



RESEARCH ARTICLE

Dynamics of total factor productivity of millets in India

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Abstract

This study examined the growth performance and determinants of total factor productivity (TFP) for three selected major millets, viz. sorghum, pearl millet and ragi in the principal millet growing states of India during 2010–11 to 2021–22. Using crop and state specific timeseries data from the Directorate of Economics and Statistics, Divisia–Törnqvist indices were employed to estimate total output index, total input index and total factor productivity, while compound growth rates and regression analysis were used to assess productivity trends and their determinants. Results indicate that, output indices rose sharply for all three millets across states, negative TFP growth was observed for sorghum and pearl millet in almost all major producing states, whereas ragi exhibited positive TFP growth in Karnataka (2.4 %) and Odisha (1.4 %). Regression results indicate that public expenditure on agricultural research, education and extension per hectare has a positive and statistically significant effect on TFP for sorghum in Andhra Pradesh (0.03) and Tamil Nadu (0.11) and for pearl millet in Gujarat (0.10) and Maharashtra (0.01), while cropping intensity has a strong positive and significant influence on sorghum TFP in Karnataka (3.96) and Maharashtra (0.53). The findings suggest that millet development strategies should transcend input intensification and prioritise efficiency gains, technology adoption and location-specific management in predominantly rainfed production environments.

Keywords: agricultural research; cropping intensity; millets; pearl millet; ragi; sorghum; total factor productivity

Introduction

Millets have been crucial part of Indian agriculture for a long time, especially within arid and semi-arid regions of the country. Among them, sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.) and finger millet (*Eleusine coracana* L.) are widely cultivated across diverse agro-climatic conditions of the country (1–3). India is the world's largest producer of millets, contributing about 40 % of global and 80 % of Asian millet production (4, 5). Their adaptability, low input requirement and ability to perform well under marginal conditions make them especially suitable for small and marginal farmers in rainfed, risk-prone areas (6, 7).

However, the production landscape of millets in India has undergone significant structural changes over time. Since the mid-1960s, the area under millet cultivation has declined sharply by 71 %, from 35 million hectares in 1950–51 to about 9.98 million hectares in 2024–25 (3, 8). Despite this substantial reduction in cultivated area, millet productivity has shown a remarkable increase. Average yields have more than doubled since 1966, reaching approximately 1262 kg/ha in 2023–24 (5). This trend indicates that productivity gains have primarily been driven by technological advancements and improved agronomic practices rather than expansion in cultivated area (9, 10).

In recent years, millets have gained renewed attention among researchers, policymakers and consumers; and have been rebranded as “nutri-cereals” due to their superior nutritional profile. Rich in proteins, dietary fiber, essential minerals and antioxidants, millets play a crucial role in addressing malnutrition and promoting human health (11–14). Their importance has further increased in the context of global initiatives such as the International Year of Millets (2023) led by the Food and Agriculture Organization and their contribution toward achieving Sustainable Development Goals, particularly zero hunger, good health and climate action (15–17). Moreover, in the face of climate change, water scarcity and the ecological limitations of rice-wheat dominated systems, millets offer a sustainable alternative. Being C4 crops, sorghum and pearl millet exhibit higher photosynthetic efficiency and water-use efficiency compared to C3 cereals, enabling them better performance under heat and moisture stress with a lower carbon and water footprint (18).

Despite their growing importance, the assessment of productivity in millets has largely relied on partial indicators such as yield per hectare or output per worker (19). While these indicators provide useful insights, but they do not capture the combined effect of multiple inputs viz., land, labour, machinery, seed, fertiliser, irrigation, capital used in production. Total factor productivity (TFP) provides a more comprehensive approach by relating aggregate output to bundle of inputs and it is most useful to evaluate economic

performance as an ex-post facto for resource constrained crops like millets (20, 21). Moreover, TFP analysis is critical to determining whether growth is a result of input intensification or efficiency-driven technological progress (22). Most of the empirical studies on TFP in Indian agriculture have primarily focused on three major big crops viz. rice, wheat, maize and few commercial crops, usually at national and regional levels (23–26). In contrast, research on millets has been relatively limited. Even when millets are considered, they are often grouped under broad categories like “coarse cereals,” which obscures important variations in performance across different millet types and states (27).

Against this backdrop, the present study examines the dynamics of TFP of millets in India during the period 2010–11 to 2021–22, with specific reference to sorghum, pearl millet and finger millet in the principal millet producing states. The study is guided by the objective of estimating and comparing the TFP performance of these major millet crops and identifying the determinants influencing their productivity dynamics. More specifically, it seeks to assess whether millet productivity in India is stagnating, declining or structurally transforming and to examine how this productivity trends relate to broader concerns of food security, climate resilience and diversification-oriented agricultural policy. The study hypothesises that TFP behaviour in millets is not uniform across crops and states, but varies according to differences in production environment, technological change, resource use efficiency and institutional support. It is further hypothesised that greater public investment in agricultural research, education and extension, along with favourable cropping intensity, contributes positively to millet productivity, whereas the influence of rainfall and irrigation may remain limited or crop specific in predominantly rainfed millet systems.

Materials and Methods

The analysis is based on secondary data compiled from published sources, including the comprehensive scheme for cost of cultivation of principal crops (28). The TFP captures the share of output change that cannot be attributed solely to changes in measured inputs. Accordingly, TFP growth reflects the difference between the growth of aggregate output and the growth of aggregate input use (29, 30). Estimation of TFP was carried out using the Divisia-Tornqvist index, which is widely regarded as an appropriate approach for productivity measurement (31). For computation of the total output, total input and TFP indices, the study considered major sorghum-producing states (Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu), pearl millet (bajra) producing states (Gujarat, Maharashtra, Rajasthan and Uttar Pradesh) and finger millet (ragi) producing states (Karnataka and Odisha). The analysis covered the period from 2010–11 to 2021–22, corresponding to the years for which cost of cultivation data was available. State-level farm harvest prices (current prices) were used to construct the output index.

