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Temporal dynamics of finger millet in Karnataka - non parametric statistical approach

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Abstract
Since last few decades, the policy makers and other stakeholders have been continuously promoting rice and wheat; and other crops like millets have suffered negligence thereby resulting in little public and private investment on their research and development. However, in last few years there has been a growing realization of its importance if it's attributes of being nutrient dense and ability to withstand the vagaries of changing climate. This work is an attempt to investigate the temporal dynamics that finger millet has undergone with respect to its area, production and productivity in the state of Karnataka vis-a-vis India. LOWESS (locally weighted scatter plot smooth) curve has been used to assess the long-term patterns in the data series of 67 years period of area, production and productivity of finger millet for Karnataka as well as India. Non parametric Mann Kendall test is applied to detect the presence of trend in area, production and productivity of finger millet. The time of abrupt shift in the time series pattern of area, production and productivity were detected by Pettitt-Mann-Whitney test. For the whole study period, area under finger millet cultivation was found to have declining trend for Karnataka as well as India, but production and productivity were increasing. Further based on the change point for each of the times series, the study period was divided into two segments and trend for two time segments were separately studied. It was noteworthy to observe varying increasing and decreasing trends in both the periods.

Keywords: Finger millet, Mann Kendall test, Pettitt-Mann-Whitney test, Karnataka

Introduction

The focus of agricultural research, development and policies after green revolution era has been mainly on three main staple crops *viz*. rice, wheat and maize. The policy makers and other stakeholders promoted rice and wheat; and neglected other crops like millets and which led to little public and private investment on their research and development. In recent decades, the emphasis has been mainly on producing more food grains to ensure food security across the globe. Millets have traditionally been popular across many regions of the world, especially in Sub-Saharan Africa and South Asia. According to Fischer *et al*. (2016) [4] and Taylor *et al*. (2006) [18], millets have combined potential of being climate resilient crops for resource-constrained farmers as well as nutritious foodstuff for ever growing populations in these regions. Millets are considered as 'climate-smart' cereals as they require very less inputs and can grow in poor agronomic conditions. It requires hardly 250-300 litres of water to grow one kilogram of millets as compared to 5,000 litres of water for rice.

There have been numerous studies to establish the fact that underutilized millets offer a climate resilient and nutrient dense alternative to crops like rice, wheat and maize. Willett *et al*., 2021 recognized some of these underused crops such as quinoa, millets, sorghum, or teff grains as healthy and environmentally sustainable diets. India ranks number one in the production and consumption of various types of millets, such as finger millet, pearl millet, kodo millet, foxtail millet, barnyard millet, proso millet and little millet (www.smartfood.org).

In India, millets are grown in about 21 states, with the state of Karnataka being the largest producer. Other states involved in millet production are Andhra Pradesh, Tamil Nadu, Kerala, Telangana, Uttarakhand, Jharkhand, Madhya Pradesh and Haryana. Although the production of millets have been increasing over the past few decades, from 7.7 million tons in 1961 to 10.7 million tons in 2012, but the area dedicated to them has been continuously shrinking. Area dedicated to finger millet was 2.3 million ha in 1951–1955 which reduced to 1.18 million ha in 2014–2018. The area under cultivation of other minor millets also experienced a steep decline in from 5.29 million ha to 0.97 million ha over the same period. However, technological advancements like improved varieties have led to doubling of productivity for finger millet from 704 to 1471 kg ha^{-1}. When compared to other crops like wheat whose production trebled between 1960 and 2015 and rice production witnessed an increase by 800 percent, the production of millets stagnated at very low levels (Kane-Potaka and Kumar, 2019) [10]. The underlying reasons behind the decline in millets have largely been the change in dietary habits, low-yield of millets and shift in focus towards cultivation of rice and wheat. Thus the continuous neglect by different stake holders which millets have suffered resulted in loss of its genetic diversity and gradually the traditional knowledge of its production, processing and use faded with time. Low productivity and profitability are some of the major concerns of farmers which make them shy away from cultivating millets.

