POLICY PAPER 114

Promoting Millet Production, Value Addition and Consumption

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Preface

Millets, comprising of sorghum, pearl millet, finger millet, foxtail millet, little millet, kodo millet, barnyard millet and proso millet, have been the traditional food in India especially in the marginal environments of the drylands. Because of their adaptation to hot and dry environments, millets have the potential to provide food and fodder security in the challenging environments of arid and semi-arid regions.

The incentives and policies in favour of production and consumption of wheat and rice since 'Green Revolution' had put millets in a significant disadvantage. The cultivation of millets has declined by 70% in the last seven decades. Fortunately, their production has not been affected as the productivity was enhanced by more than 2.5 times during the same period. The diversion of area under millets to other crops requiring more water has resulted in over-exploitation of groundwater and reduction in the on-farm diversity, making agricultural production system more vulnerable to ever-changing climate.

Currently, there is renewed interests in millets due to their in-built tolerance to water stress and supra-optimal temperatures, and capacity to grow well and produce good yields on soils with low fertility. Moreover, millets being highly nutritious, have an important role in achieving nutrition security. Therefore, Government of India declared millet crops as 'NutriCereals'. The year 2023 has also been declared as the 'International Year of Millets' on India's call, which is supported by 70 countries in the world to promote cultivation and consumption of millets.

The National Academy of Agricultural Sciences organized a brainstorming session on July 22, 2022 to explore the possibility of promoting millet production, enhanced value addition and greater consumption. This policy paper is an outcome of the deliberations on all these aspects involving researchers, representatives from different ministries of the Government of India, state governments and food industry, policy makers, start-ups, FPOs, chefs etc. It presents an in-depth analysis of millet cultivation dynamics and how technology and policies have influenced demand and supply of millets. This policy paper also provides insights on the role of innovations in production, processing and value-addition for addressing the issues in value-chain, and finally discusses the policies for mainstreaming millets.

I, on behalf of the Academy, thank all the participants for providing very critical inputs for promotion of millets. My thanks are also due to Drs O.P. Yadav and V.A. Tonapi and the reviewers for amalgamating the opinions, comments and suggestions of

the participants in the form of this document. My sincere thanks are due to Drs P.S. Birthal and Dr (Ms.) Malavika Dadlani for their editorial support in bringing this publication in its present shape.

(Trilochan Mohapatra)
President

Promoting Millet Production, Value Addition and Consumption

1. INTRODUCTION

Millets, defined as small-seeded annual cereals, are crops adapted to dryland agro-ecologies of the arid and semi-arid tropics, and are produced in regions characterized by low to moderate rainfall (200-600 mm) and high temperatures (42-46°C). Millets also possess good ability to adapt to marginal lands and soils with low fertility. Presently, there is a renewed interest in millets production, for several reasons. Firstly, millets are highly nutritious (Dayakar Rao *et al.*, 2017), with high calcium, iron, potassium, magnesium, and zinc contents, besides other essential molecules such as vitamins, amino acids, and fatty acids (Nithiyanantham *et al.*, 2019). Government of India has declared 10 millet crops as 'NutriCereals' for production, consumption and commerce which include three major millets i.e., pearl millet, sorghum and finger millet; five minor millets i.e. foxtail millet, proso millet, kodo millet, barnyard millet, little millet; and two pseudo millets i.e. *kuttu* (buckwheat) and amaranthus (vide F.No. 4-4/2017-NFSM (E) dated 10th April, 2018). Secondly, millets have in-built tolerance to water stress and supra-optimal temperatures due to their morpho-physiological, molecular and biochemical characteristics that confer upon them better tolerance to environmental stresses than the major cereals (Yadav *et al.*, 2012; Gupta *et al.*, 2017; De Vries *et al.*, 2020). Several traits such as short stature, small leaf area, thickened cell walls, and dense root system also contribute to circumventing the stresses. Thirdly, being C4 crops, millets have greater potential to utilize atmospheric CO_2 in the accumulation of biomass per unit of water used and thus are recognized as crops with low carbon- and water-footprints. The short life cycle of millets (10–12 weeks) as compared to other major crops (20–24 weeks) also helps in stress mitigation. Because of these attributes millets are considered climate smart crops. Moreover, as millets are largely produced with low external inputs especially chemicals, these are considered as nature friendly.

Thus, millets can play a vital role in the livelihood of the poor and malnourished population, provide food and nutrition security, and help achieving the first three sustainable development goals of the United Nations i.e. reducing poverty, zero hunger and good health and well-being. However, despite such positive attributes and qualities of millets for the present and future agriculture, their cultivation in India and elsewhere has been on decline over the last few decades, which has attracted the attention of policy makers. India celebrated 2018 as the 'National Year of Millets' to create greater awareness about unparalleled attributes of millets.

India also gave a call to the United Nations to declare 2023 as the 'International Year of Millets' to promote production, value addition and consumption of millets. The resolution was supported by 70 countries of the world to promote millets.

This policy paper provides an overview of dynamics of millet cultivation during the last six decades and technological landscape to further enhance millet productivity. Simultaneously, it deliberates on the multiple ways to stimulate utilization and production of millets and discusses strategies for promoting millets. Finally, it also examines the role of policies for mainstreaming millets in farming as well as in agrifood sector for the health benefits of the humankind around the world.

2. CULTIVATION DYNAMICS OF MILLETS

Millets are recognized among the most ancient food grains - first plants domesticated for food. Earliest evidence of their cultivation found in Indus civilization dates back to 3,000 BC. They are currently grown in 131 countries in over 78 million ha (FAO, 2022) with sorghum and pearl millet accounting for over 90% share at global level. India is the largest grower (with 19% contribution) and producer (20% production) of millets in the world. Share of India in Asia stands at 85% in area and 80% in production of millets.

Top seven countries in the world for sorghum cultivation are Sudan, Nigeria, India, Niger, USA, Ethiopia and Burkina Faso; and for pearl millet cultivation are India, Niger, Sudan, Nigeria, Mali, Burkina Faso and Chad. Thus, among the major millets India ranks first in the world with respect to pearl millet cultivation and third in sorghum cultivation. Among the millets, sorghum is the most important crop at the global level accounting for 54% area. On the other hand, pearl millet is the most important millet crop in India, having a share of 49% of millet area, followed by sorghum with 39% area, and finger millet with 8% area.