For developing the total input index, 14 input components were included viz., human labour, animal labour, machine labour, seed, fertilisers and manures, insecticides, irrigation charges, miscellaneous expenses, interest on working capital, rental value of owned land, rent paid for leased-in land, land revenue taxes and cesses, depreciation on implements and buildings and interest on fixed capital.

Total output index (TOI) between period t and $t-1$ was computed as a Tornqvist-Theil index using Equation (1):

$$TOI_t / TOI_{t-1} = \prod_j (Q_{jt} / Q_{j,t-1})^{1/2} (R_{jt} + R_{j,t-1}) = A_t \dots\dots\dots (1)$$

Similarly, the Total Input Index (TII) was estimated using Equation (2):

$$TII_t / TII_{t-1} = \prod_i (X_{it} / X_{i,t-1})^{1/2} (S_{it} + S_{i,t-1}) = B_t \dots\dots\dots (2)$$

Where, R_{jt} and $R_{j,t-1}$ = Share of the j^{th} crop output in total revenue in the year t , Share of the j^{th} crop output in total revenue in $t-1$ year,

Q_{jt} and $Q_{j,t-1}$ = Output of j^{th} crop in year t , Output of j^{th} crop in year $t-1$,

S_{it} and $S_{i,t-1}$ = Share of input i in total input cost in year t , Share of input i in total input cost in year $t-1$,

X_{it} and $X_{i,t-1}$ = Quantity of input i in year t , Quantity of input i in year $t-1$,

t = Time period.

The TFP was then obtained as the ratio of output index to input index using Equation (3):

$$TFP_t = (TOI_t / TII_t) \times 100 \dots\dots\dots (3)$$

Equations (1) to (3) yield the respective indices for total output, total input and TFP for the time period t .

While computing the TFP series, a chain index approach was adopted rather than a single fixed-base index (20). The chain method links year-to-year changes in productivity so that longer-term movement is obtained by multiplying successive annual indices. In other words, an index for year $t+1$ relative to base year t is constructed and then extended across the full series (from $t = 0$ to T) by chaining the adjacent-period indices. The comparison of period t with the initial base period 0 is therefore obtained using the chain product of consecutive indices.

$$I_{(0,t)} = I_{(0,1)} \times I_{(1,2)} \times I_{(2,3)} \times \dots \times I_{(t-1,t)} \dots\dots\dots (4)$$

The compound annual growth rate (CAGR) of TFP is commonly used to indicate whether a production system is moving toward or away from sustainability over time. A production system can be considered sustainable when it is able to maintain positive TFP growth over the long run (13). To estimate growth in output, input and TFP over the study period, an exponential trend model was fitted separately to the respective index series.

$$Y = ab_t \dots\dots\dots (5)$$

The CAGR has been computed using the formula:

$$CAGR = (\text{Antilog } b - 1) 100$$

The F test has been applied to test the significance of b (6)

Multiple regression

A multiple regression framework was used to identify the key determinants associated with TFP growth for millets across the major millet-producing states of India. In this approach, crop-specific TFP indices were taken as the dependent variable and were related to a set of explanatory factors that are expected to influence productivity performance. The functional relationship was specified in log-linear form as:

$\ln(\text{TFP}_{\text{crop}}) = f[\ln(\text{Government expenditure on agricultural research and education per hectare of cultivated land}),$

ln (Average Annual rainfall in the state in millimetre), ln (Cropping intensity), ln (Net irrigated area)} (7)

The required secondary data on public spending for agricultural research and education (per hectare of cultivated area), average annual rainfall (mm), cropping intensity and net irrigated area was compiled from the India Stat database.

Results and Discussion

The Tornqvist indices of the total output, total input and TFP of sorghum, bajra and ragi crops in India were estimated from 2010–11 to 2021–22 to assess productivity performance in the major producing states of India. The Tornqvist index is widely used in agricultural productivity analysis because it decomposes output growth into input growth and residual productivity change (32). The revised results for sorghum are presented below.

Total factor productivity of sorghum in major producing states

Table 1 and Fig. 1 present the trends and CAGR of the TOI, TII and TFP of sorghum across major producing states viz. Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu from 2010–11 to 2021–22, with 2010–11 as the base year (index = 100).

Andhra Pradesh

The TFP of sorghum in the state of Andhra Pradesh decreased annually with a CAGR value of -0.61 %, despite strong growth in TOI (8.76 % CAGR) and TII (9.43 % CAGR), shows that productivity growth did not keep pace with the rise in inputs. Average values of

TOI, TII and TFP were 149.41, 159.52 and 88.99, respectively indicating 50–60 % higher output and input use than the base year (2010–11 = 100), while productivity remained below the base level. The TOI indices were highest in the year 2021–22 (422.56), followed by 2020–21 (308.11) and lowest in the year 2018–19 (60.08). The TII was recorded highest in the year 2021–22 (353.98) and lowest in the year 2011–12 (96.08). The TFP exceeded the base value of 100 in the years 2013–14 (104.15), 2014–15 (100.68), 2015–16 (101.58), 2020–21 (105.84) and 2021–22 (119.38), suggesting that during these years improved technology, better management practices or favourable weather conditions enabled farmers to obtain more output per unit of input. In contrast, the lowest TFP values were recorded in 2018–19 (51.69) and 2016–17 (55.12), which was due to the severe drought and very low annual rainfall. During these years, farmers incurred higher input use (high TII) but achieved only modest surge in output (moderate TOI), likely due to adverse weather conditions, pest and disease outbreaks and other production shocks (23).