There are other factors too contributing towards this decline, for instance rising incomes and urbanization have changed the Indian platter and the consumption of millet is getting reduced over the years. There was drastic downfall in per capita consumption of millets in India from 32.9 kg in 1962 to 4.2 kg in 2010, while it almost doubled for wheat from 27 to 52 kg in the same time period (www.indiaspend.com). Similar declining trends in the consumption of other millets like pearl millet and sorghum have been reported by Parthasarathy Rao *et al.* (2010) [15]. To meet the ambitious goal of SDGs of eliminating all forms of malnutrition by 2030, nutrient dense and environmentally sustainable millets are being considered as an alternative to staple crops.

However, of late the awareness about health benefits of a millet-based diet has been rising. The underestimated potential of millets to tackle with the ill-effects of climate change with high nutritional value to fight global malnutrition is being realized. This has led to surge in its demand areas across the globe, including India. Millets are being promoted as “smart food” by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT). The policy-makers in India incorporated millets into the National Food Security Act in 2013, thus making them available at a subsidized rate. The year 2018 was declared as the Year of Millets by the Indian government.

The most widespread minor millet grown across many parts of India and Africa is finger millet (*Eleusinecoracana* L.) or *Ragi* and is an important staple food. Out of total minor millet production in India, 85% comes from finger millet. A total of 1.19 million hectares are dedicated to its cultivation with a production of 1.98 million tone. Karnataka accounts for 56.21% and 59.52% of area and production of finger millet respectively followed by Tamil Nadu (9.94% and 18.27%), Uttarakhand (9.40% and 7.76%) and Maharashtra (10.56% and 7.16%) (http://www.indiastat.com). In spite of being an important constituent of agriculture and diets across southern states of India, it acquired the stigma of being poor man’s food as a consequence of which its demand started decreasing and the farmers stopped growing it. The government introduced finger millets in public distribution system (PDS), which provides cheap grains to the poor because of which it started vanishing from people’s plates. Between 1997 and 2013, area under finger millet and its production witnessed reduction by 20% and 18% respectively whereas it was more than 20% increase in wheat and rice during the same period (aps.dac.gov.in). It is still widely grown in Karnataka state (671,000 ha in 2013) followed by other states, such as Andhra Pradesh, Maharashtra and Tamil Nadu (286,000 ha altogether in 2013).

The scientific assessment has a crucial role in accurate prediction of future production potential of this crop based on its past trends. Keeping in view the richness of finger millet in terms with respect to its status as a climate resilient crop and nutrient dense crop, it is important to develop an insight of the movement in area, production and productivity of the crop over a period of time based on an approach involving quantitative data analysis of past trends of area, production and productivity. The present study is an attempt to investigate the temporal dynamics that finger millet has undergone with respect to its area, production and productivity in the state of Karnataka vis-a-vis India.

Materials and Methods

Study Area

The state of Karnataka is located in the western part of the country on the shores of the Arabian Sea. It is bordered by Telangana to the east, the Arabian Sea to the west, Goa and Maharashtra to the north, Kerala to the south, and Tamil Nadu to the southeast. The state covers an area of 191,791 square kilo meters or 5.83 percent of the total geographical area of India. It extends from 15° 19' 2.1972" N and 75° 42' 50.0040" E covering 31 districts. Among all major states in the country Karnataka constitutes the highest proportion of drought-prone area; and 79% of the total arable area are being managed by resource-poor farmers.

Data Description

Yearly data on area (‘000 ha), production (‘000 tonnes) and productivity (kg ha^{-1}) of finger millet for Karnataka, India for the period starting from 1950-51 to 2017-18 have been obtained from www.indiastat.com.

