, lack of MSP on small millets, lack of proper guidelines with standards in terms of processing, branding, packaging, labeling, etc., establishment of quality standards, certification process, lack of knowledge about export policies and understanding about the markets in different countries etc. are the primary responsible factors. `

Stimulating the demand and supply of millets is essential for addressing multiple issues pertaining in the country like nutrition deficiency, low sustainability, marginal farmer welfare, over-exploitation of groundwater, deterioration of soil health, and stressed environment. Concerted efforts towards mainstreaming millets by diversifying production technologies, building forward and backward linkages, nurturing the start-up ecosystem have the potential to strengthen the miller value chain.

Policy interventions

To ensure that future agriculture can effectively address the challenges posed by climate change, limited water availability, and declining agro-biodiversity, it is imperative to significantly increase investment in millet research. There should be a strong focus on genetic improvement and agronomic management to develop high-yielding cultivars that are well-adapted to environmental conditions and possess high production potential. Advanced biotechnological methods, such as tissue culture, genetic engineering, and molecular marker technology, are being increasingly utilized to enhance millet research. However, these techniques have primarily been applied to a limited number of millet species and regions. Integrating nutritional traits into millet breeding is also essential for the development of high-yield cultivars with improved grain quality (Sharma *et al.*, 2022; Yadav *et al.*, 2019, 2024).

Technology and innovation are pivotal in enhancing production, productivity, and value addition in millet cultivation, which in turn boosts both demand and supply. The expansion of frontier and digital technologies is crucial for implementing 'farm-to-fork' traceability, ensuring food safety and quality. The establishment of a Centre of Excellence at the Indian Institute of Millet Research in Hyderabad marks a significant advancement by the government in promoting research and development in this sector. India, producing 40 percent of the world's millets (excluding sorghum), has a critical role in developing and exporting low-cost, efficient processing equipment and technologies, especially to Africa, which currently lacks significant agricultural R&D capacity. By focusing on diversifying processing technologies for millets, India can foster a long-term sustainable food system that benefits both producers and consumers. Encouraging private sector investments is essential for accelerating the development of cost-effective and large-scale processing techniques. These innovations are vital for efficient storage and minimizing post-harvest losses. Private sector participation can be incentivized in the ready-to-eat (RTE) and ready-to-cook (RTC) segments, allowing for greater responsiveness to consumer demands for products like *ragi* cookies, pizza bases, noodles, and jowar flour. Moreover, boosting the consumption of biofortified millets is crucial for establishing a sustainable food strategy, particularly for populations at higher risk of iron deficiency.

A primary focus must be placed on increasing millet production, as promoting millet consumption without a corresponding rise in output risks making these nutritious foods accessible only to the wealthy, rather than to those in need. Given the high yield risks associated with millet cultivation, it is essential to provide special insurance coverage for these crops. Millets should also

be prioritized under the Bhartiya Prakritik Krishi Padhati (BPKP), a sub-scheme of the Paramparagat Krishi Vikas Yojana (PKVY) that promotes traditional indigenous agricultural practices. Furthermore, integrating millet production with broader development initiatives, such as watershed management, rural development programs, and livelihood missions, will enhance the resilience and sustainability of millet farming.

Startups, Farmers' Producer Organizations (FPOs), Self-Help Groups (SHGs), cooperatives, and Primary Agricultural Credit Societies (PACS) are crucial for establishing a robust millet value chain. This is essential for diversifying the agri-food production system and fostering an ecosystem that supports millet promotion. To ensure the sustainability of food processing enterprises and the export of value-added Ready-to-Eat and Ready-to-Cook products, there needs to be significant investment in landholding and capacity building for farming communities. Training in business development, entrepreneurship, and food safety standards will empower these communities and enhance their competitiveness. Additionally, establishing rural Food Safety and Standards Authority of India (FSSAI) licensed Food Processing Units and business incubation centers, such as Centers of Excellence in Food Processing, will further promote entrepreneurship.

The Odisha Millet Mission (OMM), launched in 2017 through collaboration between the state government, academia, and civil society, serves as an exemplary model for promoting millets across the entire value chain, including production, processing, consumption, marketing, and integration into government schemes. The mission has been implemented in 30 districts, 177 blocks, and 14,654 villages, directly benefiting 228,808 farmers. Due to the government's efforts, approximately 1,43,463 hectares of land have been dedicated to millet cultivation in the 2023-24 period. Notably, 4,50,869 quintals of finger millet have been procured with the participation of 48,706 farmers, and 4,02,500 quintals have been distributed through the Public Distribution System (PDS). The mission has achieved significant milestones, including the inclusion of finger millet *laddoos* as a morning snack for pre-school children under the Integrated Child Development Services (ICDS) program in Keonjhar and Sundargarh districts. Additionally, 17 "Millet Shakti Cafes" have been established to serve millet-based food items, further promoting the consumption and cultural relevance of millets in the region (Odisha Millet Mission, 2024).

