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RESEARCH NOTE

Millets' Status in India: An Integrated Assessment for Harnessing their Potential

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ABSTRACT

Millets or Shree Anna often termed as nutri-cereals are a type of cereal grain having small seeds, can be grown in a range of tropical and subtropical regions, and requires very little input. They were the first crops domesticated by humans in Asia and Africa, and they eventually spread over the world as essential food sources for developing civilizations. Over the years, India's millet production has faced a significant challenge due to declining cultivation area and a widening demand-supply gap. This paper estimates past trends and instability in millet production in India, and analyses three scenarios for realizing their production potential by 2030. Base or business as usual (BAU) scenario using the ARIMA Model was compared with three alternative scenarios of millet production. The alternative scenarios are: i) Bringing the fallow and waste lands under cultivation; ii) Bridging the yield gap; and iii) An integrated approach– that combines the first two scenarios. The findings revealed that with an integrated approach millet production by 2030 could be increased by approximately 50 percent compared to the current levels. The integrated approach would enable the country not only to meet millet demand by 2030 but also contribute towards enhanced food security and economic stability for the future.

Keywords: Millet production forecast, yield gap analysis, ARIMA model, sustainable agriculture, fallow land utilization
JEL codes: C22, Q1, Q12, Q16, Q18

I

INTRODUCTION

Millets are small-seeded grasses that can grow in arid and semi-arid regions. They are also referred to as dryland cereals or nutri-cereals. Millets can survive in a wide range of climatic conditions. Based on the size of the grain, millets are categorized as major millets and minor millets such as sorghum (Jowar), pearl millet (Bajra), and small millets such as kodo millet (Kodon), proso millet (Cheena), little millet (Kutki), finger millet (Ragi), and foxtail millet (Kakun) (Gowri, *et al.*, 2020). They are a good source of phytochemicals, minerals, and protein, and high in dietary fibre. Millets contain 7–12 percent protein, 2-4 percent fat, 65–75 percent carbohydrates, and 15-20 percent dietary fibre (Saravand *et al.*, 2022).

Millets have the potential to support achieving of the sustainable development goals (SDG) of no poverty (SDG1), zero hunger (SDG2), good health and well-being (SDG3), gender equality (SDG5), decent work and economic

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growth (SDG8), responsible consumption and production (SDG12), and climate action (SDG13) (Kumari *et al.*, 2023). India leads in millet production, with 40% (12.2 million tons) share of the global production in 2023. The cultivated area of millets in the country was 12.88 million hectares, with a production of 17.24 million metric tons and an average yield of around 1,262 kg per hectare (APEDA, 2023). At the national level, Rajasthan has the highest area under millets cultivation (36%) followed by Maharashtra (21.67%) and Karnataka (13.46%). The annual per capita millet consumption in the country has decreased substantially from 30.94 kg to just 3.87 kg in the last six decades. Recognizing the diverse role of millets, India declared 2018 as the National Year of Millets and also renamed these crops as "Nutri Cereals". The increase in millets export to US$ 75 million within five years by 2022–23, may be attributed to such policy initiatives. The role of millets in nutritional security was emphasized at the global level too as the United Nations adopted a resolution on March 5, 2021, designating the year 2023 as the International Year of Millets. This resolution was supported by 72 nations (PIB, 2023). However, there is a long way to go to harness the potential of millet to improve food and nutritional security.

NITI Aayog has projected the total demand for millets to be between 57 to 64 million tons by 2029-30, far exceeding the current production (NITI Aayog 2020). This necessitates exploring alternative scenarios that could boost the supply of millets, as the Centre's ambitious plan also aims to increase millet production almost three-fold in the country by 2030 (45 million tons from the current level of 17 million tons). Therefore, making timely and reliable forecasts is essential for stakeholders to make informed decisions (Bellundagi *et al.*, 2016). It is also important to analyse feasible alternative strategies for millet production, such as bringing fallow and waste lands under cultivation and bridging the yield gap. This paper assesses the present scenario and analyses alternative strategies to harness millet production potential to meet future demand in India.

II

MATERIALS AND METHODS

The study utilizes secondary sources of time series data (www.Indiastat.com) on area, production, and productivity for the last four decades (1980-81 to 2022-23). To get an insight into millet production trends and instability, compound annual growth rates (CAGR) and the Cuddy Della Valle Instability Index (CDVI) were estimated as follows:

The decadal CAGR of millet area, production, and productivity were analysed from 1980 to 2023 using the exponential function:

$$Y_t = ab^t u_t \quad \ldots\ldots (1),$$

Where,

Y_t: Dependent variable (area/production/yield) for which growth rate is estimated *a*: Intercept (constant)

b: Regression coefficient

t: Years which take values, 1, 2, …, n

u_t: Disturbance term for the year t

The equation $Y_t = ab^t u_t$ was transformed into log linear form and was estimated using the Ordinary Least Square (OLS) method. The CAGR (g) in percentage was then computed from the following relationship:

$$g = (Antilog\ of\ ln\ b - 1) \times 100$$

The significance of the regression coefficient was tested by using the 't' test.