Statistical Methodologies

The methodologies following the sequence of the analyses; namely (1) the preliminary analysis of area, production and productivity of finger millet (mean, standard deviation, skewness, kurtosis and coefficient of variation) was obtained for the period of 1950-51 to 2017-18, (2) general patterns over time in data series have been checked by locally weighted scatter plot smooth (LOWESS) curve, (4) to detect the direction and magnitude of the trend, MK test and Sen slope estimator test (Sen, 1968) have been applied to the whole time series, (5) Mann-Whitney-Pettitt (PWM) test (Pettitt, 1979) has been applied to detect abrupt changes. Different statistical techniques used are described as follows:

LOWESS regression

LOWESS is a powerful non parametric technique for fitting a smoothed line for a given data set either through univariate or multivariate smoothing. A regression is applied on a collection of points in a moving range, with weights assigned according to distance, around abscissa values and ordinate values are calculated. Since locally weighted regression is used for data smoothing, therefore it is called “LOWESS” and “LOESS”, an acronym for “Locally Weighted Scatter plot Smooth”.

LOWESS is similar to a moving average, where an observation for a year is smoothed by using observations of adjacent years; the smoothed value so obtained is then used in the analysis. A low degree polynomial equation (usually linear) is fit through that subset of the data, the subset constituting a set of observations along the x axis selected adjacent to the point being predicted. The points closest to the value being predicted are given higher weights. This resulting equation is then used to predict the value for the selected point. The data are then shifted one point ahead and the process continues, with a new prediction for the second point, and so on. The resulting points are then connected together with a line.

Mann-Kendall Test

Mann Kendall Trend Test (*M-K test*) (Mann1945; Kendall, 1955) has been used to assess the statistical significance of consistently or monotonic increasing or decreasing trends in the time series data. It is a non-parametric statistical test based on rank system to detect the trend in long term trend in the time series data. The Mann-Kendall tests are based on the calculation of Kendall's tau (τ) which measures the association between two samples, and is based on the ranks with the samples. It is based on the assumption that the observations are independent and measures the strength of the monotonic relationship between the study variable and time. If a positive correlation exists, the yield increases more often than decreases as time advances. For a negative correlation, the yield decreases more than increase.

The null hypothesis, H_0, is that the population from which data has been taken is independently and identically distributed i.e., there is no trend in the data. The alternative hypothesis, H_1, is that the data has a monotonic trend. The Mann-Kendall test statistic is calculated according to:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_j - X_i)$$

where

$$sign(X_j - X_i) = \begin{pmatrix} 1\ if\ (X_j - X_i) > 0 \\ 0\ if\ (X_j - X_i) = 0 \\ -1\ if\ (X_j - X_i) < 0 \end{pmatrix}$$

In a time series, $X_i, i = 1,2,3 \ldots\ldots n$, the values of S is supposed to be similar as the normal distribution with a mean E(S) = 0 and variance

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18}$$

where n is the number of observations, m is the number of tied groups (a tied group is a set of sample data having the same value) and t_i is the number of data points in the i^{th} group. The standardized test statistic Z is computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}\ if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}\ if\ S < 0 \end{cases}$$

The null hypothesis H_0 of no significant trend is accepted if the test statistic Z is not statistically significant.

Theil-Sen estimator

Theil-Sen's slope estimator (Theil, 1950 and Sen, 1968) has been used to estimate the slope of n pairs of data points and is given by

$$\beta = Median\left(\frac{X_j - X_i}{j-i}\right) \text{ for all } i < j$$

in which $1 < j < i < n$ and β is the robust estimate of the magnitude of trend. An 'upward trend' is indicated with a positive value of β and a 'downward trend' with a negative value of β (Xu *et al*., 2007) [24].