However, since 1950, there had been a steady decline of 60% in millet cultivation in India, with the total area decreasing from 34.8 m ha to 13.6 m ha. The decline in millet cultivation was more after early nineties (Fig. 1), though the decline is different in its magnitude in various millet crops. The area under sorghum, that was over 17.9 m ha in 1950s and was the second most important crop of India after rice, has declined to 4.9 m ha in 2020 (Fig. 1) registering a reduction of 70% area in seven decades. Similarly, there is 90% decline in the area of small millets. Finger millet area has been reduced from 2.25 million ha to 1.0 million ha. The minimal decline of area among millets has been observed in pearl millet which is still grown over 7 m ha (Fig. 1) in some of the most harsh and marginal environments of arid and semi-arid regions.

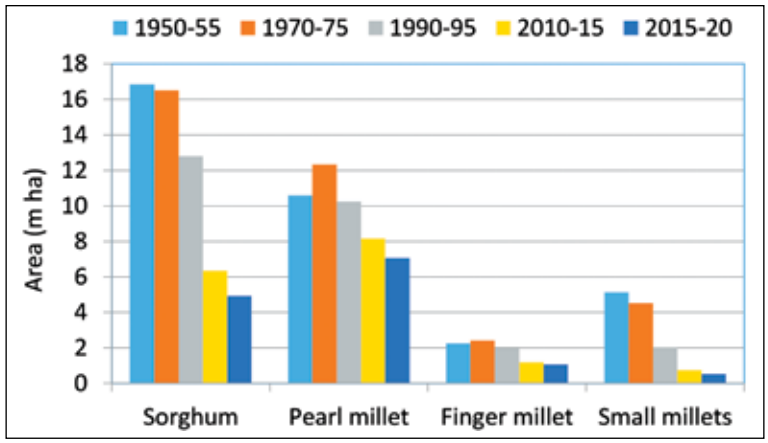

Fig. 1: Area under different millets in India since 1950

Globally as well as in India, millets are important regionally depending up on climatic conditions and food habits. For example, Maharashtra, Karnataka and Rajasthan account for 2/3rd area under sorghum. The most important states for pearl millet cultivation are Rajasthan, Uttar Pradesh and Maharashtra having a total share of 78%. Karnataka alone accounts for more than 2/3rd acreage of finger millet. Chhattisgarh and Madhya Pradesh grow more than 60% of small millets.

Total production of millets in the world is 98 million tonnes, with sorghum contributing 63%, followed by pearl millet with a contribution of 24%. India produces nearly half of the total world production of both pearl millet and finger millet, but only 7% of world sorghum (Fig. 2). Three minor millets viz. Kodo millet, Little millet and

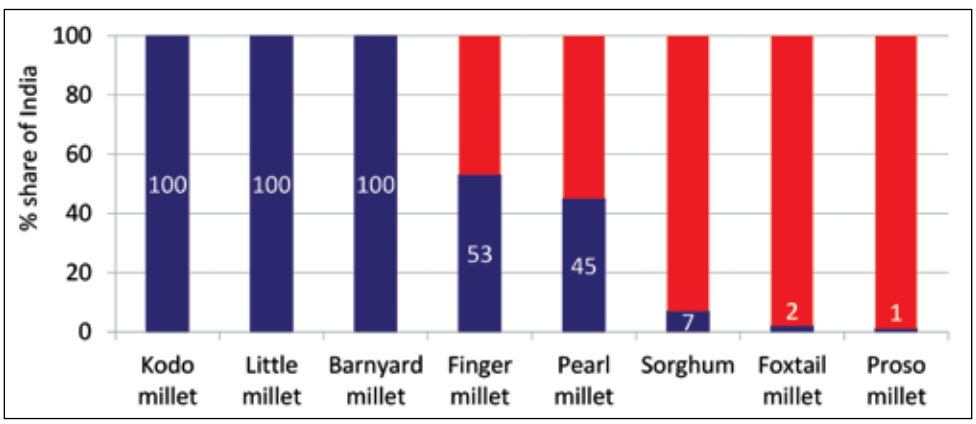

Fig. 2: Contribution of India to world production of individual millet crops

Barnyard millet are exclusively grown in India with a production of only 1-3 million tonnes.

Production of millets in India has shown very interesting trends. There has been a consistent increase in the production from 1950 until nineties (Table 1). The production increased 1.4 times between 1950 and 1990 as there was increase of similar magnitude in the millet productivity with only marginal decline (8%) in millet area. Millet cultivation witnessed a drastic change after nineties. Though the productivity showed 73% increase during 2010-20 in comparison to 1980-90, production came down by 20% as the area declined by 54%. Thus a very high gain in productivity could not compensate for the reduced area (Table 1).

Table 1: Production, yield and area under millets in India between 1950 and 2020

Period	Production (million ton)	Yield (kg/ha)	Area (million ha)
1950-60	14.75	415	35.41
1960-70	17.15	460	37.30
1970-80	19.35	552	35.06
1980-90	20.60	633	32.58
1990-2000	19.64	778	25.26
2000-10	18.02	868	20.81
2010-20	16.42	1097	15.01

3. ROLE OF TECHNOLOGY, POLICY AND DEMAND IN MILLET PRODUCTION IN INDIA

Cultivation and production dynamics of different food crops over last six decades reflect the role of technology and policy, which eventually influence the demand and supply of individual food crops. There has been a tremendous growth in the productivity of millets since mid-sixties (Table 2). Maximum gains in productivity have been achieved in pearl millet (3.45 times), which was close to that in wheat (3.71 times). The productivity enhancement of 2.8 and 2.6 times was achieved in maize and rice, respectively. Productivity was doubled in sorghum, finger millet and small millets. The progress can largely be attributed to the development and adoption of improved cultivars with higher yield potential and crop management technologies (Yadav *et al.*, 2019). However, despite consistent rise in productivity, production trends present a very interesting and contrasting scenario in millets as compared to that in wheat, rice and maize. It is well recognized that production is a function

Table 2: Production, productivity and area of wheat, rice, maize and different millets in India since 1963