Karnataka

The TFP of sorghum in the state of Karnataka annually decreased with a CAGR value of -2.37 %. This occurred despite strong growth in the TOI at 8.10 % per annum and an even faster rise in the TII at 10.72 % per annum. The average, TOI, TII and TFP were 181.83, 194.76 and 93.58, respectively, implying that output and input use increased by approximately 80–95 % higher than in the base year, while productivity remained below the base level. The TOI values were recorded highest in the year 2019–20 (281.99), followed by 2018–19 (260.80) and 2021–22 (235.54) and lowest in the year

Table 1. Total factor productivity of sorghum in major producing states of India from 2010–11 to 2021–22

Years	Andhra Pradesh			Karnataka			Maharashtra			Tamil Nadu		
	TOI	TII	TFP	TOI	TII	TFP	TOI	TII	TFP	TOI	TII	TFP
2010–11	100	100	100	100	100	100	100	100	100	100	100	100
2011–12	83.24	96.08	86.64	169.23	152.09	111.27	52.64	63.71	82.62	234.76	236.44	99.29
2012–13	92.74	107.87	85.98	100.24	133.3	75.2	65.02	79.76	81.52	155.74	242.54	64.21
2013–14	148.96	143.03	104.15	169.16	165.95	101.94	111.25	132.14	84.19	228.87	166.74	137.27
2014–15	123.14	122.31	100.68	165.17	179.15	92.2	123.16	167.14	73.69	219.24	171.5	127.83
2015–16	124.37	122.44	101.58	128.9	159.06	81.04	83.13	122.62	67.8	202.05	191.05	105.76
2016–17	74.96	136	55.12	138.04	152.77	90.36	132.07	152.14	86.81	202.95	242.12	83.82
2017–18	150.19	192.15	78.16	198.42	222.21	89.29	135.81	187.21	72.54	216.21	284.3	76.05
2018–19	60.08	116.23	51.69	260.8	243.09	107.28	170.56	187.53	90.95	297.15	310.29	95.77
2019–20	104.56	132.98	78.63	281.99	261.1	108	203.16	212.98	95.39	311.77	346.88	89.88
2020–21	308.11	291.11	105.84	234.44	261.75	89.57	133.57	186.7	71.54	316.98	282.1	112.36
2021–22	422.56	353.98	119.38	235.54	306.67	76.81	145.61	192.02	75.83	280.16	298.59	93.83
Average	149.41	159.52	88.99	181.83	194.76	93.58	121.33	148.66	81.91	230.49	239.38	98.84
CAGR	8.76	9.43	-0.61	8.14	8.92	-0.72	8.52	9.53	-0.92	7.3	7.61	-0.29

Note: TOI: Total output index; TII: Total input index; TFP: Total factor productivity.

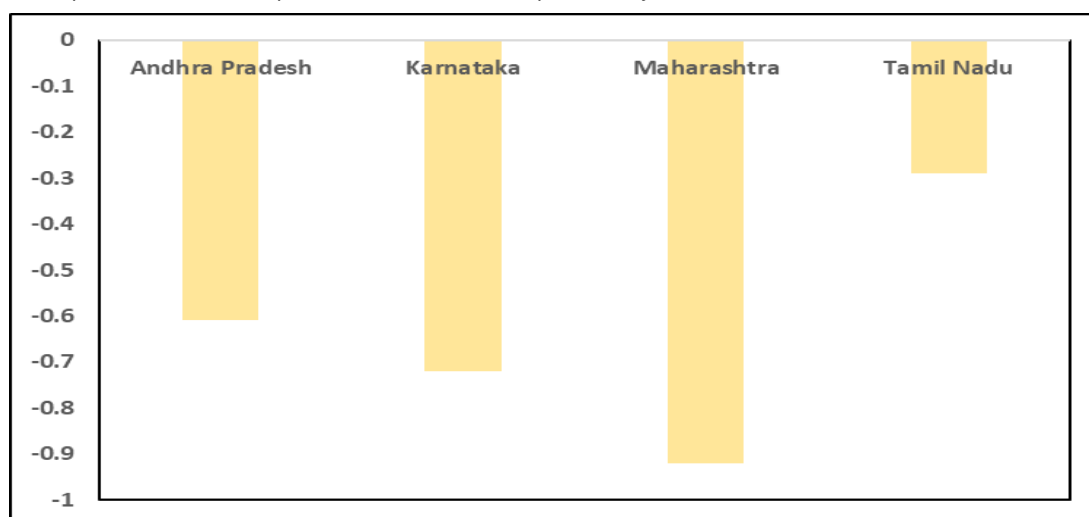


Fig. 1. Compound annual growth rates of total factor productivity of sorghum in major producing states of India from 2010–11 to 2021–22.

2012–13 (100.24). TII was highest in the year 2021–22 (306.67). The TFP values recorded more than base year in 2011–12 (111.27), 2013–14 (101.94), 2018–19 (107.28) and 2019–20 (108.00), suggesting that in these years, farmers obtained more output per unit of input than base year, these years reflect periods of better technology, management and favourable seasons. In contrast, the lowest TFP values were recorded in 2012–13 (75.20) and 2021–22 (76.81). These years reflect input driven, drought affected production and the low investment in agricultural research, education and extension may have contributed to the subdued productivity growth. Empirical studies have consistently highlighted public expenditure on research and extension as an important driver of crop productivity growth in Karnataka (33–35).

Maharashtra

The TFP of sorghum in the state of Maharashtra annually decreased with a CAGR value of -0.92 % over the period. This occurred despite strong growth in the TOI at 8.52 % per annum and an even faster rise in the TII at 9.53 % per annum. The average values of TOI, TII and TFP were 121.33, 148.66 and 81.91, respectively, reveals that output increased by 20 % while input use increased by nearly 50 % over the base year (2010–11 = 100), with productivity remaining well below the base level. The TOI values were highest in the year 2019–20 (203.16), followed by 2018–19 (170.56) and 2016–17 (132.07) and lowest in the year 2011–12 (52.64) and 2012–13 (65.02). The TII, were recorded highest in the year 2019–20 (212.98) followed by 2018–19 (187.53) and 2017–18 (187.21) and lowest in the year 2011–12 (63.71) and 2012–13 (79.76). The TFP remained below the base value, because output falls more than inputs due to bad seasons with limited cost adjustment, so the efficiency of sorghum production never surpasses the base-year level.

