Vision 2050

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Printed : July 2015

संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो-तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट-परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान-जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन-2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

(राधा मोहन सिंह)
केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pest and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Indian Institute of Millets Research (IIMR), Hyderabad has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

(S. AYYAPPAN)
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Preface

Millets (sorghum, pearl millet and small millets) are the important food and fodder crops in semi-arid regions, and are predominantly gaining more importance in a world that is increasingly becoming populous, malnourished and facing large climatic uncertainties. These crops are adapted to wide range of temperatures, moisture-regimes and input conditions supplying food and feed to millions of dryland farmers, particularly in the developing world. Besides they also form important raw material for potable alcohol and starch production in industrialized countries. Among these crops, sorghum is the world's fourth most important cereal, in terms of both production and area planted. Millet, a general category for several species of small-grained cereal crops, is the world's seventh most important cereal grain. Roughly 90% of the world's sorghum area and 95% of the world's millet area lie in the developing countries, mainly in Africa and Asia. These crops are primarily grown in agro-ecologies subjected to low rainfall and drought. Most such areas are unsuitable for the production of other grains unless irrigation is available. Sorghum is widely grown both for food and as a feed grain, while millets are produced almost entirely for food.

The economic importance of the millets is increasing in terms of feed value, particularly that of sorghum though it is grown in contrasting situations in different parts of the world. Millets are grown in the harshest environments where there is limited scope for growing other crops. Millet production systems in Africa and Asia are generally characterized by extensive production practices and limited adoption of improved varieties, yields still average only 0.3 to 1.0 tonnes per hectare. While hybrids are being adopted in sorghum and pearl millet, most of the world's millet area remains under traditional varieties. Few farmers apply fertilizer or use improved moisture conservation practices. Therefore the yield levels remained low for long but increasing wherever improved hybrids and management practices are increasingly adopted like in India. After almost 67 years of Independence, malnutrition continues to plague India. Even while vast segments of resource-poor people suffer from undernutrition, particularly micronutrient deficiencies (hidden hunger), there is a growing incidence of obesity and chronic diseases like diabetes, cardiovascular diseases, cancer etc. Both the ends of this grim spectrum are at least partly due to changing food habits, loss of millets from the diet being one of the million millets offer unique advantage for health being rich in micronutrients, particularly minerals and B vitamins as well as nutraceuticals. These phytochemicals have been shown to mitigate above mentioned chronic diseases. Millets can also withstand environmental stress being resistant to drought and warming. Thus, these are grains for the future and "harbingers for evergreen revolution". Currently, they sustain the livelihood of over 60% of small and marginal farmers. Time trends show marked reduction in area under millet cultivation due to variety of reasons. Thanks to technological breakthroughs, productivity and production have shown some increase despite erosion in farm area.

The sorghum and millets are crucial to the world food economy because they contribute to household food security in many of the world's poorest, most food-insecure regions. In the main production regions in Africa and Asia, more than 70% of the sorghum crop and over 95% of the millet crop are consumed as food. A large proportion of farm households aim simply to produce enough grain to meet household requirements - and many often fail to meet even this limited goal. Only a small proportion of the harvest is traded, mostly on local food markets. In some countries like India, sorghum contributes to 1% of the total agricultural GDP while it goes up to 7% in Maharashtra and 5% in Karnataka the two major sorghum growing provinces in India. We hope to overcome the issue of profitability of sorghum and millets production by research and extension on value addition, marketing research and liaison with the user industries. Simultaneously, we will pursue other avenues such as growing sorghum as a biofuel crop for which we have done significant work, in addition to promotion of millets as functional health foods.

Millets continue to be important food and feed crops in developing world. Their versatility in multi-purpose use, stress adaptation and nutritive value makes them even more important crops in the era of extreme climate variability and high incidence of dietary induced malnutrition. Recent advances in sorghum and millets research and development in enhancing their yields, adaptation, stress resistance, nutritional value and processed products development discussed above contributes to increased economic value of these crops to the producers. The biofortified pearl millet and sorghum, sweet sorghum for bioenergy are some of the examples showcasing the potential of these crops in providing nutritional and energy security in developing world. Sorghum genome sequence is available and put to use for improving various traits. A consortium is sequencing the pearl millet genome and the draft genome sequence is expected soon. Efforts are underway to sequence the finger millet genome also. The challenge will be to make use of the genome information and developing customized research products and technologies to suit various climatic, food, nutritional and product quality requirements. Besides productivity enhancement the whole value chain will be looked into to make these crops more remunerative to farmers and processors. This calls for increased interest and investment from national governments and private sector for developing thriving integrated value chains for sorghum and millets.