Crop	Production (million t)		Productivity (kg/ha)		Area (million ha)	
	1963-67	2015-20	1963-67	2015-20	1963-67	2015-20
Wheat	12.1	100.31 (8.3)*	892	3311 (3.71)*	13.5	30.3 (2.24)*
Rice	35.0	112.36 (3.2)	974	2563 (2.63)	35.9	43.84 (1.22)
Maize	5.0	26.72 (5.3)	1019	2866 (2.81)	4.9	9.31 (1.90)
Pearl millet	4.4	9.19 (2.1)	363	1251 (3.45)	12.0	**7.34 (0.61)**
Sorghum	9.1	4.36 (0.48)	504	864 (1.71)	18.1	**5.10 (0.28)**
Finger millet	1.77	1.63 (0.92)	746	1524 (2.04)	2.41	**1.06 (0.43)**
Small millets	1.79	0.39 (0.21)	385	759 (1.96)	4.64	**0.53 (0.11)**

* Figures in parentheses indicate number of times change occurred during 2015-2020 over 1963-1967.

of productivity and area under cultivation. The latter is driven by the demand for the produce, which in turn is significantly influenced by the policy interventions and/or market forces. In case of wheat, an eight-time increase in production during last six decades, is a bright example of combined effect of deployment of better technology, extensive cultivation and adequate policy support. Despite 3.7 times increase in wheat yields, acreage under wheat continued to increase as farmers went on getting remunerative price for their produce; consequently, minimum support price (MSP) and procurement of wheat grain prompted farmers to grow more wheat. Hand-in-hand, distribution of wheat through public distribution system (PDS) created a mechanism to absorb more production, which helped maintain a balance between demand and supply (of wheat) in the market. Similar is the case of rice, where the production has gone up over three times and the country is annually producing more than 105 million tonnes during the past ten years. This is an outcome of 'tripartite holy alliance' of the scientists, policy makers and farmers (Swaminathan, 2013 and 2015), which transformed India from a food-deficit nation with a population of 0.33 billion in 1950s to a food-secured nation with more than 1.39 billion current human population.

The increase in maize production, which has gone up more than five times since 1960s, is undoubtedly one of the most successful stories in the recent past. This could be achieved through a combination of improved productivity (2.8 times) and increased area under cultivation (1.9 times) (Table 2). Unlike wheat and rice, though there is no procurement of maize by the government machinery; yet, the farmers continued to grow more maize due to tremendous increase in its demand during

last four decades because of growth in the poultry industry, which is expected to grow further at a CAGR of 8-10% during 2021-2026. Increased use of maize in starch production and processed foods also contributed to the increased demand of maize. Thus, major driving force for twofold expansion of area under maize has been its increased market-driven demand (Table 3), rather than direct policy-driven demand as in case of wheat and rice.

The situation of millets is entirely different from that of wheat, rice and maize. Even the scenario among different millets is quite contrasting. For example, the gains in pearl millet productivity have been as much impressive as in wheat (Table 2), where increased productivity led to higher production, but was not absorbed by the market due to lack of both policy- and market-driven demands (Table 3). Without adequate incentives to produce more, cultivation of pearl millet has declined. The land used under pearl millet was diverted to other crops as farmers were able to meet their local demand by producing more from lesser area. But still pearl millet production was doubled despite 30% decline in area. Therefore, a two-fold increase in pearl millet production in the absence of any policy support was solely technology-driven (Table 3).

Area under sorghum has been continuously declining, with current cultivation restricted to 5.1 million ha which was 18.0 m ha in 1960s due to several reasons. Firstly, relatively lesser improvement in productivity in comparison to other crops (Table 2) made it a less remunerative crop in *kharif* season. Secondly, the demand for *kharif* produce (as food) almost vanished due to supply of wheat and rice through PDS, and poor quality of *kharif* sorghum due to occurrence of grain moulds. Resultantly, production declined by more than 50% and area by 72% during 2015-20

Table 3: The role of technology, policy and market in maize, rice, wheat and different millets

Crop	Role of		
	Technology	Policy-driven demand	Market-driven demand
Wheat	Yes	Yes	Yes
Rice	Yes	Yes	Yes
Maize	Yes	No	Yes
Pearl millet	Yes	No	No
Sorghum	Yes	No	No
Finger millet	Yes	No	No
Small millets	Yes	No	No

in comparison to mid-sixties. However, *rabi* sorghum sustained to a large extent in post-rainy season (now grown in around 2 million ha) in Maharashtra, Karnataka and Telangana as there is no other crop that could fit into this production environment. Hence, there is a need to revisit the priority-setting, and re-orient and strengthen the breeding programme in sorghum.

In case of finger millet, while the cultivation decreased by over 50% from mid-sixties, its production came down only by 10% due to two-fold increase in productivity. This means that demand of finger millet has remained largely the same since mid-sixties. The cultivation of small millets was 4.64 million ha in sixties but with the decline in area to the tune of 90%, the production has decreased by 80%. Two times increase in productivity of small millets could not compensate for the lower production due to reduced area. The production and cultivation scenario of sorghum and small millets, thus, clearly suggested that the demand of these crops have come down drastically since 1960s (Table 2). Thus, decreased demand, and not the short supply, is the real issue. Demand of finger millet continues to be largely static.

The states that have lost major share of area under millets are Maharashtra, Karnataka, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Tamil Nadu, Rajasthan, Uttrakhand, Haryana and Gujarat. The crops replacing millets are maize, cotton, mungbean and soybean because these are more remunerative than millets (Table 4). Though the MSP is also declared annually for two millet crops *viz*., sorghum and pearl millet (Table 4), and has been raised significantly over the years, since these commodities are not procured by the government agencies, it influenced their economics of cultivation.

MSP of wheat and rice were 14-27% higher than that of sorghum and pearl millet in 2010-11 (Table 4). Though the enhancement in MSP declared for 2022-23 was

Table 4: The minimum support price (MSP) for rice (paddy), wheat, sorghum and pearl millet in 2010-11 and 2022-23

Crop	MSP per q		% increase in MSP over 2010-11
	2010-11	2022-23	
Paddy	1000	2040	104
Wheat	1120	2015	80
Sorghum	880	2970	238
Pearl millet	880	2350	167

much higher for both millets in comparison to that for rice and wheat, it has not raised the area of cultivation, clearly indicating that the announcement of MSP has merely become a ritual and did not help popularise millets.