Tamil Nadu

The TFP of sorghum in the state of Tamil Nadu annually decreased with a CAGR value of -0.29 %, where CAGR of TOI and TII were 7.30 % and 7.61 % over the period of the study. The average values of TOI, TII and TFP were 230.49, 239.38 and 98.84, respectively, implying that output and input use were both more than double when compared to base year, while productivity stayed just below the base level. The TFP index exceeded the base value of 100 in the year 2013–14 (137.27), 2014–15 (127.83), 2015–16 (105.76) and 2020–21 (112.36), due to good seasons, better yields, shift from animal labour to machinery and efficient use of fertilisers, so each rupee of input produced significantly higher output relative to the base year. In contrast, the lowest TFP values were observed in 2012–13 (64.21), 2016–17 (83.82) and 2017–18 (76.05), coinciding with periods of severe drought and rising input costs, which constrained output growth relative to input use. Such declines highlight the sensitivity of sorghum productivity to climatic stress and cost pressures. Evidence from Tamil Nadu indicates that climatic variability and agro-ecological suitability across districts play a crucial role in determining sorghum performance and productivity outcomes (36).

The inter-state comparison showed negative TFP growth

for sorghum in all four major producing states during the study period, despite substantial increases in output. The steepest decline was observed in Karnataka (-2.37 %), followed by Maharashtra (-0.92 %) Andhra Pradesh (-0.61 %) and Tamil Nadu (-0.29 %). These results indicate that sorghum output growth in the selected states was driven primarily by increased use of inputs rather than by improvements in overall productivity. Previous researchers reported positive TFP growth during a period characterised by stronger technological progress and improved resource-use efficiency in coarse cereals (17). In contrast, the present study reflects a more recent phase marked by increasing input intensification, rising cultivation costs and slower technological gains, resulting in declining productivity. However, broadly consistent with the evidence reported by previous researchers (26). A closer examination of inter-state dynamics further reveals that Tamil Nadu exhibited the highest efficiency resilience, maintaining relatively stable productivity levels over time. In contrast, Karnataka showed the strongest input dependence, where output growth was largely supported by increased input use. Andhra Pradesh, on the other hand, demonstrated the highest climate sensitivity, with pronounced fluctuations in productivity linked to climatic variability. Overall, these findings underscore significant inter-state disparities in sorghum productivity dynamics and highlight the urgent need for targeted technological, agronomic and institutional interventions to enhance efficiency, particularly in rainfed production systems.

Determinants of total factor productivity of sorghum

The determinants of TFP of sorghum from Table 2 show that the regression models explain a substantial proportion of productivity variation across the states, with R^2 values of 0.60 in Karnataka, 0.87 in Maharashtra, 0.79 in Andhra Pradesh and 0.83 in Tamil Nadu. Expenditure on agricultural research, education and extension per hectare had a positive and statistically significant effect on TFP in Andhra Pradesh (0.03) and Tamil Nadu (0.11), indicating that public investment in these areas contributed positively to sorghum productivity in these states (21, 23, 32). Cropping intensity also had a positive and significant effect in Karnataka (3.96) and Maharashtra (0.54), suggesting that more intensive land use was associated with higher productivity where suitable production systems were in place. Annual rainfall showed a negative coefficient in Karnataka and Tamil Nadu, indicating that greater rainfall alone did not necessarily improve sorghum productivity under existing conditions. Overall, the regression results suggest that public investment and cropping intensity were more important drivers of sorghum TFP than rainfall in the study states (32).

Total factor productivity of pearl millet in major producing states

Table 3 and Fig. 2 present the trends and CAGR of the TOI, TII and TTFP of pearl millet across major producing states viz. Gujarat, Maharashtra, Rajasthan and Uttar Pradesh from 2010–11 to 2021–

Table 2. Determinants of total factor productivity of sorghum

Contents	Andhra Pradesh	Karnataka	Maharashtra	Tamil Nadu
R^2	0.79	0.60	0.87	0.83
Expenditure on Agri research, education and extension per ha	0.03*	0.00	0.002	0.11**
Annual rainfall	0.01	-0.04	0.007	-0.05
Net irrigated area	0.01	0.00	0.007	0.06
Cropping intensity	0.48	3.96*	0.538**	0.65

Note: * Significance at 5 % level, ** Significance at 1 % level.

22, with 2010–11 as the base year (index = 100).

Gujarat

The TFP of pearl millet in the state of Gujarat annually decreased with a CAGR value of -0.77 %, where CAGR of TOI and TII were 9.13 % and 8.28 % over the period of the study (36). The average values of the TOI, TII and TFP index in Gujarat over the period were 204.15, 219.03 and 93.80, respectively. The value of the TOI was reached peak in the year 2019–20 (291.66) and 2018–19 (286.99), while TII were highest in the year 2021–22 (317.63) and 2020–21 (288.73). The TFP index exceeded the base year in 2012–13 (108.57), 2018–19 (108.52) and 2019–20 (102.39) because in these years the growth in total output clearly outpaced the growth in total input use. In contrast, TFP index was lowest in 2020–21 (79.95), as total output fell sharply while total input costs continued to rise, so each rupee of input generated much less output than in the base year, leading to decline.

Maharashtra

The TFP of pearl millet in the state of Maharashtra annually decreased with a CAGR value of -0.11 %, where CAGR of TOI and TII were 9.27 % and 9.28 % over the period of the study. The average values of the TOI, TII and TFP index in Maharashtra over the period were 158.02, 193.82 and 81.85, respectively. The TOI reached peak in the year 2018–19 (242.41) and 2019–20 (237.77), whereas the lowest TOI was in 2014–15 (98.34). The TII was highest in the year 2021–22 (298.16). The TFP index exceeded the base year in only once, in 2019–20 (101.20) but remained below the base year in all the other years, hitting a lowest in the year 2015–15 (55.31), indicating that pearl millet production efficiency failed to keep pace with rapidly rising

input costs.

Rajasthan

The TFP of pearl millet in the state of Rajasthan showed annual decline, with a CAGR of -0.92 % over the study period. The average values of the TOI, TII and TFP indices over the period were 170.74, 217.37 and 79.44, respectively. The value of TOI attained its highest in the year 2020–21 (255.42), whereas TII reached its maximum in the year 2021–22 (322.81) and 2020–21 (302.96). The TFP never exceeded the base year and dropped to particularly lowest levels in the year 2015–16 (64.29) and 2021–22 (68.18). This pattern clearly indicates persistent efficiency losses, with input intensification not translating into proportionate gains in sorghum output.