The Cuddy Della Valle Instability Index (CDVI), proposed by Cuddy and Della Valle in 1978, is a modification of the coefficient of variation that accounts for trends in the data. Unlike scale-dependent measures like the standard deviation, the CDVI provides a more comprehensive view of the instability in the data, as it captures not only the variations in millet area, production, and yield but also shows the exact direction of instability. The instability index of millet area, production, and productivity was analysed for the last decade (2010 -2023) using Cuddy-Della Valle Index (CDVI) as follows:

$$CDVI = CV \times \sqrt{1 - AdR^2}$$

CDVI: instability index (in percent)

CV: Coefficient of Variation (in percent); CV= (Standard Deviation/ Mean) * 100

AdR^2: Adjusted Coefficient of determination.

The CDVI ranges and interpretation is as follows (Sihmar, 2014):

0-15= Low instability;

>15 but <30=Medium instability;

>30= High instability

In addition to the *BAU scenario*, the following alternative scenarios were considered for analysis:

- Scenario I: Bringing the fallow and waste lands under cultivation;
- Scenario II: Bridging the yield gap with a constant baseline area; and
- Scenario III: Integrating both Scenario I and Scenario II.

These scenario analyses aim to provide comprehensive insights into the potential impacts of different strategies on millet production.

III

RESULTS AND DISCUSSION

The trends for the area, production, and productivity of millets in India depicted in Figure 1 highlight substantial changes over the past few decades. Since 1971–72, there has been a consistent decline in the area under millet cultivation, with a notable drop from 2006 (20 million hectares) to 2023 (12 million hectares). In contrast, the yield of millets in India has more than doubled since 1966 (452 kg per hectare), reaching an average of 1262 kg per hectare in 2023-24. This increase suggests the adoption of improved farming practices and technologies. Even though the cultivation area has decreased, the rising yield levels have helped maintain a relatively stable production level over time, with some fluctuations, indicating efforts to sustain production levels or potential shifts in agricultural practices.

Addressing the key factors that limit production, such as land availability and yield optimization, it is essential to explore alternative strategies to enhance millet production, such as bringing fallow and waste lands under cultivation and bridging the yield gap. These strategies are crucial for ensuring a sustainable increase in millet production to meet future demand in India.

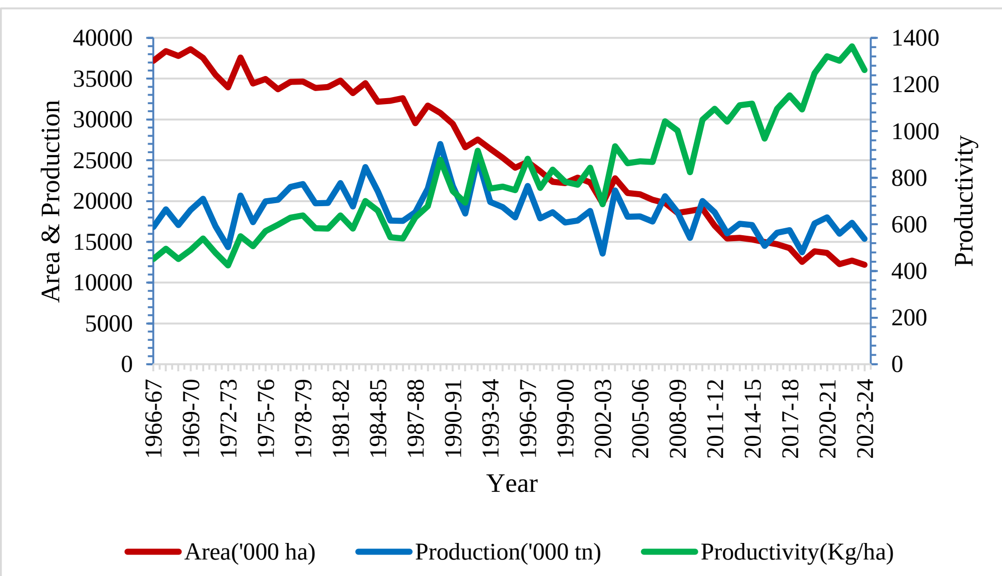

Figure 1. Trends in Area, Production & Productivity of Millets- India

3.1 Growth analysis- production performance of millets:

Decadal analysis of millet cultivation in India reveals distinct patterns. During 2011-2023, Sorghum experienced a consistent decline with a substantial negative growth rate in area (-4.76%) and, production (-2.91%) (Table 1).