4. LESSONS LEARNT

With the beginning of green revolution, the country moved towards the target of self-reliance in food grain production and achieved it successfully, predominantly in the cereals. The experience in the strategic research of crop science strongly suggests that the country would continue to produce sufficient food grain to meet the requirement of its growing population through further improvement in productivity. However, new challenges are now emerging particularly in high productivity areas due to over-exploitation of groundwater, emphasis on limited crops and heavy reliance on chemicals (fertilizers and plant protection chemicals). Therefore, maintenance of soil productivity, integrated nutrient management, integrated pest management, efficient irrigation technologies and diversification of farming systems will need to be on high priority. The millets will play a very important role in diversification of farming, enhancing the resilience of agriculture and improving the livelihood in the drylands. Technological innovations to augment productivity and creating suitable policy and markets for millet will be essentially needed for promoting millets.

5. TECHNOLOGICAL INNOVATIONS IN MILLETS

5.1. Innovations in enhancing production and productivity

In early 1960s, India was facing a major challenge of feeding its fast-rising population of about half a billion people (439 million in 1961). Rice and wheat production was 35.66 million tonnes and 12.07 million tonnes, respectively in 1961-62. Three coarse cereals viz. sorghum, pearl millet and maize contributed 16 million tonnes to the national food basket. But the country was experiencing deficit of food grain by 10 million tonnes necessitating food grain imports. There was urgency among all the stakeholders to enhance food grain production in shortest possible time. This was strongly supported by the political will to achieve the goal.

***5.1.1. Genetic innovations*:** Early 1960s witnessed some exciting scientific developments in major food crops. In wheat, evaluation of genetic materials introduced from Mexico possessing dwarfing genes, *Rht1* and *Rht2* originating from Japanese wheat variety 'Norin 10' showed good adaptation to Indian agro-ecologies coupled with resistance to lodging even under high irrigation and fertility conditions and higher productivity (Singh *et al.*, 2016; Sharma *et al.*, 2022). Similarly, rice with *sd1* dwarfing

gene from Taiwanese rice variety 'Dee-geo-woo-gen' had shown promise under Indian conditions (Singh *et al.*, 2016; Sharma *et al.*, 2022). Discovery of cytoplasmic male-sterility and availability of male-sterile lines in pearl millet (Burton, 1965) and sorghum (Stephens and Holland, 1954) paved the way for developing hybrids in these crops. In maize, the exploitation of heterosis had started earlier than 1960s (Crow, 1998). Thus, millets were not at any disadvantage as far as technological innovations are concerned.

***5.1.2. Hybrid development*:** All the innovations of 1960s, involving dwarfing genes (in wheat and rice) and exploitation of heterosis through hybrid development (in pearl millet, sorghum and maize) proved to be disruptive in the next few decades. Hybrids viz. HB 1 and HB 3 of pearl millet; and CSH 1 and CSH 2 of sorghum were outstanding hybrids developed in the late 1960s and this was followed by a series of new cultivars at regular intervals. Since then, more than 500 cultivars have been released. The newer cultivars had higher genetic potential to realize greater yields and several of them were widely adopted in their production domain.

***5.1.3. Seed production*:** Hybrid seed production in pearl millet and sorghum also evolved rapidly and very extensively in India. The 'seed village' concept involving multiplication of specific cultivars in particular villages has been effectively used to undertake seed production programme in non-traditional areas. Seed production by small farmers under contractual arrangements with seed corporations and private seed companies has been a unique example of willingness of Indian farmers to adopt an intricate technology for producing genetically pure seed with high seed vigour and quality. During the last two decades, yield levels in seed production plots of hybrids have been doubled, mainly due to development of high-yielding parental lines and improved crop management skills of farmers. Seed processing period was also shortened considerably, reducing the time from harvesting to delivery of seed in the target regions within a month. This circumvented the need of storage of seed over seasons, resulting in reduced overhead costs and better seed quality.

***5.1.4. Management innovations*:** Multi-location agronomic research conducted at research station and on-farm trials led to regional recommendations with respect to the planting time, seed rate, weed management, fertilizer application including biofertilization, cropping systems and moisture conservation (De and Gautam, 1987; Bhatnagar *et al.*, 1998). Management research included i) intensive management for regions where moisture is generally adequate and ii) low-input management in areas where moisture is the major production constraint. Intensive management focused on increased plant population by following differential crop geometry.

However, a lower plant population had to be maintained by wider row spacing in drier zones with low and erratic rainfall pattern. Fertilizer doses were worked out using soil-test-crop response approach. Response to applied nitrogen fertilizer as high as 90-140 kg/ha was reported in high rainfall areas, but average farmers recommendations were in the range of 40-80 kg/ha in various agro-climatic zones. Inoculation of seed with bio-fertilizers was also recommended, which saved nitrogen to the extent of 10-20 kg/ha. Weed, disease and insect-pest management practices were standardized to achieve stability in production.

5.2. Innovations in value-addition

***5.2.1. Processing technologies*:** Primary processing technologies of millet grains such as milling, malting, dehulling, blanching, dry heating and fermentation, which reduce anti-nutritional factors and increase the digestibility and shelf-life of various traditional food products such as unleavened flat bread (*roti/chapati*) and porridges were developed. Machinery for primary processing, requiring less labour and with 50-70% efficiency, are now available [For example millet threshers-cum-pearler developed by ICAR-VPKAS, Almora (Gupta, 2015)]. In addition, a range of secondary processing technologies have been devised for flaking, popping, extrusion and baking to produce a large number of diverse value-added products. Currently, more than 100 such ready-to-eat or ready-to-cook products are available.

Gluten intolerance, leading to protein allergy (specifically gliadin allergy), is a physiological disorder in a large population (Hassan *et al.*, 2021). Millets, being gluten-free, have a good chance of being commercialized for the food-based management of this health problem. Modern processing technologies provide more options to develop value added foods from millets. Being gluten free, millets are not suitable for making good quality leavened bread when used alone. However, it can be milled and combined with other flours to make delicious value-added products. Millets are the best choice for functional and nutraceutical foods, and are characterized to be potential prebiotic and can enhance the viability or functionality of probiotics with significant health benefits.