Uttar Pradesh

In Uttar Pradesh TFP showed a marginal decline, with a CAGR of -0.13 %, while the CAGR of TOI and TII were 7.36 % and 7.50 %, respectively. The average values of the TOI, TII and TFP indices were 173.50, 180.34 and 95.61, indicating that output and input levels increased by about 74 % and 80 %, over the base year, while productivity remained only slightly below the base level. The TOI reached highest in the year 2019–20 (260.79), whereas TII was highest in the year 2018–19 (229.85). The highest TFP were recorded in the year 2019–20 (113.58) followed by 2016–17 (108.20), 2012–13 (102.84) and 2018–19 (100.63). These periods reflect comparatively favourable seasons and more efficient use of human labour, machinery, seed, fertilisers and irrigation, so that each rupee spent on input generated more output. The lowest TFP values were recorded in 2011–12 (79.96) and 2020–21 (81.30), due to higher input costs. These are therefore input-driven or stress-affected years, in

Table 3. Total factor productivity of pearl millet in major producing states of India from 2010–11 to 2021–22

Years	Gujrat			Maharashtra			Rajasthan			Uttar Pradesh		
	TOI	TII	TFP	TOI	TII	TFP	TOI	TII	TFP	TOI	TII	TFP
2010–11	100	100	100	100	100	100	100	100	100	100	100	100
2011–12	130.81	145.22	90.08	103.64	117.06	88.53	98.12	137.98	71.11	90.02	112.58	79.96
2012–13	174.98	161.16	108.57	113.76	125.69	90.51	115.33	146.99	78.46	137.54	133.75	102.84
2013–14	168.09	174.68	96.23	129.94	186.01	69.86	153.21	168.64	90.85	144.31	156.5	92.21
2014–15	194.27	218.81	88.79	98.34	177.81	55.31	152.43	201.19	75.76	173.11	176.89	97.87
2015–16	207.23	226.67	91.42	99.01	170.87	57.94	128.91	200.5	64.29	186.1	189.21	98.36
2016–17	193.23	225.74	85.6	180.32	214.31	84.14	199.71	237.46	84.1	233.97	216.24	108.2
2017–18	184.09	220.37	83.54	164.03	196.02	83.68	168.59	239.23	70.47	148.33	178.36	83.16
2018–19	286.99	264.46	108.52	242.41	250.44	96.79	209.88	260.92	80.44	231.31	229.85	100.63
2019–20	291.66	284.84	102.39	237.77	234.96	101.2	247.14	289.71	85.31	260.79	229.61	113.58
2020–21	230.84	288.73	79.95	190.59	254.46	74.9	255.42	302.96	84.31	173.24	213.09	81.3
2021–22	287.61	317.63	90.55	236.46	298.16	79.31	220.08	322.81	68.18	203.31	228	89.17
Average	204.15	219.03	93.8	158.02	193.82	81.85	170.74	217.37	79.44	173.5	180.34	95.61
CAGR	8.28	9.13	-0.77	9.27	9.28	-0.01	9.11	10.13	-0.92	7.36	7.5	-0.13

Note: TOI: Total output index; TII: Total input index; TFP: Total factor productivity.

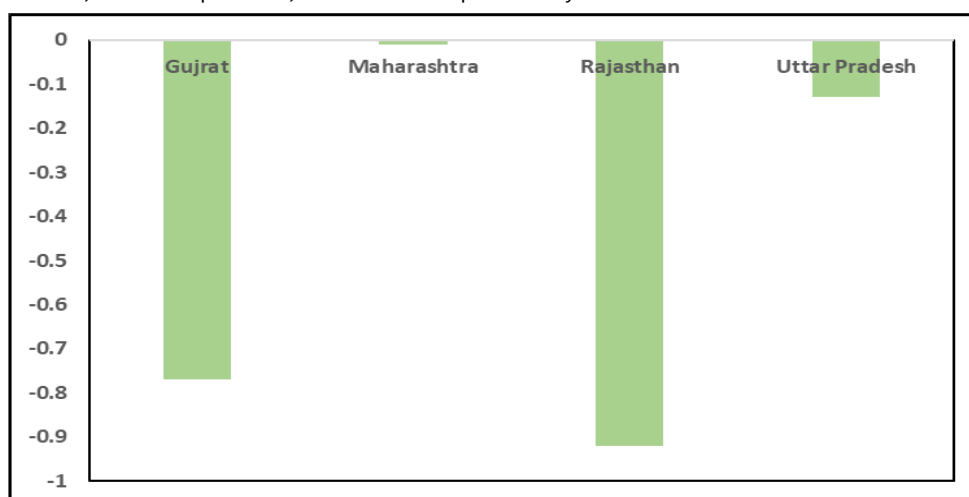


Fig. 2. Compound annual growth rates of total factor productivity of pearl millets in major producing states of India from 2010–11 to 2021–22.

which rising costs and adverse production conditions pushed pearl millet productivity well below the base year level.

The inter-state comparison showed negative TFP growth in all four major pearl millet-producing states during the study period. The steepest decline was observed in Rajasthan (-0.92 %), followed by Gujarat (-0.77 %), Uttar Pradesh (-0.13 %) and Maharashtra (-0.11 %). Hence, pearl millet output growth across these states was predominantly input-led rather than productivity-led. A closer examination of inter-state dynamics shows considerable variation in productivity performance. Among the selected states, Uttar Pradesh exhibited the highest efficiency resilience, maintaining TFP levels close to the base and recording several years with TFP greater than unity. In contrast, Rajasthan demonstrated the strongest input dependence, where rapid increases in input use were not matched by corresponding gains in output, resulting in persistently low productivity levels. Gujarat, on the other hand, showed the highest climate sensitivity, with notable fluctuations in TFP, particularly during stress years when output declined despite continued input use. This pattern suggests that further improvement in pearl millet performance will depend more on efficiency enhancing technologies, climate-resilient cultivars and better crop management than on additional input intensification alone (21, 35).