TABLE 1: COMPOUND ANNUAL GROWTH RATE (CAGR) OF MILLET CULTIVATION AREA, PRODUCTION, AND PRODUCTIVITY IN INDIA, 1981-2023

Crops	Area (%)				Production (%)				Productivity (%)			
	1981-90	1991-00	2001-10	2011-23	1981-90	1991-00	2001-10	2011-23	1981-90	1991-00	2001-10	2011-23
Sorghum	-1.62*	-3.03	-3.13**	-4.76	0.78	-3.08*	-0.17	-2.91**	1.87	0.03***	3.10	1.97*
Bajra	-0.85	-0.97**	0.11	-1.91*	1.40	1.51	0.69**	0.86	2.36**	2.61	2.09	2.83**
Ragi	-1.59**	-2.05	-2.63	-0.68	-0.88***	-0.42	0.75	-0.84	0.63	1.74	3.56*	0.19
Small Millets	-4.50	-4.52	-5.15	-5.74**	-2.58	-4.95	-2.66**	-2.45	2.12	-0.59**	2.58	3.64
Total Millets	-4.33***	-4.40	-5.06*	-6.45**	-5.10***	-5.30	-1.83	-2.24	1.71*	-0.76**	3.20	4.53***
Rice	1.47**	0.71	0.04	0.66	3.66	2.07*	1.66	2.36	3.26	1.26	1.67	1.75
Wheat	0.63*	1.76	1.11	0.10**	3.63	3.49	1.96	2.28	3.04**	1.75	0.76**	2.06

Growth rates were estimated using log-linear regression. Statistical significance is based on standard t-tests. (Significance: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$Though productivity showed a positive trajectory (3.10%) during 2001–2010 mainly due to the adoption of improved practices, it has decelerated to 1.97 percent during the latest decade. Bajra displayed positive productivity trends with a growth rate of 2.61 in 1991–2000, and the introduction of improved varieties of ragi in the 2000s has led to a favourable production trajectory with a growth rate of 0.69 percent. Small millets faced persistent negative growth in cultivation area and production (Devi *et al.*, 2024), but a positive trend in productivity from 2011-2023 (3.72) signifies advancements in yield improvement despite challenges in cultivation area.

The decline in the area under millet cultivation can be attributed to several factors. Firstly, the shift is driven by economic considerations, as farmers may find other major cereals more profitable due to higher yields or better market prices (Kumar *et al.,* 2023). Additionally, the labour-intensive nature of millet processing, predominantly done by women, could be a deterrent, especially when compared to the mechanized processing of other cereals. (Harish *et al.,* 2024).

Changing dietary preferences and lifestyles have also played a role, as there is a greater demand for processed and convenience foods, which major cereals like rice and wheat can fulfil more readily than millet. Furthermore, the lack of marketing infrastructure and limited processing facilities for millets have hindered their widespread adoption. These trends underscore the need for strategic interventions to promote millet cultivation and address the factors driving the shift towards other cereals.

3.2 Instability in millet production

The instability index of millet area, production, and productivity was analysed for the last decade, from 2010 to 2023. Compared to rice and wheat, millets such as ragi, sorghum, small millets, and bajra show more variability in the area, production, and yield. The highest instability is seen in area of cultivation of ragi (8.15) and sorghum (7.76), followed by small millets (5.26) and bajra (6.45) presented in Table 2. Production instability in sorghum (11.74) and ragi (14.33) is almost three times higher than in rice and wheat.

Unlike other cereals, this instability is mostly related to decreased growing area and inadequate adoption of improved varieties. Additionally, the yield instability of millet (10.66) is twice as large as that of major cereals (~4), highlighting the technological and variety advances in major cereals compared to millets. The results alignwith the research conducted by Kumar *et al.* (2023).

TABLE 2: CDVI OF INSTABILITY OF AREA, PRODUCTION AND YIELD OF MILLETS VIS-A-VIS MAJOR CEREALS (RICE AND WHEAT) IN INDIA

Crop	Sorghum	Bajra	Ragi	Small millets	Rice	wheat
Area	7.76	6.45	8.15	5.26	2.32	1.91
Production	11.74	9.41	14.33	6.6	3.72	4.72
Productivity	10.66	5.09	11.87	5.15	2.87	4.33

3.3 Production forecast under BAU s*cenario:*

To forecast the production of millets in India from 2024 to 2030 under the BAU scenario, an ARIMA model was employed. The model captures trends, seasonality, and past values in the production time series data. Multiple ARIMA configurations were tested, such as ARIMA(2,1,2), ARIMA(1,1,0), ARIMA(1,1,1), ARIMA(0,1,2), and the optimal model was selected based on statistical criteria including Akaike Information Criterion (AIC)**,** Bayesian Information Criterion (BIC)**, and** Root Mean Square Error (RMSE)**.**

The ARIMA(0,1,1) with drift was found to be the best-fitting model for millet production ('000 tonnes) based on minimum AIC and BIC values (Table 3). The goodness-of-fit statistics are reported in Table 4, with low RMSE (0.10) and MAE (0.08) indicating a satisfactory fit to the historical data. The estimated model parameters, including a significant MA(1) term and drift component, are provided in Table 5.