Change magnitude as percentage of mean

The percentage change in a variable during the study period has been computed by approximating it with a linear trend. That is change percentage equals median slope multiplied by the period length divided by the corresponding mean, expressed as percentage followed by Yue and Hashino (2003) [25].

$$\text{Percentage Change (\%)} = \frac{\beta \times length\ of\ year}{mean} \times 100$$

Mann–Whitney–Pettitt method (MWP)

The change point analysis is used to detect where significant change takes place in time series data and is a fundamental tool in time series analysis. There are different non-parametric statistical methods to detect change points in the time series applied by many researchers have (Chen and Gupta, 2001; Gallagher *et al*., 2012; Mohammad *et al*., 2014; Jaiswal *et al*., 2015; Kalpana and Kiran, 2019) [1, 5, 13, 8, 9]. Let $\{X_1, X_2 \ldots, X_n\}$ be a time series with a length n and t be the time of the most likely change point. Two samples, $\{X_1, X_2 \ldots, X_t\}$ and $\{X_{t+1}, X_{t+2}, \ldots, X_n\}$, can then be derived by dividing the time series at time t. An index, U_t, is derived by:

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} sign(X_j - X_i)$$

Where

$$sign(X_j - X_i) = \begin{pmatrix} 1\ if\ (X_j - X_i) > 0 \\ 0\ if\ (X_j - X_i) = 0 \\ -1\ if\ (X_j - X_i) < 0 \end{pmatrix}$$

A plot of U_t against t for a time series with no change point would result in a continually increasing value of $|U_t|$. However, if there is a change point, then $|U_t|$ would increase up to the change point and then begin to decrease. The most significant change point t can be identified as the point where the value of $|U_t|$ is maximum:

$$K_T = \max_{1 \le t \in T} |U_t|$$

The approximated significance probability p(t) for a change point (Pettitt, 1979) is given as

$$p = 1 - exp\left[\frac{-6K_T^2}{n^3 + n^2}\right]$$

The change point is statistically significant at time t with a significance level of α or when p(t) exceeds (1-α).

Results and Discussion

Preliminary Analysis of Area, Production and Productivity of Finger Millet

Table 1 shows the summary statistics of area, production and productivity of finger millet for Karnataka as well as India over the period of 1950-51 to 2017-18. During the study period, an average of 954.81 thousand ha of area in Karnataka have been dedicated to finger millet and 2061.6 thousand ha in the whole country.

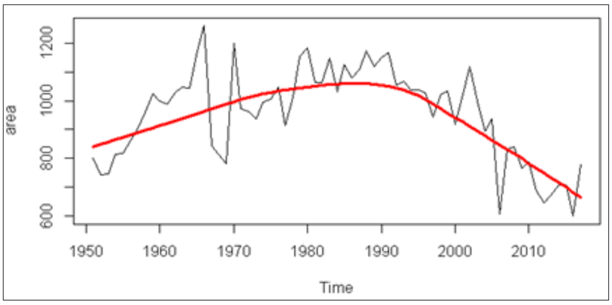
Table 1: Summary statistics for the time series data of finger millet cultivation in Karnataka and India from 1950-51 to 2017-18

Parameters	Mean	Standard Deviation	Kurtosis	Skewness
Karnataka				
Area ('000 ha)	954.81	159.97	-0.429	-0.622
Production ('000 tonne)	1097.34	390.06	-0.164	-0.914
Productivity ('000 kg/ha)	1158.45	429.06	0.183	-0.919
India				
Area ('000 ha)	2061.65	510.42	-0.629	-1.009
Production ('000 tonne)	2135.32	435.11	0.047	-0.357
Productivity ('000 kg/ha)	1099.29	327.17	0.261	-1.100

An average of 1097.34 thousand tonnes of finger millet was produced in Karnataka and 2135.32 thousand tons in India. The presence of skewness and kurtosis (Table 1) in area, production and productivity indicate that the data did not follow normal distribution.