Determinants of total factor productivity of pearl millet

The regression results in Table 4 show that the explanatory variables account for a high proportion of TFP variation in Gujarat ($R^2 = 0.90$) and Maharashtra ($R^2 = 0.93$) and a moderate proportion in Rajasthan ($R^2 = 0.49$) and Uttar Pradesh ($R^2 = 0.59$). Expenditure on agricultural research, education and extension per hectare had a positive and statistically significant effect on TFP in Gujarat (0.10) and Maharashtra (0.01). By contrast, rainfall and net irrigated area showed small negative and non-significant coefficients in Gujarat and Maharashtra, while rainfall also showed a negative coefficient in Uttar Pradesh. These results indicate that knowledge and innovation-related investment contributed more to TFP improvement than simple expansion of water use. Recent work likewise shows that agricultural research, innovation and extension are central to

productivity growth and farmer adaptation (17, 36).

Total factor productivity of ragi in major producing states

Table 5 and Fig. 3 shows the trends and CAGR of the TOI, TII and TFP of ragi across major producing states viz. Karnataka and Odisha from 2010–11 to 2021–22, with 2010–11 as the base year (index = 100).

Karnataka

The TFP of ragi in Karnataka increased at a CAGR of 2.4 % per annum, while the CAGR of TOI and TII were 11.0 % and 8.4 %. This indicates that expansion in ragi output was driven predominantly by higher input use rather than strong productivity gains. The average TOI, TII and TFP over the period were 226.04, 180.01 and 123.73, respectively, implying that output more than doubled and input use increased by about 80 % over the base year, while productivity improved by only about 24 %. The TOI peaked in 2020–21 (383.83), followed by 2019–20 (316.36), reflecting years of exceptionally high ragi output, whereas the lowest values were recorded in the initial years of the series. The TII was highest in the year 2020–21 (271.47) and 2019–20 (234.83) and remained well above the base from 2012–13 onwards. The TFP remained above the base value of 100 in most of the years, notably in 2012–13 (124.92), 2013–14 (132.36), 2015–16 (111.66), 2016–17 (169.76), 2018–19 (149.69), 2019–20 (134.72) and 2020–21 (141.39), suggesting that in these years farmers were able to secure higher output per unit of input, possibly due to better varieties, improved agronomic practices or favourable weather conditions. These findings are consistent with earlier empirical evidence (32, 35, 37), which reported that technological advancements and enhanced crop management practices contributed significantly to productivity gains in dryland cereal systems.

Odisha

In Odisha, TFP of ragi was showed a positive but slower improvement, with a CAGR of 1.63 %, while the CAGR of TOI and TII were 6.95 % and 5.23 % respectively. The average TOI, TII and TFP were 162.45, 164.36 and 98.06, respectively, indicating that both output and input use were around 60 % higher than the base year, while productivity, on average, remained slightly below the base level. Output growth was strongest

Table 4. Determinants of total factor productivity of pearl millet

Contents	Gujrat	Maharashtra	Rajasthan	Uttar Pradesh
R^2	0.90	0.93	0.49	0.59
Expenditure on Agri research, education and extension per ha	0.1006*	0.010**	0.00	0.03
Annual rainfall	-0.0002	0.001	0.05	-0.01
Net irrigated area	-0.0002	-0.012	0.00	0.01
Cropping intensity	0.0086	0.221	0.98	0.33

Note: * Significance at 5 % level, ** Significance at 1 % level.

Table 5. Total factor productivity of ragi in major producing states of India from 2010–11 to 2021–22

Years	Karnataka			Odisha		
	TOI	TII	TFP	TOI	TII	TFP
2010–11	100	100	100	100	100	100
2011–12	104.96	113.74	92.28	92.97	113.43	81.96
2012–13	154.09	123.35	124.92	131.23	138.82	94.53
2013–14	181.44	137.08	132.36	164.45	159.16	103.33
2014–15	185.8	187.2	99.25	153.23	171.02	89.6
2015–16	229.93	205.93	111.66	144.64	176.94	81.75
2016–17	272.26	160.38	169.76	189.69	184.15	103.01
2017–18	249.67	205.69	121.38	159.46	182.71	87.28
2018–19	292.89	195.67	149.69	178.67	181.15	98.63
2019–20	316.36	234.83	134.72	247.86	189.43	130.84
2020–21	383.83	271.47	141.39	175.63	180.71	97.19
2021–22	241.24	224.76	107.33	211.58	194.83	108.6
Average	226.04	180.01	123.73	162.45	164.36	98.06
CAGR	11	8.4	2.4	6.95	5.23	1.63

Note: TOI: Total output index; TII: Total input index; TFP: Total factor productivity.

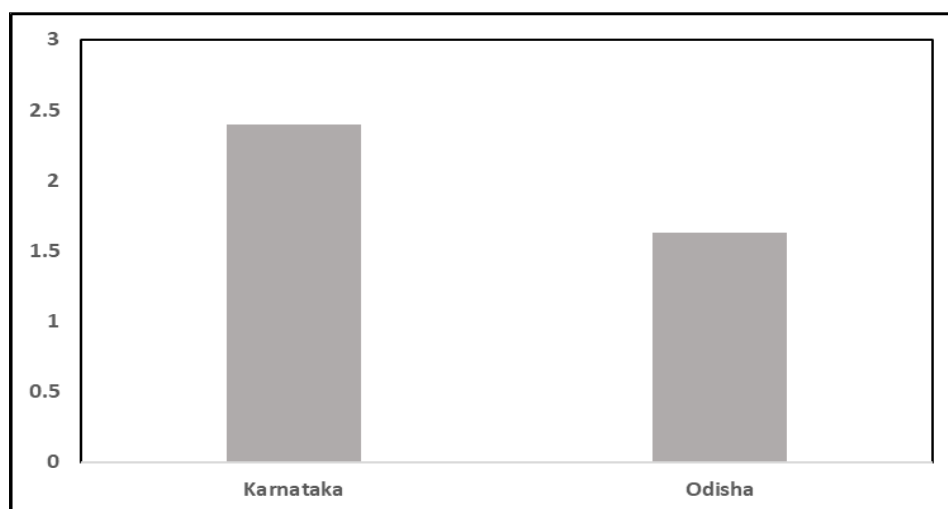


Fig. 3. Compound annual growth rates of total factor productivity of ragi in major producing states of India from 2010–11 to 2021–22.