TABLE 3: AIC AND BIC OF ALTERNATIVE ARIMA MODELS FOR MILLET PRODUCTION

	(2,1,2)	(0,1,0)	(1,1,0)	(0,1,1)	(0,1,0)	(1,1,1)	(0,1,2)	(1,1,2)	(0,1,1)
AIC	-113.1	-90.9	-101.2	-116.3	-91.6	-114.5	-114.5	-113.9	-107.7
BIC	-99.5	-86.4	-94.6	-109.5	-86.4	-105.4	-105.5	-102.6	-103.2

TABLE 4: GOODNESS-OF-FIT STATISTICS FOR THE SELECTED ARIMA (0,1,1) MODEL

ME	RMSE	MAE	Variance	AIC	AIC_C	BIC	Log likelihood
0.0048670	0.1009626	0.0803743	0.01064	-116.31	-115.95	-109.52	61.15

TABLE 5: PARAMETER ESTIMATES OF ARIMA (0,1,1) WITH DRIFT

	Type	Estimate	Standard error
Production	MA_1	-0.7477	0.0807
	Drift	0.0141	0.0033

TABLE 6: FORECAST OF MILLETS PRODUCTION BY USING TIME-SERIES ARIMA MODEL (2023-24 TO 2029-30)

	Jowar			Bajra			Ragi			Small millets		
Year	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production	Area	Yield	Production
2022-23	3535	1079	3814.3	7572	1360	10297.9	1163	1454	1691.0	428	898	384.3
2023-24	3422	1137	3890.8	7528	1431	10772.6	1153	1540	1775.6	415	942	390.9
2024-25	3309	1203	3980.7	7484	1502	11241.0	1142	1627	1858.0	402	986	396.4
2025-26	3173	1224	3883.8	7248	1536	11132.9	1040	1663	1729.5	385	1004	386.5
2026-27	3037	1245	3781.1	7011	1571	11014.3	938	1700	1594.6	368	1021	375.7
2027-28	2907	1279	3718.1	6879	1601	11013.3	895	1730	1548.4	332	1033	343.0
2028-29	2842	1297	3686.1	6797	1623	11031.5	867	1757	1523.3	303	1044	316.3
2029-30	2778	1314	3650.3	6715	1645	11046.2	839	1783	1495.9	274	1054	288.8

NB: Area ('000 ha); Production ('000 tons); Yield (kg/ha)

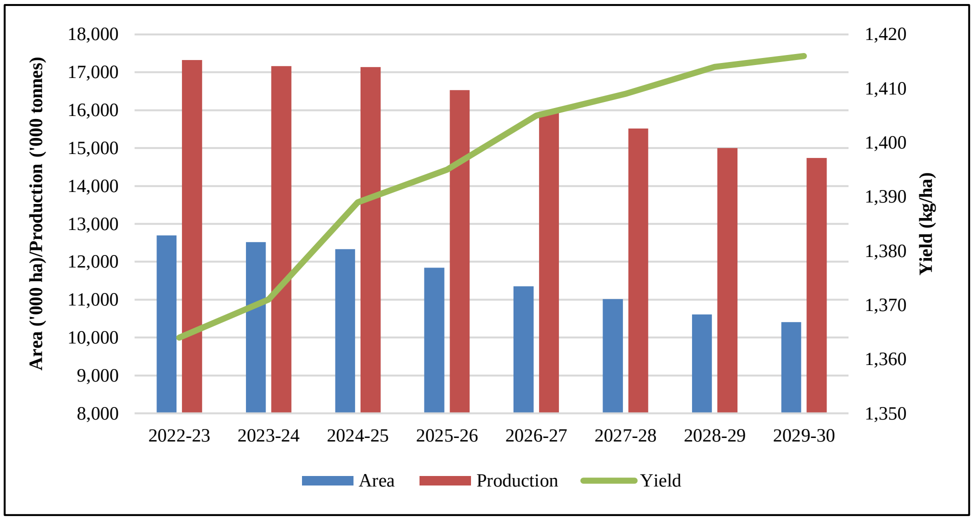

Figure 2. Trends in Area, Production, and Yield of millets in India (2022–2030)

TABLE 7: FORECAST OF TOTAL MILLETS PRODUCTION BY USING TIME-SERIES ARIMA MODEL (2023-24 TO 2029-30)

		2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
Total millets	Area	12,698	12,518	12,337	11,846	11,354	11,013	10,609	10,406
	Yield	1,364	1,371	1,389	1,395	1,405	1,409	1,414	1,416
	Production	17,320	17,162	17,136	16,525	15,952	15,517	15,001	14,735

Area ('000 ha) x Yield (kg/ha) = Production ('000 tons)

The ARIMA results indicate that the production of millets is projected to decline to 14.7 million tons and the area to 10.4 million ha by 2030, as compared to the current production level of 17.3 million tons and 12.6 million hectares in 2022-23, respectively.