Long term pattern in Area, Production, Productivity of Ragi

The long-term patterns in the data series of 67 years period of area, production and productivity of finger millet for Karnataka as well as India were assessed. The data were fitted with LOWESS (Cleveland, 1979, 1984; Helsel and Hirsch, 2002) curve to reduce the local fluctuations and identify the general patterns in the data over time. The time series plot of area under finger millet during the study period for Karnataka has been presented in the fig. 1(a). As indicated by the LOWESS curve, area under finger millet crop experienced a gradual rise up to the year 1980 followed by stagnation for few years; and from 1997 onwards, there was a continuous declining trend.



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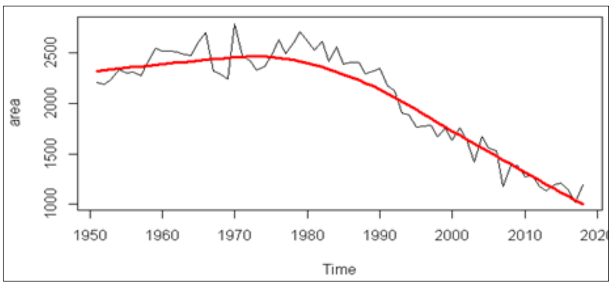
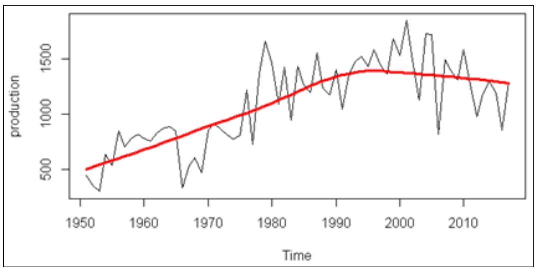


b

Fig 1: Area under finger millet crop and LOWESS trend line during 1951-2018 for (a) Karnataka and (b) India



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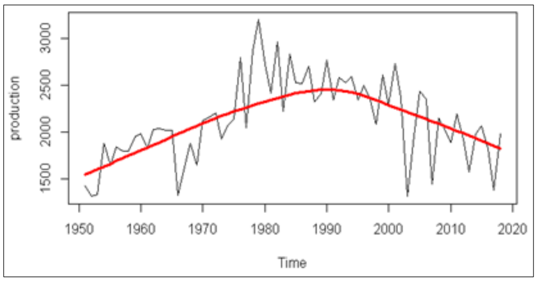
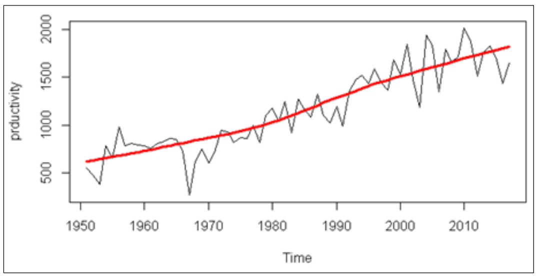


b

Fig 2: Production of finger millet and LOWESS trend line during 1951-2018 for (a) Karnataka and (b) India

The time series plot of area under finger millet for India during the study period has been shown in fig 1(b). LOWESS curve shows that the area under finger millet crop is observed to be increasing initially followed by a period of stagnation till late 1970s and afterwards it started declining continuously. LOWESS regression curve for finger millet production (fig. 2(a)) shows a steady increase up to mid-1990s followed by gradual declining trend during the study period in Karnataka. The time series plot of finger millet production showed an increasing trend (Fig. 2(b)) up to initial part of 1990s and thereafter a continuous decrease in rest of the study period.