***5.2.2. Value-added food products*:** Millet grit and flour can be used to prepare ready-to-eat (RTE) products and such products have crunchy texture and can be coated with traditional ingredients to prepare sweet or savoury snacks. Alternatively, the grits could be mixed with spices and condiments prior to extrusion to obtain RTE snacks of desirable taste. Noodles, macaroni and pasta-like extruded products could be prepared from millet flour (Dayakar Rao *et al.*, 2017). Extruded snacks prepared with mixed millet flour also possess enhanced *in vitro* protein digestibility

of foods (Malleshi *et al.*, 1996). Extensive work has been carried out on sorghum flaking and popping at CSIR-CFTRI, Mysore and ICAR-IIMR, Hyderabad and various process parameters, such as soaking time, temperature, wet-heat or dry-heat treatment conditions, have been standardized.

Millets, especially finger millet, can be successfully utilized for the development of weaning foods, as it can satisfy the nutritional requirement of infants during the crucial transitional phase of life from breast milk to other type of food, at reasonable cost. Keeping in view the delicate digestive system and nutritional requirement of the infants, malting seems to be an effective process as it provides an opportunity to develop easily digestible and nutritious weaning foods of low viscosity, low dietary bulk and of high calorie density. In addition, malting also improves the availability of protein, minerals, free sugars, vitamin B and ascorbic acid by reducing the level of antinutrients. It also imparts desirable flavour and taste to the product. Blanched pearl millet can also be used for weaning foods. Blanching improves the storage stability by retarding the lipolytic spoilage of meal without much altering its nutrients. Nutritive value of millet-based weaning foods can further be enhanced when mixed with legumes like cowpea or green gram because these pulses complement the profile of essential amino acids which is beneficial for infants' optimum growth. Millets are also used in preparing various types of health foods as they contain higher proportion of insoluble dietary fibre. This causes slow release of sugars, making the millet-based food products especially suitable for those suffering from or prone to diabetes. Millet flour is used in making different types of drinks. A fermented drink known as *rab/rabari* is consumed widely during summer months in Rajasthan. Similarly, traditional drink called as 'Cumbu Cool' is consumed in Tamil Nadu. The ICAR-National Dairy Research Institute, Karnal has developed and launched pearl millet '*lassi*' made from pearl millet flour. Several milk analogues are also being tried at ICAR-IIMR, Hyderabad.

6. PROMOTING PRODUCTION, VALUE-ADDITION AND CONSUMPTION

6.1. Promoting production

With the increase in human and livestock population and a fragile balance between food supplies and its demand especially in drylands, production of millets, particularly sorghum and pearl millet need to be increased to meet the food and fodder needs. Millet market is expected to grow over 14 billion USD at a CAGR of 4.6% during 2019-2027. Share of organic millets is expected to grow over 29.7% at a CAGR of 5.6%. Asia Pacific is the dominant market with 40.9% market share followed by the Middle East (32.0%) and Europe (14.1%). Taking cognizance of

water economy among different crops, and the rising temperature as a result of climate change (I-2°C increase expected by 2050), millets have the potential to cover 35 million ha of land with production of 85 million tonnes if millets receive favourable policy push.

6.1.1. Vertical approach: The enhancement of yield per unit area in millets is likely to play an important role in future to augment production. The farmers' average yield is 22-44% lower than the yield realized at the on-farm demonstrations (Fig. 3). Hence, the short-term goal could be to bridge the existing yield gaps. The potential yield of different millet crops is 2-3 times higher in finger millet and minor millet, four times higher in pearl millet and five times higher in sorghum. This indicates that productivity of all millets can be easily increased from their current levels of productivity, which would require integration of water conservation, adopting the newest high yielding crop cultivars, integrated nutrient management and integrated insect-pest and disease management. The adequate number of demonstrations using cluster-approach in different agro-ecological zone should be conducted using all above-mentioned interventions. This would go a long way in convincing the farming community to adopt new technologies for enhancing millet productivity.

However, on the long-term basis, new cultivars with high production potential will determine enhancement in their production. The needed interventions include:

- ✦ Accelerating genetic gains by way of improving efficiency and precision of breeding through development and application of high-throughput genomic tools, speed breeding and precision phenotyping protocols.

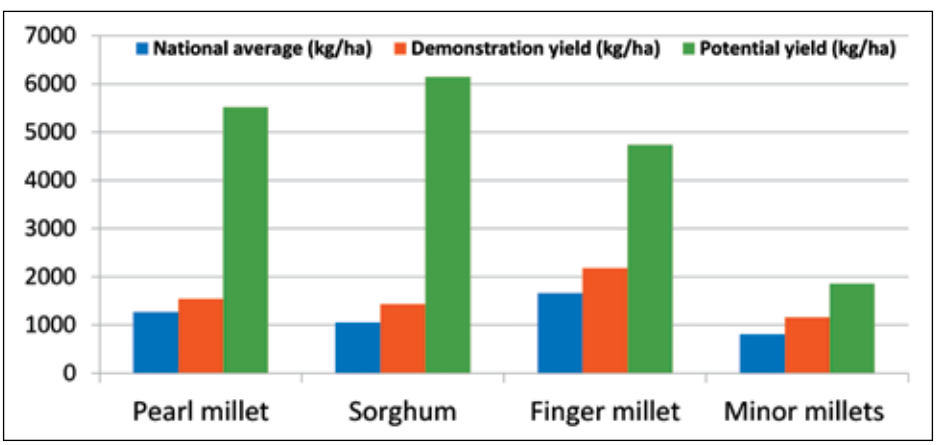

Fig. 3: Yield of pearl millet, sorghum, finger millet and minor millets realized at national level, demonstration level and potential level

- Strategic utilization of huge wealth of native genetic variation available in millets germplasm (>137,000 germplasm available in ICAR and ICRISAT gene banks) for diversification of the genetic base, discovering new traits conditioning tolerance to multiple biotic and abiotic stress environmental adaptation and greater yields in order to make millets more adapted and productive to challenging production environments.
- Strengthening hybrid breeding efforts for drought-prone north-western India for pearl millet and post-rainy season in central India for sorghum to develop hybrids with higher production potential in these challenged agro-ecosystems.
- Heterotic grouping of hybrid parental lines to increase the magnitude of heterosis and to achieve sustainable productivity gains on a long-term basis. Mainstreaming of the nutritional traits improvement in millet breeding programs to develop bio-fortified millets.
- During the last decade, more than 220 cultivars of millets have been released for different agro-ecologies. These new cultivars are to be brought in seed production chain to augment productivity in farmer's fields. Thus, there is an urgent need of strengthening seed chain by creating adequate number of seed-hubs especially for minor millets to increase the adoption of new cultivars and to further enhance the seed replacement rate. These seed hubs would be the source of the quality breeder and foundation seed to further take up the quality seed production. Targeting production systems and management in niche production environment by developing customized agronomic practices for millets in *kharif*, *rabi* and summer seasons is needed.