3.4 Alternative scenarios to harness the millet production

Scenario I: Bringing fallow and wastelands under cultivation

As of 2022-23 India has around 25.18 million hectares of culturable waste and fallow land, signifying vast potential for expanding cultivable area. States like Rajasthan, Gujarat, and Maharashtra lead in such land availability, indicating scope for targeted land development strategies. (Agricultural Statistics at a Glance, 2022)

TABLE 8: TOP STATES WITH HIGHEST CULTURABLE WASTE AND FALLOW LAND (IN '000 HA)

State	Culturable Waste Land	Current Fallow Land	Total waste & fallow land
All India	11,920	13,255	25175
Rajasthan	3680	1585	5265
Gujarat	1917	661	2578
Maharashtra	944	1456	2400
Andhra Pradesh	402	1499	1901
Jharkhand	382	1386	1768
Odisha	577	943	1520
Uttar Pradesh	369	966	1335
Madhya Pradesh	886	344	1230
Tamil Nadu	346	800	1146
Karnataka	394	678	1072

3.5 Production Projections in Leading Millet-Producing States

The top five millet-producing states in India are Rajasthan (48.09 lakh tons), Uttar Pradesh (26.98 lakh tons), Karnataka (17.49 lakh tons), Maharashtra (17.15 lakh tons), and Madhya Pradesh (12.68 lakh tons) at the forefront of millet cultivation.

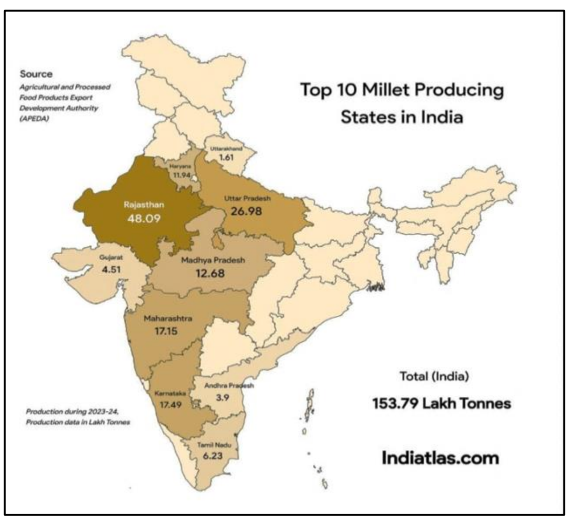

Figure 3. Top 10 Millet Producing States in India

These states were examined to estimate the production potential of millets by bringing a proportion of their wastelands and fallows under cultivation. The analysis assumes no change in yield levels and considers three stages of land utilization: 4%, 8%, and 12% of available wasteland/fallow area, corresponding to short-, medium-, and long-term scenarios respectively (2024–25, 2026–27, and 2029–30).

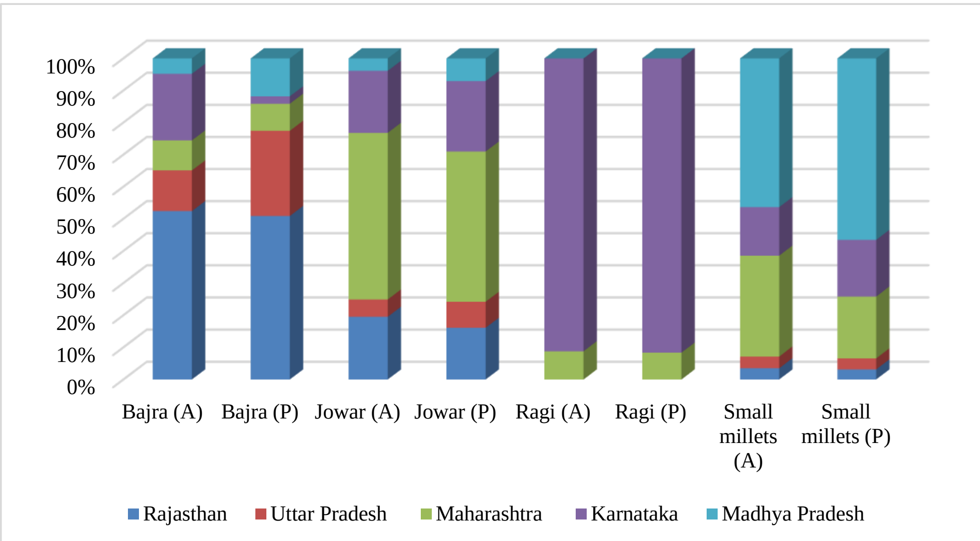

Figure 4. Leading States in India by Millet Cultivation Area and Production

These five states were selected for further analysis due to their dominant share in both the cultivation area (A) and production (P) of various millet crops, as illustrated in the graph above Fig 3. Rajasthan leads significantly in the area and production of bajra (pearl millet), contributing over half of the national figures. Maharashtra is the primary state for jowar (sorghum), accounting for the largest proportion of both its area and production. Karnataka dominates in the case of ragi (finger millet), with nearly 90–100% of the crop's cultivation and output concentrated in the state. For small millets, Madhya Pradesh emerges as the leading contributor, followed by Maharashtra and Karnataka (APEDA 2023). This state-wise leadership in specific millets justifies their selection for production potential estimation, as any expansion in area under these crops particularly on fallow and wasteland could significantly enhance national output. With the largest expanse of cultivable waste and fallow land (5.27 million ha), Rajasthan offers the greatest scope for expansion. Assuming a stable yield of 1001 kg/ha, additional production of bajra is 210.81 thousand tons in 2024–25 and 421.62 thousand tons in 2026–27, and 632.43 thousand tons in 2029–30.