"Chakti," the first iron biofortified pearl millet variety developed for West and Central Africa, directly addresses malnutrition and combats iron deficiency anemia among children, adolescent girls, and pregnant women, thereby enhancing food security in the region. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has also contributed to food security through the development of the pearl millet single cross hybrid "ICMH 147007" and by establishing effective seed systems in West and Central Africa. In Bangladesh, the Bangladesh Agricultural Research Institute (BARI) has released several high-yielding millet varieties suitable for Char lands, including BARI Kaon 2, BARI Kaon 4, and BARI Cheena 1. Farmers in the Char region who cultivate these BARI-released millet varieties are experiencing positive outcomes, demonstrating the potential of improved millet varieties to enhance agricultural productivity and food security (NITI Aayog and UNWFP, 2024).

CONCLUSION AND WAY FORWARD

India faces dual challenges of malnutrition, overnutrition and undernutrition, both of which can be addressed through targeted interventions in the millet sector. A collaborative effort among scientists, policymakers, and farmers is crucial to tackle the pressing issues of productivity, pricing, profitability, processing, and partnerships with producers. Leveraging science, technology, innovation, and effective policies can significantly enhance productivity and expand the area under millet cultivation. Key strategies include genetic innovations, hybrid development, and the introduction of high-yielding, water-responsive seeds. Improved agronomic practices and robust research and development (R&D) are essential to achieving breakthroughs in millet productivity, which is necessary for competing with other crops and ensuring better price realization for farmers. R&D efforts should also focus on developing low-cost, efficient, and modern millet processing equipment and technologies, potentially financed through public-private partnerships. Furthermore, the government should provide insurance to farmers against price and yield risks, which would incentivize the expansion of millet cultivation.

Incorporating millets into the Public Distribution System (PDS) across all states is crucial for stimulating demand and enhancing large-scale consumption. Government procurement followed by distribution through the PDS can ensure that millet production is effectively absorbed, making these nutritious grains accessible to those who need them most. Adopting a regional approach to PDS is recommended, where specific millets are prioritized based on local dietary traditions. For instance, pearl millet could be emphasized in Rajasthan and Gujarat, sorghum in Maharashtra and Karnataka, finger millet in Karnataka and Tamil Nadu, and minor millets in states like Odisha, Uttarakhand, Madhya Pradesh, and Chhattisgarh.

Additionally, integrating millet-based products into nutrition intervention programs, such as the Integrated Child Development Scheme (ICDS) and the Mid-Day Meal (MDM) scheme, can significantly boost demand and improve health outcomes for women and children. Replacing just 1 kg of rice with millets each month for a quarter of PDS beneficiaries (approximately 200 million people) could save around US$ 770 million. This reduction in cost would largely stem from decreased greenhouse gas emissions and more sustainable water use, alongside savings of $110 million in food grain procurement and distribution expenses (TCI 2023).

Decentralizing the procurement system at the state level is crucial for enhancing efficiency in the millet supply chain. Facilitating procurement and sales through entities such as the Tribal Cooperative Marketing Development Federation of India (TRIFED), Primary Agricultural Credit Societies (PACS), cooperatives, and Farmer Producer Organizations (FPOs) can streamline processes and empower local farmers. To promote greater distribution and diversity, it's essential to allow excess grains produced in leading millet-producing states to be traded in regions with minimal production. Granting inter-trade exemptions by Agricultural Produce Market Committees (APMC) for millets, similar to those already in place for horticultural produce, can facilitate this movement. This approach will help extend the reach of millets to the 14 states with low or negligible production, ensuring that a wider audience benefits from these nutritious grains. Increasing millet output is critical to meet the rising demand. Without a boost in production, there's a risk that millets could become a luxury item, accessible only to wealthier consumers, thereby exacerbating food insecurity for low-income populations.

Increased production of millets, while beneficial, poses a risk if it isn't effectively absorbed by the market, potentially leading to decreased incentives for farmers to cultivate them. To counter this, various interventions are crucial. Promoting millets as functional foods, nutraceuticals, and superfoods can significantly enhance their appeal. There's also potential to increase their use in animal feed, as raw materials for various industries, and for producing biomass and alcohol. A comprehensive strategy for branding, positioning, and marketing millets across different consumer segments is essential. Leveraging existing social structures such as Anganwadi Centers, local government bodies, self-help groups, and cooperatives can help raise awareness about the nutritional and health benefits of millets at the household level. Social media and public campaigns can further enhance the acceptability of millets, presenting them as aspirational foods and healthy alternatives to staple grains like wheat and rice. Awareness initiatives, including cooking competitions, recipe videos, and expert endorsements from health professionals, can effectively communicate the benefits of millets to the public. Collaborating with various government departments, such as those in railways, tourism, sports, education, and welfare, alongside private sector entrepreneurs can create a responsive market that caters to consumer demands for innovative millet products like *ragi* cookies, pizza bases, and jowar flour. Ultimately, a concerted effort involving academia, industry, and government is vital to revitalize millet cultivation and ensure that their nutritional benefits are recognized and enjoyed by a broader population.

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