6.1.2 Horizontal approach: Millets have been a very important and regular component of farming in states like Bihar, Uttrakhand, Madhya Pradesh, Chhattisgarh and Tamil Nadu. In certain states, like Karnataka, Telanagana and Maharashtra, where water is becoming a serious limitation, there is considerable scope to revive millet cultivation to address the issues related to water and soil management. Incentivization of growing millets in such regions would be a boost for their expanded cultivation even in identified wastelands/fallow lands. Increasing the cropping intensity in dryland agriculture can only be achieved through millets. Millets are the most viable solution in maintaining round-the-year cropping system in the dryland agriculture. Most of the millets are short duration in nature (generally 65-80 days) and can be successfully grown in the post-*kharif* fallows. Given the minimum requirements for water, small millets like *kodo*, little and barnyard millets can be successfully grown in the post-*kharif* fallows with the residual moisture content in the drylands. This will significantly increase the cropping intensity in dryland agriculture and yield generating

income throughout the year for farmers. Sorghum can also be successfully grown throughout the year in many parts.

6.2. Enhancing value-addition

Enhancing value-addition and nutritional value of millet is essential to further promote millets with a brand of health food with better nutrition. Some of the most important interventions in this area are:

6.2.1. Biofortified food: Pearl millet is the first crop in India to have a biofortified variety named "Dhanashakti". Subsequently, some more biofortified pearl millet hybrids, and varieties of finger millet and little millet with high iron and zinc have been released. These varieties need to be promoted as biofortified food.

6.2.2. Health food: Millets are the storehouses of nutrition. Millets being rich in optimal and slow releasing carbohydrates, higher in protein and fat content, higher dietary fibre conferring good gastrointestinal wellness, rich micronutrient and amino acids composition supporting body growth, maintenance and ability to cope up with stresses are naturally branded health food. Life style diseases such as hyperglycaemia, obesity, cardiovascular diseases, incidence of colon cancer, etc. have been known to be reduced or well managed by adopting millet based diets.

6.2.3. Market segmentation and demand: A package of strategies for branding, positioning, and marketing in various consumer segments, is needed to promote millets efficiently. The market segments for millet products can be grouped into two broad categories, high-end and low-end. Market functioning can be useful for positioning the millets. Millet food segments like instant foods, ready-to-eat foods, high-calorie foods, plant-proteins, organic foods, healthy foods, immunity foods; gluten-free, etc. can be grouped into high-end foods. These segments can be addressed by ease, convenience and easy availability to consumers. Ready-to-cook and ready-to-eat products of millets are gradually becoming available in Tier 1 and Tier 2 cities. Multi-grain millet flour, flakes of sorghum and pearl millet, finger millet malt, sorghum semolina and pasta, millets based breakfast cereals, millets-based regional snacks and fast foods, etc. are the commercially available millet products in India both in retail and online. Delectable foods and easy to cook products which are enjoyed by all age groups need to be in place to sustain the good work of promoting healthy foods like millets.

6.2.4. Skill development in processing and value-addition: Trainings on value addition technologies are to be made available at local level under the government-funded programmes. Several millet food recipes have also been published in books and are available on-line, which can be popularised with necessary training.

6.2.5. Encouraging entrepreneurs by making available processing machinery with high efficiency: Standardized primary and secondary processing machinery for millets need to be developed on a larger scale. Also, the recovery of grains in primary processing is an issue to be addressed in small millets. More efforts are needed to develop more efficient and affordable machines.

6.2.6. Availability of quality raw material: This is incumbent on assured procurement of quality raw material. Use of right seed recommended cultivation practices and buyback support would enhance the availability of quality material for the food processing industry. The digital buyer-seller platforms can also facilitate such networking and final transactions.

6.3. Promoting consumption

Increasing consumption of millets is the key issue for creating their demand in the market as food, feed and industrial raw material.

6.3.1. Mainstream millets in food system through policy interventions: Mainstreaming of millets in the Public Distribution System (PDS) like wheat and rice is essential in creating bulk demand. Since different millets are traditional food in different regions, a regional approach in PDS can be followed which may include pearl millet for Rajasthan, Haryana and Gujarat; sorghum for Maharashtra, Karnataka and Telanagana; finger millet for Karnataka; and minor millets for Orissa, Uttarakhand, Madhya Pradesh and Chhattisgarh.

Utilization of millets in the mid-day meals by the central and state governments is essential not only for augmenting the demand of millets but also for ensuring the proper nutrition to women, children and people at large, in addition to income security for farmers. Localized procurement and distribution can be efficient while supplying the excess grain to other locations. Specific plans are to be formulated for supplying millets in mid-day meals in schools which will go a long way in popularizing millets benefitting future generations of farmers as well as consumers.

6.3.2. Branding millet as health and functional food: Millets contain more dietary fibre and higher amylase inhibitory activity and thus millets-based foods are low in glycemic index. Life style diseases such as hyperglycemia, obesity, cardiovascular diseases, incidence of colon cancer, etc. are known to be reduced or well managed by adopting millet based diet. The recent scientific case for consuming millets has been made through a series of studies led by ICRISAT along with NIN and others which have established that regular consumption can help lower the risk of diabetes and obesity, while improving cholesterol levels and contributing to lowered risk of cardiovascular disease. The research effort had also demonstrated

the effectiveness of millets in combating iron-deficiency anaemia and deficiencies of calcium. Millets are largely grown without use of insecticides and pesticides. They are also called eco-friendly crops due to their lower requirement of water, chemicals and management interventions for raising the crops.

***6.3.3. Addressing shelf-life and rancidity*:** The current level of shelf-life of millets is less compared to other major cereals. Bringing good taste and convenience with an increased shelf-life of about six months have been shown with some promising technologies. A shelf-life of 8-10 months will be vital for export markets. In pearl millet, efforts are on to reduce rancidity by standardizing processing and storage, besides resolving through biochemical and molecular interventions.