TABLE 9: PROJECTED INCREASE IN PRODUCTION OF BAJRA IN RAJASTHAN WITH ADDITIONAL AREAS FROM WASTE AND FALLOW LAND[ASSUMING NO CHANGE IN YIELD]

Component	2024-25	2026-27	2029-30
Additional waste & fallow land area under millets ('000 ha)	4% of 5265 = 210.60	8% of 5265 = 421.20	12% of 5265 = 631.80
Bajra area ('000 ha)	210.60	421.20	631.80
Yield level (kg/ha) *(assumed constant)*	1001.00	1001.00	1001.00
Additional production ('000 tons)	210.81	421.62	632.43

Total fallow and wasteland available in Rajasthan in 2023: 5265 '000 ha (area × yield = production)

TABLE 10: PROJECTED INCREASE IN PRODUCTION OF BAJRA IN UTTAR PRADESH WITH ADDITIONAL AREAS FROM WASTE AND FALLOW LAND[ASSUMING NO CHANGE IN YIELD]

Component	2024-25	2026-27	2029-30
Additional waste & fallow land area under millets ('000 ha)	4% of 1335 = 53.4	8% of 1335 = 106.8	12% of 1335 = 160.2
Bajra area ('000 ha)	53.4	106.8	160.2
Yield level (kg/ha) *(assumed constant)*	2156.0	2156.0	2156.0
Additional production ('000 tons)	115.13	230.26	345.39

Total fallow and wasteland available in Uttar Pradesh in 2023: 1335 '000 ha

TABLE 11: PROJECTED INCREASE IN PRODUCTION OF JOWAR IN MAHARASHTRA WITH ADDITIONAL AREAS FROM WASTE AND FALLOW LAND[ASSUMING NO CHANGE IN YIELD]

Component	2024-25	2026-27	2029-30
Additional waste & fallow land area under millets ('000 ha)	4% of 2400 = 96	8% of 2400 = 192	12% of 2400 = 288
Jowar area ('000 ha)	96	192	288
Yield level (kg/ha) *(assumed constant)*	945.01	945.01	945.01
Additional production ('000 tons)	90.72	181.44	272.16

Total fallow and wasteland available in Maharashtra in 2023: 2400 '000 ha

TABLE 12: PROJECTED INCREASE IN PRODUCTION OF RAGI IN KARNATAKA WITH ADDITIONAL AREAS FROM WASTE AND FALLOW LAND[ASSUMING NO CHANGE IN YIELD]

Component	2024-25	2026-27	2029-30
Additional waste & fallow land area under millets ('000 ha)	4% of 1072 = 42.88	8% of 1072 = 85.76	12% of 1072 = 128.64
Ragi area ('000 ha)	42.88	85.76	128.64
Yield level (kg/ha) *(assumed constant)*	1332.0	1332.0	1332.0
Additional production ('000 tons)	57.12	114.24	171.35

Total fallow and wasteland available in Karnataka in 2023: 1072 '000 ha

TABLE 13: PROJECTED INCREASE IN PRODUCTION OF SMALL MILLETS IN MADHYA PRADESH WITH ADDITIONAL AREAS FROM WASTE AND FALLOW LAND[ASSUMING NO CHANGE IN YIELD]

Component	2024-25	2026-27	2029-30
Additional waste & fallow land area under millets ('000 ha)	4% of 1230 = 49.2	8% of 1230 = 98.4	12% of 1230 = 147.6
Small millets area ('000 ha)	49.2	98.4	147.6
Yield level (kg/ha) *(assumed constant)*	1079	1079	1079
Additional production ('000 tons)	53.08	106.17	159.26

Total fallow and wasteland available in Madhya Pradesh in 2023: 1230 '000 ha

TABLE 14: PROJECTED INCREASE IN PRODUCTION OF MILLETS IN INDIA WITH ADDITIONAL AREAS FROM WASTE AND FALLOW LAND[ASSUMING NO CHANGE IN YIELD]

Component		2024-25	2026-27	2029-30
Additional area under millets		4% of Total Land =1434.6	8% Of Total Land = 2869.2	12% of Total Land = 4303.8
Millets-wise share of area ('000 ha)	Sorghum	399.34	798.69	1198.04
	Pearl Millet	855.41	1710.82	2566.23
	Finger Millet	131.38	262.76	394.15
	Small Millet	48.45	96.91	145.36
Yield level (kg/ha) at constant level	Sorghum	1079	1079	1079
	Pearl Millet	1360	1360	1360
	Finger Millet	1454	1454	1454
	Small Millet	898	898	898
Additional production ('000 tons)	Sorghum	430.90	861.80	1292.70
	Pearl Millet	1163.36	2326.72	3490.08
	Finger Millet	191.03	382.07	573.10
	Small Millet	43.51	87.03	130.54
Total additional production ('000 tons)		1828.80	3657.61	5486.61

States such as Rajasthan, Uttar Pradesh, Maharashtra, Karnataka, and Madhya Pradesh, which are already major producers, possess untapped land resources that can significantly increase output even without yield improvements. By strategically reclaiming just 4 percent to 12 percent of the available waste and fallow land, these five states alone could potentially produce an additional 0.53 million tons (2024-25) to 1.58 million tons (2029-30) of millets. These estimates underscore the importance of region-specific land development policies, extension services, and support infrastructure to operationalize this latent potential.