in the year 2019–20 (247.86), followed by 2021–22 (211.58) and 2016–17 (189.69), whereas the lowest TOI was seen in the year 2011–12 (92.97), pointing to an early year slump in production. Input use was increased steadily and peaked in the year 2021–22 (TII 194.83) and 2019–20 (189.43), showing a clear intensification of ragi cultivation over time. However, TFP exceeded the base value only in a few years viz., 2013–14 (103.33), 2016–17 (103.01), 2019–20 (130.84) and 2021–22 (108.60) indicating that genuine productivity gains were sporadic and often associated with specific favourable conditions like better varieties and policy measures and awareness about millets.

The inter-state comparison of TFP for ragi in two major producing states showed positive TFP growth rate over the study period. While Karnataka shows a more robust and consistent path toward improving productivity, Odisha's efforts will require continued focus on addressing the barriers to sustained productivity improvements. Policy support, technological adoption and targeted interventions will be crucial for both states to ensure that ragi production remains economically viable and competitive in the long term.

Determinants of total factor productivity of ragi

The determinants of TFP of ragi from the Table 6 show that productivity changes much better in Odisha with $R^2 = 0.85$ it indicates that 85 % variation than in Karnataka with $R^2 = 0.33$ indicates 33 % variation. Expenditure on agricultural research, education and extension per hectare and cropping intensity have positive but non-significant effects in both the states, suggesting that greater investment in knowledge systems and more intensive land use is generally supportive of TFP growth (32). In Odisha, annual rainfall (0.039) is the only factor with a positive and statistically significant effect at the 5 % level, highlighting the crucial role of adequate rainfall in sustaining ragi productivity. By contrast, the negative coefficients for rainfall in Karnataka (-0.039) and net irrigated area in Odisha (-0.05), though non-significant, indicate that increases in rainfall or irrigation under existing management conditions do not increase TFP.

Table 6. Determinants of total factor productivity of ragi

Contents	Karnataka	Odisha
R^2	0.33	0.85
Expenditure on Agri research, education and extension per ha	0.009	0.004
Annual rainfall	-0.039	0.039*
Net irrigated area	0.010	-0.050
Cropping intensity	0.195	2.115

Note: * Significance at 5 % level, ** Significance at 1 % level.

Conclusion

The study shows that sorghum and pearl millet experienced negative or near stagnant total factor productivity in most major states, while ragi recorded positive total factor productivity (TFP) growth in Karnataka and Odisha. Public investment in research, education, extension and improved cropping intensity emerged as key factors supporting TFP growth, whereas rainfall and irrigation showed limited influence. Overall, sustained millet productivity will require both stronger technological advancement and better farm-level efficiency in resource use.

Our results suggest that the predominance of input-driven growth in sorghum and pearl millet implied that policy advocacy must be focused on improving input-use efficiency and promoting technological progress, rather than increasing input use in Indian agriculture. The consistent positive role of agricultural research, education and extension services underscores the need for greater and more targeted public investment in millet-focused research and development, including the development of stress-tolerant, high-yielding and nutrient-rich varieties, location-specific agronomic practices and stronger last-mile extension through Farmers Producer Organizations (FPOs), Self-Help Groups (SHGs) and local institutions. The positive association between cropping intensity and TFP in several states suggests that promoting millet-based, diversified cropping systems, including rotations and intercropping with pulses and oilseeds, can enhance resource-use efficiency, soil health and farm incomes, provided suitable risk management and market support mechanisms are in place. The TFP evidence suggests a complete transformational shift to strengthen millet markets, assured remunerative prices, assured procurement, inclusive public distribution schemes, support for local processing, value addition and rural entrepreneurship in the declined millet area (by acreage) by boosting circular economy.

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Authors' contributions

AN contributed to the conception and design of the study and to the analysis and interpretation of the results. SM performed data collection, analysis, interpretation of results and drafted the manuscript. DRB, DTM, S, RRC, AS and CTS contributed to critical revision of the manuscript. All authors read and approved the final version of the manuscript.