***6.3.4. Developing diversified products*:** Making available the diverse food according to the taste, requirement and convenience of traditional and modern consumer is the key factor behind increasing the millet consumption in food sector. Good progress has been made in processing diversification through 40 retrofitted machineries to develop more than 50 diversified millet value-added processing technologies (puffing, baking, popping, flaking, cold and hot extrusion, milling) that are used in making millet food in a convenient way.

***6.3.5. Promotion campaigns*:** Devising and implementing campaigns with ambassadors of public standing (celebrities, social media influences) from public to engage them in popularization through social media would be helpful. Fairs, exhibitions, festivals and campaigns can be organized for promoting millets. National Level 'Eat Millets Campaigns' would be helpful to promote the awareness about the usefulness of millets and to reach out to the larger groups of consumers for creating a demand for millets thereby enhancing production. The campaign on TV could be further reinforced by advertisements in publications, documentary films, rural publicity through vans, unique schemes of providing millet kitchen carts to unemployed youths and women, recipe booklets, exhibitions, seminars and sponsorships of sports, brand ambassadors and cultural events.

6.3.6 ***Mission on millet*** is extremely important in generating additional demand. Government of India has taken initiatives to include millets in National Food Security Mission. Further, Indian government had announced 2018 as National Year of Millets to boost production and consumption of millets. Owing to their nutritional, economic and climatic characteristics, Indian Government has started efforts towards mainstreaming the millets in the country and across the world. Being the leader is millets production, the Government of India is exercising its leadership to position millets for the global markets. Recognising the importance of millets, the Government of India along with other country governments had urged the United

Nations to declare a year as the International Year of Millets. The India-sponsored International Year of Millets was supported by 70 countries and United Nations has slotted 2023 for promoting the millets globally as the future foods in the changing climatic conditions.

Promotion efforts are being made to showcase millets as the future alternative health food options that offer nutritional security to all the needy consumers across the world, besides offering a climate resilient option to farming. In the last decade, research efforts on diversifying uses of millets has been attempted by several R&D institutes, SAUs and private agencies. Today, a wider range of ready-to-eat and ready-to-cook products made are available, on par with rice and wheat. The private-sector players such as ITC, Britannia, Kellogg's, MTR, Parle Agro, Soulful, 24 Mantra, etc. have launched a few products either as solo or in combination with millets. Grocery e-commerce stores such as Big Basket are offering 50+ millet-based products benefitting millions of consumers by diverse millet products. Besides, the efforts by the R&D institutes like ICAR-IIMR, CFTRI, NIFTEM, IIFPT and SAUs with support from DST and RKVY RAFTAAR have built the traction of millet-based startups which has manifested as 400+ millet startups in the last 5-year span.

Several state governments have piloted the inclusion of millet foods in PDS, ICDS, etc. programs. Some of the notable interventions are pilot inclusion of millet foods by the governments of Odisha, Karnataka, Telangana, Madhya Pradesh, Andhra Pradesh and Tamil Nadu. Under the ODOP program, MoFPI has formulated a committee constituting IIFPT, NIFTEM, ICAR-IIMR, IIT-Kharagpur and other CSRI and ICAR institutes to formulate the detailed cost norms and model DPRs, and appraise the proposals for setting up the Common Incubation Facilities (CIFs). MoFPI has called for applying to CIFs, and received proposals from 23 states and 2 UTs. Out of 25 proposals, MoFPI has approved 5 millet-based incubation centres. For implementing these projects, ICAR-IIMR was chosen to be the Mentor Institute for two states- Telangana and Kerala.

***6.3.7. Millets Business Incubation*:** Millets Technology Business incubator (TBI) of IIMR, is institutionalised and branded as "Nutrihub" and is engaged with proactive measures to build a pipeline of entrepreneurs, so far handholding more than 200 millet-based start-ups and their brands, which has received instant recognition and overwhelming response and several success stories are coming up. These start-ups are being connected with both the markets in niche and public funded captive markets. ICAR has enabled them to connect with Government e-market place (GeM).

ICRISAT has launched the “Millet Finder” website to help users find over 500 products across 30 countries. Another 500 products are identified and set to be included and mapped by end of the year by the Smart Food team at ICRISAT.

6.4. Creating additional demand

The creation of additional demand of millet is the key factor for promoting millets on sustainable basis. Millets can be important source of feed for poultry and livestock. Specific areas where demand of millets can be enhanced are given below:

***6.4.1. Using grain as poultry and cattle feed*:** Pearl millet and sorghum grains are being fed to poultry, cattle and swine. The grains in the form of ground, dry rolled, soaked, pelleted, steam rolled, extruded, flaked, popped, etc. are being used as poultry feed. Replacing the maize with pearl millet, sorghum or other millets in broiler ration has been reported to improve the body weight gaining because of high feed conversion ratio. In India, pearl millet is used as an alternative to maize grain when the prices of maize are high.

6.4.2. Use in bioethanol production: Sweet sorghum varieties have potential uses as complementary crop to sugarcane and the sugars and starches in it could be fermented to ethanol and lignocellulose could be gasified to methanol. The high energy sorghums are capable of 75-100% more energy than sweet sorghum also. The distilled ethanol finds various applications such as cooking, lighting, gas engines, boilers, etc. The bioethanol can be sourced from stalks of sweet sorghum and is now being propagated through technology partners IIMR and ICRISAT with some industries who are involved in piloting use of sweet sorghum stalks as feedstock for ethanol production to supplement sugarcane molasses-based ethanol for bioethanol to be used for blending bioethanol with petrol up to 20%.

6.4.3. Potable alcohol: *Ethanol* is the most important fermentation product of grain sorghum, while beverage alcohol is feasible with procedural changes. Other possible fermented products include citric acid, lactic acid, riboflavin, antibiotics and microbial polysaccharides. There are number of distillation units in India that are into potable alcohol from sorghum and pearl millet grain especially when it is mould infested. States like Maharashtra have given policy support to grain-based distilleries.