As of 2021-22, India has approximately 36 million hectares of fallow and waste land. The target is to cultivate 4 percent of these lands with millet by 2024–25, 8 percent by 2026–27, and 12 percent by 2029–30. The distribution of these lands to distinct millet is determined by the ratio of cropped areas in 2022–23. Thus, bringing wastelands under cultivation has the potential to increase millet production by approximately 5.48 million tons by 2030. As millets can survive in water-stressed environments, the promotion of millet production in states such as Tamil Nadu, Madhya Pradesh, Odisha, Maharashtra, and Gujarat, where fallow land can be converted into profitable millet fields, will result in enhanced farm incomes in dryland regions.

Scenario II: Bridging the yield gap

This scenario is based on assessing the difference between the potential yield and actual yield of millets. The yield gap represents the difference between the yield of an improved seed variety at the research station and its yield at the farmer's field. Frontline demonstrations at research stations primarily aim to showcase the productivity potential and profitability of the latest seed technologies in real farm conditions. These yield gaps vary significantly across states: Rajasthan (449%), Maharashtra (333%), Karnataka (211%), Uttar Pradesh (224%), as well as millet types: Sorghum (44%), Bajra (17%), Ragi (40%), Small millets (57%) (NABARD 2023), highlighting the immense potential for increasing production through state- and millet-specific policies and practices.

The strategy to bridge the yield gap involves improving farming practices, such as better soil management, optimal use of inputs like fertilizers and water, and adopting advanced agricultural techniques, to achieve higher yields per unit area. Table 15 below presents the attainable level of millet production if yield gaps are bridged by 5 percent by 2024–25, 10 percent by 2026–27, and 20 percent by 2029–30. With this strategy, an additional 0.80 million tons of millet could be produced by 2024–25. This would increase to 1.61 million tons by 2026–27, and further to 3.23 million tons by 2030.

TABLE 15: PROJECTED INCREASE IN PRODUCTION OF MILLETS IN INDIA BY BRIDGING A YIELD GAP WITH A CONSTANTBASELINE AREA

Components		2024-25	2026-27	2029-30
Millets-wise share of area ('000 ha) at constant level	Sorghum	3535	3535	3535
	Pearl Millet	7572	7572	7572
	Finger Millet	1163	1163	1163
	Small Millet	428.92	428.92	428.92
Change in yield percentage		5 % increase intotal yield	10% increase in total yield	20 % increase in total yield
Yield level (kg/ha)	Sorghum	53.95	107.9	215.8
	Pearl Millet	68	136	272
	Finger Millet	72.7	145.4	290.8
	Small Millet	44.9	89.8	179.6
Additional production ('000 tons)	Sorghum	190.71	381.42	762.85
	Pearl Millet	514.89	1029.79	2059.58
	Finger Millet	84.55	169.10	338.20
	Small Millet	19.26	38.52	77.03
Total additional production ('000 tons)		809.42	1618.84	3237.67

Scenario III: Integrated approach

This approach is based on bringing the fallow and waste lands under cultivation, and at the same time bridging the yield gap. The target under this strategy is to bring the 4 percent wastelands under millet cultivation and also bridge the 5 percent yield gap by 2024-25. These targets can be raised to 8 percent area and 10 percent yield gap by 2026-27, and 12 percent area and 20 percent yield gap by 2029-30. This integrated approach shows that an additional 2.63 million tons of millets could be produced by 2024-25, and it would increase to 5.27 million tons by 2026-27, and further to 8.72 million tons by 2030.

TABLE 16: PROJECTED INCREASE IN PRODUCTION OF MILLETS IN INDIA BY INTEGRATED APPROACH

Component		2024-25	2026-27	2029-30
Additional area under millets		4% Of Total Land =1828	8% Of Total Land = 3632	12% Of Total Land = 7228
Additional production ('000 tons) [scenario I]	Sorghum	430.90	861.80	1292.70
	Pearl Millet	1163.36	2326.72	3490.08
	Finger Millet	191.03	382.07	573.10
	Small Millet	43.51	87.03	130.54
		5% increase in total yield	10 % increase in total yield	20 % increase in total yield
Additional production ('000 tons) [scenario II]	Sorghum	190.71	381.42	762.85
	Pearl Millet	514.89	1029.79	2059.58
	Finger Millet	84.55	169.10	338.20
	Small Millet	19.26	38.52	77.03
Total additional production ('000 tons)	Sorghum	621.61	1243.22	2055.55
	Pearl Millet	1678.25	3356.51	5549.65
	Finger Millet	275.58	551.17	911.30
	Small Millet	62.77	125.54	207.57
Total additional production ('000 Tons)		2638.22	5276.44	8724.08

3.6 Comparative analysis of alternative strategies

The projected increase in millet production through various strategies from 2024 to 2030 is given in Table 17. The analysis compares 3 scenarios with BAU as a base scenario (ARIMA model). The ARIMA model clearly indicates a potential decrease in millet production by 2029-30, raising important challenges for planners and policy-makers. It is the integrated approach and other strategies that offer opportunities not only to mitigate the decline but also to achieve sustainable increases in production.