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References

- Kumari D, Thakur N, Upmanyu S. The world of millets: a comprehensive overview of millets and their significance. *J Cereal Res.* 2024;16(3):239–45.
- Sukanya TS, Prabhakar KT, Gowda K, Swarna R, Hariprasanna K, Tonapi VA. Good agronomic practices for higher yield in small millets. Hyderabad: ICAR-Indian Institute of Millets Research; 2022.
- Yadav OP, Singh DV, Kumari V, Prasad M, Seni S, Singh RK, et al. Production and cultivation dynamics of millets in India. *Crop Sci.* 2024;1–26.
- Harish MS, Bhuker A, Chauhan BS. Millet production, challenges and opportunities in the Asia-Pacific region: a comprehensive review. *Front Sustain Food Syst.* 2024;8:1386469. <https://doi.org/10.3389/fsufs.2024.1386469>
- Nayak SH, Singh H, Srivastava SK, Nithyashree ML, Balasubramania M. Millets' status in India: an integrated assessment for harnessing their potential. *Indian J Agric Econ.* 2025;80(2):441–59. <https://doi.org/10.63040/25827510.2025.02.011>
- Kumar L, Naresh RK, Tiwari H, Kataria SK, Saharan S, Reddy BR. Millets for food and nutritional security in the context of climate resilient agriculture: a review. *Int J Plant Soil Sci.* 2022;34(23):939–53. <https://doi.org/10.9734/ijpss/2022/v34i232504>
- Dayakar Rao B, Bhaskarachary K, Arlene Christina GD, Sudha Devi G, Tonapi VA. Nutritional and health benefits of millets. Hyderabad: ICAR-Indian Institute of Millets Research; 2017.
- Directorate of Economics and Statistics. Area, production and yield of crops in India. New Delhi: Ministry of Agriculture and Farmers Welfare, Government of India. 2021.
- ICAR-Indian Institute of Millets Research. Vision 2050. Hyderabad: ICAR-Indian Institute of Millets Research. <https://www.millets.res.in/vision/vision2050.pdf>
- Chand R, Kumar P, Kumar S. Total factor productivity and returns to public investment on agricultural research in India. *Agric Econ Res Rev.* 2012;24(1):37–45. <https://doi.org/10.1177/0971344120120201>
- Chapke RR, Satyavathi CT, Srinivas A, Anuradha N, Sevanayak D, Spanditha M. Millets primary processing for income and nutritional security: custom hiring models for farmers. Hyderabad: ICAR-Indian Institute of Millets Research; 2025.
- Nithiyanantham S, Kalaiselvi P, Mahomoodally MF, Zengin G, Abirami A, Srinivasan G. Nutritional and functional roles of millets: a review. *J Food Biochem.* 2019;43(7):e12859. <https://doi.org/10.1111/jfbc.12859>
- Gupta SM, Arora S, Mirza N, Pande A, Lata C, Puranik S, et al. Finger millet: a “certain” crop for an “uncertain” future and a solution to food insecurity and hidden hunger under stressful environments. *Front Plant Sci.* 2017;8:643. <https://doi.org/10.3389/fpls.2017.00643>
- Patel S, Dey A, Yadav A, Singh R. Harnessing millets for climate resilience and nutritional security in India. *Int J Environ Clim Change.* 2023;13(11):1942–49. <https://doi.org/10.9734/ijecc/2023/v13i113352>
- Food and Agriculture Organization. The global status of millets and their potential in sustainable food systems. Rome: FAO; 2023.
- NITI Aayog. Millets in India: policy and prospects. New Delhi: Government of India; 2021.
- Das VK. Total factor productivity growth of jowar and bajra in India. *Agric Econ Res Rev.* 2015;28(Spec Issue):129–40. <https://doi.org/10.5958/0974-0279.2016.00008.2>
- Satyavathi C, Ambawat S, Khandelwal V, Srivastava R. Pearl millet: a climate-resilient nutriceal for mitigating hidden hunger and providing nutritional security. *Front Plant Sci.* 2021;12:659938. <https://doi.org/10.3389/fpls.2021.659938>
- Saikia D. Total factor productivity in agriculture. *Rom J Econ Forecast.* 2017;20(3):81–96.
- Coelli TJ, Rao DSP, O'Donnell CJ, Battese GE. An introduction to efficiency and productivity analysis. New York: Springer; 2005.
- Verma KD, Singh H, Burark SS, Suman J, Lal P. Estimation of total factor productivity growth of major pulse crops in Rajasthan, India. *Legume Res.* 2023;46(1):90–94. <https://doi.org/10.18805/LR-4611>
- Pandey A, Bolia NB. Millet value chain revolution for sustainability: a proposal for India. *Socioecon Plann Sci.* 2023;87:101592. <https://doi.org/10.1016/j.seps.2023.101592>
- Jain R, Chand R, Singh A. Total factor productivity growth in Indian crop sector. *Indian J Agric Econ.* 2017;72(4):535–54.
- Buragohain R, Hazarika JP, Deka N. An analysis of total factor productivity of rice in Assam. *Econ Aff.* 2022;67(4):471–78. <https://doi.org/10.46852/0424-2513.4.2022.12>
- Janaiah A, Achoth L, Bantilan C. Has the Green Revolution bypassed coarse cereals? The Indian experience. *J Agric Dev Econ.* 2005;2(1):20–31.
- Shanmugan K, Prakash BB. Total factor productivity in Indian agriculture. *Indian J Agric Econ.* 2018;73(4):501–14.
- Monga S, Sidana BK. Total factor productivity of coarse cereals in India: state-level analysis using Malmquist approach. *J Pharmacogn Phytochem.* 2020;9(3 Suppl):683–89.
- Directorate of Economics and Statistics. Cost of cultivation/production estimates of principal crops in India. New Delhi: Ministry of Agriculture and Farmers Welfare, Government of India; 2023.
- Aswathy N. Total factor productivity (TFP). In: CMFRI Spec Publ. Kochi: Central Marine Fisheries Research Institute; 2017;127:45–52.
- Rosegrant MW, Evenson RE. Total factor productivity and sources of long-term growth in Indian agriculture. EPTD Discuss Pap No. 7. Washington, DC: Int Food Policy Res Inst; 1995.
- McLellan N. Measuring productivity using the index number

- approach. Treasury Work Pap No. 04/05. Wellington: New Zealand Treasury; 2004.
32. Dinesh TM, Suhasini K, Dayakar Rao B, Rao IS, Srinivasa Chary D. Estimation of determinants of total factor productivity of millets in Karnataka: an application of parametric approach. *Int J Curr Microbiol Appl Sci*. 2019;8(7):1990–97. <https://doi.org/10.20546/ijcmas.2019.807.237>
 33. Kannan E. Total factor productivity growth and its determinants in Karnataka agriculture. Work Pap No. 265. Bengaluru: Inst Soc Econ Change; 2011. <https://www.isec.ac.in/wp-content/uploads/2023/07/WP-265-Elumalai-Kannan.pdf>
 34. Ranjitha S, Mruthyunjaya. Total factor productivity and returns to public investments in agricultural research in India. New Delhi: Natl Cent Agric Econ Policy Res; 2005.
 35. Ananth GS, Chengappa PG, Janaiah A. Impact of research investment on technology development and total factor productivity in major field crops of peninsular India. In: *Proc Int Assoc Agric Econ Conf*; 2006; Gold Coast, Australia.
 36. Abinaya J, Janaki Rani A, Kokilavani S, Nirmala Devi M, Gangaiselvi R. Examining the prospective zones for maize and sorghum in Tamil Nadu. *Biol Forum Int J*. 2022;14(2a):209–12.
 37. Suresh K, Chandrakanth MG. Total factor productivity and returns to investment in ragi (finger millet) crop research in Karnataka state, India. *Indian J Econ Dev*. 2015;3(3):199–205.

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