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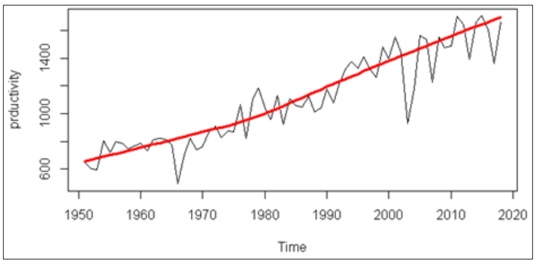

b

Fig 3: Productivity of finger millet and LOWESS trend line during 1951-2018 for (a) Karnataka and (b) India

Similarly the productivity of finger millet in Karnataka witnessed a continuous increase throughout the study period. There was gradual increase in initial phase of the study period and later it followed sharp increase. The continuous increase in the productivity may be attributed to technological advancements over the time. For India, there was a gradual rise in productivity up to the year 1980 (fig. 3(b)) followed by sharp increase afterwards.

Trend analysis of Area, Production, and Productivity of Finger millet

Table 2 presents the results of MK test applied on area, production and productivity of finger millet for Karnataka as well as India. Area under finger millet crop showed significant decreasing trend for both Karnataka and India, as evident from the Kendall's tau. The production and productivity of finger millet exhibited a significant increasing trend for both the cases.

Table 2: Results of Mann Kendall test statistic (**Z**), Sen Slope Estimator (β), % change test and Change Point using Pettit test

Parameters	Kendall's Tau (τ)	Slope (β)	% Change	Change Point
Karnataka				
Area ('000 ha)	-0.12*	-1.85	-12.98	2003
Production ('000 tonnes)	0.499*	15.19	92.74	1977
Productivity ('000 kg/ha)	0.728*	19.44	112.43	1983
India				
Area ('000 ha)	-0.573*	-23.11	-76.22	1990
Production ('000 tonnes)	0.166*	6.57	20.92	1974
Productivity ('000 kg/ha)	0.771*	15.59	96.44	1989

Theil Sen Slope estimator β shows that the decrease in area under finger millet crop is much higher for the whole country (-23.11 thousand ha per year) as compared to that for Karnataka (-1.85 thousand ha per year). Although there was sharp decline in the area under finger millet crop in the country as a whole has been continuously decreasing, it was very slow in Karnataka. Thus there was stark difference in the declining trend if area under cultivation of finger millet in the country compared to Karnataka. Contrary to 76.22% decline in area under cultivation for India, it was only 12.98% in Karnataka. Table 2 also presents the detected change point using Pettit-Mann-Whitney test. The most probable change year for Karnataka is 2003 whereas for India, it is 1990. Thus while the area under cultivation of finger millet in the country as a whole started shrinking in favour of other crops quite early, it was fairly stable in Karnataka up to early 2000. Change in the diet pattern in other states, especially northern states of the country might have led to decrease in its consumption thus forcing farmers of those regions to adopt other crops instead of finger millets. Both Karnataka and India witnessed statistically significant increasing trend in production, however, the magnitude of increase was higher (15.19 thousand tonnes per year) as compared to India (6.57 thousand tonnes per year). In terms of percentage increase in production, it was approximately 93% for Karnataka and only 21% for India. According to the Pettit-Mann-Whitney change point detection, 1977 was the year during which there was an abrupt shift in the production of finger millet and for India, the shift was observed in 1974.

There was a statistically significant steady pattern of increase in productivity of finger millet both in Karnataka and India over the period of study. The magnitudes of trend given by Theil Sen slope estimator were almost at par for Karnataka (19.44 thousand kg/ha per year) and India 15.59 thousand kg/ha per year. The percentage increase in productivity was 112% in Karnataka, whereas for India it is 96.44%. The most probable change year for Karnataka is 1983 whereas for India, it is 1989. Further with the help of detected significant change point for each parameter, the whole-time series is split into two sub-time series and Mann Kendall test for the existence of trend has been performed and Thiel-Sen slope has been used to compute the magnitude of trend. The results of this exercise have been presented in Table 3. The values have been presented for Karnataka as well as India separately. Area under cultivation for finger millet before the change point exhibited an increasing trend which got reversed in the period after it. Similar trend is observed for the whole country.