TABLE 17: PROJECTED INCREASE IN MILLET PRODUCTION THROUGH VARIOUS STRATEGIES

Particulars	2024-25	2026-27	2029-30
Business as usual (BAU) approach	17074 (-246)	15811 (-1,509)	14613 (-2,707)
Scenario I: Additional Millet Production by Bringing the Fallow & Wastelands Under Cultivation	1828.80	3657.61	5486.41
Scenario II: Additional Millet Production by Bridging the Yield Gap	809.42	1618.84	3237.67
Scenario III: Integrated Approach	2638.22	5276.44	8724.08

NB: Production ('000 tons)

In this context, the ARIMA model has predicted a potential decrease in millet production of 2.70 million tons by 2029-30 compared to the baseline production of 17.32 million tons in 2022-23. The findings indicate that the integrated approach shows the most promising results in increasing millet production, with an additional production of 8.72 million tons by 2029-30. Bringing fallow and waste lands under cultivation could lead to an additional production of 5.48 million tons by 2029-30 while bridging the yield gap could result in an additional production of 3.23 million tons. The integrated approach not only significantly increases millet production but also offers benefits such as improved soil health, water conservation, enhanced biodiversity, and increased resilience to climate change.

3.7 Strategies for Promoting Millet Cultivation on Fallow Lands

The successful conversion of fallow land into productive millet-growing areas across states like Madhya Pradesh, Odisha, Tamil Nadu, and Maharashtra points toward a replicable set of strategies that can be scaled nationally.

Policy and Governmental Interventions:

- Integrate millet promotion into flagship schemes such as Rashtriya Krishi Vikas Yojana (RKVY), PM-KISAN, and Mahila Kisan Sashaktikaran Pariyojana (MKSP) by earmarking funds for fallow land development.
- Incentivize millet cultivation on fallow land through input subsidies (for seeds, biofertilizers), land conversion incentives, and assured procurement at MSP.
- Facilitate access to land for landless and marginal farmers via community leasing models and sharecropping frameworks, as demonstrated under the Odisha Millet Mission.
- Adopt state-level targets and convergence models, like Tamil Nadu Vision 2023, to bring fallow lands under cultivation through scientific interventions.

Agricultural Extension Agencies (KVKs, ATMA, Departments of Agriculture):

- Conduct targeted awareness and capacity-building programs via farmer field schools and on-farm demonstrations to showcase the benefits of millet cultivation on fallow lands.
- Promote scientific practices, such as row sowing, use of improved varieties/hybrids, organic nutrient management, and critical stage irrigation.
- Facilitate training in post-harvest processing and marketing, including grading, branding, and linking farmers to buyers or FPOs for better price realization.

- Develop custom hiring centers in millet clusters to provide access to necessary farm machinery and reduce drudgery.

Farmer Producer Organizations (FPOs) and NGOs:

- Mobilize farmers to collectively lease and cultivate fallow lands, especially for women and tenant farmers.
- Support input supply and market linkage functions, ensuring scale economies and better bargaining power.
- Build community seed banks for local adaptation and cost reduction, and support training in value-added millet products to boost income.

Research and Academic Institutions:

- Bridge the yield gap in millet cultivation through adaptive trials and localized varietal recommendations, as seen in Maharashtra's Madgyal village.
- Develop location-specific agronomic packages and tools to assess the suitability of fallow lands for millet crops.

Private Sector and Digital Platforms:

- Introduce mobile-based advisory services and e-market platforms for millet growers to access real-time guidance and price intelligence.
- Partner with agri-tech startups to provide input delivery, credit access, and post-harvest solutions tailored to millet cultivation.

Promoting millet cultivation on fallow lands through coordinated efforts of government policies, extension services, FPOs, research institutions, and private players can significantly improve land use and farmer incomes. (Gautam *et al.*, 2023). Scaling these strategies across regions can help increase millet production and support sustainable agriculture.

IV

CONCLUSIONS

The research findings clearly bring out the huge potential of an integrated approach to increasing millet production. This strategy is projected to yield an additional 8.72 million tons by 2029-30. NITI Aayog predicts millet demand by 2029-30 will be between 57-64 million metric tons, which is much higher than present production levels (17 million tons). In response to the rising demand, the Center has set an ambitious goal to increase production to 45 million metric tons by 2030. Adopting this integrated approach will allow us to increase millet production by an additional 50%, bridging the gap between demand and supply. This strategy not only aligns with the Centre's goals but also ensures food security and supports sustainable agricultural practices. Implementing this approach is imperative for meeting future millet demand and securing the nation's nutritional needs.

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