6.4.4. Connecting with FPOs for better bargaining in pricing: Farmer Producers Organizations may be strengthened in such a way that pooling, cleaning, farm-gate processing, storage and supply to market will enable them to reap the economic benefits for their enhanced incomes, which will have a huge motivation for increasing

the millets cultivation area. Farmers in India buy all the inputs from retailers and sell their produce to wholesalers, also accounting for the transportation costs and losses on them. This unorganized approach where farmers are lacking both Backward and Forward linkages is making their cultivation a non-remunerative business. There are 100 Millets based FPOs supported by NFSM under the National Mission on Nutricereals of which 6 millet FPOs from Telangana, Andhra Pradesh, Karnataka and Madhya Pradesh states are being handheld by ICAR-IIMR to model them.

6.4.5. Exploring export potential: *India* traditionally export millets in commodity form. World over, sorghum and other millets are used for feed purposes except in India, SE Asia, and Africa. However, in the changed context, the millet export is emerging in terms of diversified food uses. India is the global leader in the production of millets with a share of around 15% of the world total production i.e., around 15 Million tonnes annually. India is the second-largest exporter of millets and the country exported millets of worth 28.5 million USD during 2019-20 to Nepal, Saudi Arabia, Pakistan, UAE, Tunisia, Sri Lanka, Yemen, Libya, Namibia and Morocco. The export can be further enhanced by mapping additional market in different countries.

7. NEED FOR INCREASING INTENSITY OF RESEARCH ON MILLETS

The intensity of research in terms of investment and manpower deployment have been very high for the obvious reasons for attaining self-sufficiency in food grains with special reference to cereals like wheat, rice and maize. In contrast millets have received much lesser support for creating infrastructural and human resources. Despite this, magnitude of yield improvement in millets under rainfed conditions is a successful demonstration of technology-led development. As millets are further being recommended for more marginal environments of drylands, it would require greater resources for conducting basic, strategic and applied research in order to raise millet productivity. At the same time, it is equally important to mobilize research networks within academic and research institutions to fully appreciate the role of millets in agricultural and economic growth. Stakeholders involved in millets research and development needs to invest in innovation for improving production, marketing and distribution of millets for which establishing partnerships with governmental and non-governmental organizations is critical. Addition of two crops viz. buckwheat and amaranth by the Govt. of India in the millet club is a welcome step as both the crops are of extreme importance due to their nutritional advantages. Whereas buckwheat has very low glycemic index (55) as compared to wheat (75) and rice (73) and is also gluten-free; amaranth is a nutritious, gluten-free

grain that provides plenty of fiber, good quality protein as well as micronutrients especially iron. India is now the global diabetic capital where 28% of the urban Indians are either diabetic or vulnerable to diabetes. Thus, increasing the intensity of research with higher allocation of funds and scientific manpower will go a long way in strengthening R&D on millets, which will, in turn, provide solid base for production of these millets and pseudo-cereals. With diversification of rice-wheat centric agrifood system coupled with easy availability of millets and their diversified processed products in urban areas, the urban Indians vulnerable to lifestyle ailments like diabetes can be motivated to add millets in their daily food intake.

8. RECOMMENDATIONS

The current and future agriculture faces multiple challenges posed by climate-change, malnutrition of a large section of population, overexploitation of soil and water resources and reduced agro-biodiversity. Of late, water has assumed great significance as its per capita availability in India has reduced to 1/3rd as compared to 1950. Promoting millets in the Indian agriculture will address all of these and therefore, the following suggestions merit attention of all stakeholders:

- A "Millet Mission" needs to be launched at the national level with specific objectives to promote production, processing, consumption and popularization.
- The average productivity of millet crops is lower than that of fine cereals because of cultivation of former in the challenging agro-ecosystem. Therefore, increased emphasis in their genetic improvement is required to develop new cultivars, using new tools and technologies, with high production potential and adequate environmental adaptation to make millets competitive with other crops.
- There is an urgent need to strengthen the seed chain by creating adequate number of seed-hubs especially for minor millets to increase the adoption of new cultivars and to further enhance the seed replacement rate.
- Mainstreaming the improvement of the nutritional traits in millet breeding programs to develop bio-fortified millets should get top priority. The strategic utilization of millets germplasm for higher density of micro-nutrients in grains as well as better tolerance to multiple biotic and abiotic stresses and environmental adaptation. Enhancing shelf-life has to be on the top of the agenda using new and emerging technologies including gene editing.
- The biggest challenge in mainstreaming millets was the lack of balance between their supply and demand. Incentivization of farmers for growing millets and

involvement of private sector for establishing a sustainable millet value-chain will go a long way in bringing back millets in the states of Bihar, Uttarakhand, Madhya Pradesh, Chhattisgarh, Orissa and Tamil Nadu. Millets need to be promoted in water-limited regions of Rajasthan, Gujarat, Haryana, Karnataka, Telanagana and Maharashtra.

- Primary and secondary processing of millets require efficient and low-cost machines. Designing, manufacture and promotion of such machines are recommended through appropriate public-private partnerships.
- Creation of additional demand for millets is the most important intervention for promoting millets on sustainable basis. Mainstreaming of millets in the Public Distribution System (PDS) as in care of wheat and rice is required for creating bulk demand. Regional approach in PDS can be followed, by including pearl millet in Rajasthan, Haryana and Gujarat; sorghum in Maharashtra, Karnataka and Telanagana; finger millet in Karnataka and Uttarakhand; and minor millets in Orissa, Uttarakhand, Madhya Pradesh and Chhattisgarh.
- Alternate usage of millets as feed for poultry and livestock and as industrial material for bioethanol and potable alcohol production are already established. There is ample scope to further enhance the demand of millets in these industries.
- Busy lifestyle, upmarket choices, and lack of skills for cooking millets has necessitated the creation of new generation health food from millets in the form of RTE/RTC/RTS foods, convenience foods, functional and nutraceutical foods, plant-based proteins, vegan foods and nutrient rich foods using millet as primary or secondary ingredient. A number of diversified millet food products according to the taste, requirement and convenience of traditional and modern consumer have been developed. Promotion campaigns with personalities of public standing; organization of fairs, exhibitions, festivals and campaigns; brand ambassadors and national level 'Eat Millets Campaigns' would be helpful in creating awareness about the benefits of millet-based food and popularise these.
- Doubling investment in research and development of millets is essentially needed to create adequate infrastructure and sufficient human resource for carrying out R & D work on millets. Creation of millet-based FPOs, start-ups, incubation centres and Nutri-Hubs during 2023, the International Year of Millets can be a starting point.

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