Table 3: Results of Mann Kendall test statistic (τ), Sen Slope Estimator (β) before and after Change Point

Parameter	Karnataka			India		
	Segmentation year	Kendall's Tau (τ)	Slope (β)	Segmentation year	Kendall's Tau (τ)	Slope (β)
Area	1951-2003	0.312	3.80	1951-1990	0.167	3.38
('000 ha)	2004 - 2017	-0.41	-17.86	2004 - 1991	-0.833	-36.16
Production	1951-1977	0.32	12.26	1951-1974	0.471	19.8
('000 tonnes)	1978-2017	-0.053	-2.37	1975-2017	-0.498	-22.37
Productivity	1951-1983	0.477	12.07	1951-1983	0.627	11.31
('000 kg/ha)	1984-2017	0.487	20.2	1984-2017	0.493	15.54

The magnitude of increasing trend given by Sen's slope for Karnataka as well as the whole country was more or less similar, however, the decrease in area for India during the period after the change point was observed to be twice that of

Karnataka. Thus on the whole, area under finger millet in the country has been shrinking in favour of other crops while Karnataka retained it.
There was an increasing trend in production in the first sub-time series i.e., before the change point, in Karnataka as well as whole country. The second time-series i.e., after the change point for Karnataka as well as India exhibited declining trend in production. The decline for the whole country was very high (-22.37 thousand tones / year) as compared to that for Karnataka (-2.37 thousand tonnes). The productivity for both the sub-time series was observed to be increasing for Karnataka and the country as a whole, however, the magnitude of trend was higher for Karnataka (20.2 thousand kg/ha per year) in comparison to India (15.54 thousand kg/ha). Thus it may be concluded that Karnataka has been one of the leading states of the country in finger millet production. With the initiatives of Karnataka backed by the GoI, the United Nations (U.N.) adopted a resolution, sponsored by India and supported by more than 70 countries and declared 2023 as the International Year of Millets. The resolution intends to enhance public awareness on the health benefits of millets and to promote them as climate resilient crop.

Conclusion
Based on the results obtained, it can be concluded that the farmers and policy makers involved in finger millet production in other states should take cue from Karnataka and make a concerted effort to improve the situation in favour of finger millets. All the stakeholders should be made aware of this nutrient dense and extremely resource efficient crop and its status as one of the smart food crops of India for future and hence emphasis must be on nationwide push for finger millets. The strategy for promoting millets must be based on popularizing its multiple benefits in terms of its nutritious value, property of being climate-resilient with increased farm incomes. Therefore the interventions to enhance its production must be based on the factors associated with production as well as consumption. Farmers should be encouraged to adopt improved crop cultivation technologies such as line sowing and fertilzation for increasing the yield as well as reducing the hard manual work undertaken by women working on farms. As per the ministry of agriculture and farmers welfare, the costs of production per quintal of paddy (a competing crop) are much lower and the yield much higher than that of finger millet. Therefore to make finger millets compete with other crops, increase in minimum support price (MSP) may boost cultivation.
In many parts of the country millets are considered as the poor man's grain and therefore there is a need to change the 'social status' of millets among other food grains. Finger millets have the potential to address the grave problem of malnutrition among vulnerable populations, and hence the National Food Security Act (NFSA) provided for disbursing millets through public distribution system (PDS), Karnataka was the only state to introduce it. Given the multitude of benefits, there is a need of initiatives for promoting millets to reach the whole population, rural and urban alike. Of late there has been a spur in consumption of finger millets in urban areas. According to a survey coordinated by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (Kane-Potaka *et al*., 2021) [10], in urban areas, health and wellness are the driving factors of increased consumption of millets. Since the outbreak of the novel corona virus disease (COVID-19), micro-nutrient rich millets may be considered to serve as 'immunity foods'. Thus concerted efforts are required to urge farmers for enhancing millet cultivation and at the same time focused awareness campaigns on dietary benefits are required to increase its consumption and then only the potential of millets can be completely realized.

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