With our strategic planning based on this vision document, it is anticipated that overall, atleast 30% increase in millet acreage over the current levels is expected to be attained by 2050 AD. Accordingly, the estimated production in sorghum is computed to be 30.06 million tonnes, of which rabi production contribution alone will be 83% of total production. Similarly 24.4 million tonnes in pearl millet, 4.40 million tonnes in finger millet, 1.8 million tonnes in other small millets with overall aggregate production of 60.60 million tonnes of Sorghum, pearl millet and small millets put together by the end of 2050 AD. Area gains in favour sorghum, pearl millet and small millet may come from other crops which are less remunerative (sorghum, pearl millet and small millet demand is going to higher due to value addition and due to their importance as functional health foods) and from areas where commercial crops like sugarcane cannot be continued due to lowering of water table making it difficult for them while it still favours sorghum, pearl millet and small millets which with minimal Irrigations will help to double the yields. Another area that has not been taken into account at all is area under multicut fodder sorghum under area under sorghum. The present acreage under multicut fodder sorghum is one lakh hectares. The seed yield productivity is 15 quintals per acre. Thus a total of 37, 50,000 quintals of seed is produced, which @ 20kg per hectare as seed rate will crop 18.7 million hectares area under multicut fodder sorghum. The 5-6 cuts from each hectare yields 92 tons of green fodder to the farmer. With the policy push and ever increasing demand for fodder required by domestic and dairy industry suggests that with improvement in yields and commensurate with demand, the fodder sorghum area by 2050 will be 27.0 million hectares. It can be inferred from above that the maximum production gains will be attained through policy interventions as in scenario 3 for millets to the extent of 300% over the current situation. Such gains will enable meeting both food and nutritional security of millions. Thus productivity improvement may be within the realms of reality in the near future. Different genotypes suited to different growing conditions may be essential to bring in all-round increase in productivity. The economic gains that may be augmented by addressing envisaged benchmarks will result in significant improvement in productivity, profitability and even export earnings. All these are expected to translate sorghum and millets farming into a healthy and prosperous proposition, justifying the public support for sorghum and millets research in the country.

We are highly obliged to Dr. S Ayyappan, Secretary, Department of Agricultural Research and Education and Director General, Indian Council of Agricultural Research for his guidance and encouragement. We are grateful to Dr. SK Datta, DDG (Crop science), ICAR, for his sustained interest and support for sorghum research. Our gratitude is due to Dr. RP Dua, Former ADG (F&FC) and Dr. JS Chouhan, ADG (Seed) for their keen interest and support in preparing this important document. Further this document has been made possible because of the inputs from members of different committees such as RAC, IRC and QRT, and my colleagues in IIMR. I specially appreciate the efforts of Drs. Vilas A. Tonapi, B Dayakar Rao, B Venkatesh Bhat and KV Raghavendra Rao and all the scientists in the preparation of this document. The secretarial and pictorial support from K Sanath Kumar and HS Gawali are gratefully acknowledged.

Director
IIMR, Hyderabad

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Context

The Indian Institute of Millets Research (IIMR), Hyderabad with its AICRPs on Sorghum, Pearl Millet and Small Millets has been instrumental in developing high yielding varieties and hybrids of Sorghum and Pearl Millet and high yielding varieties of small millets, as well as novel production and product development technologies. The Indian Institute of Millets Research conducts basic and strategic research, while All-India Coordinated Sorghum Improvement Program with 21 centers spread over 10 states, 14 centres of All India Coordinated Pearl Millet Improvement Project located in 10 states, and 13 centres of All India Coordinated Small Millets Improvement Project located in 9 small millet growing states with its Headquarter at IIMR (coordinating units) undertakes applied research and pilot extension work in a network mode. The overall objective is to enhance production, productivity and profitability to enable the agricultural sector to accelerate the transformation of "subsistence farming" to "market and income-generation oriented" Millet production system. Millet crops have been dominant components of rainfed agriculture on a regional/local basis. Their adaptation to harsher environments and diverse cultural and agro-climatic situations is well known. Hence, they constituted critical elements in the food, livelihood and nutrition security of the poor in particular. They also provided for genetic diversity and cropping systems stability. Some of the species are known for their specific attributes to withstand drought, heat, salinity and adaptability to poor soils. Nutritionally some of them are rich sources for micronutrients, dietary fibre and some attributes of therapeutic value besides industrial uses. Hence, they provide sources for genes involved in many biochemical pathways and processes.

Historically, millets used to be cultivated in an area of 35 – 37million hectares in India. Past researches have largely been in the area of improving yields. The successful development and spread of hybrids and improved varieties of sorghum (*jowar*), pearl millet (*bajra*) and finger millet (*ragi*) made a significant impact on the productivity of these crops during the 70s and 80s. The private sector gained considerably from hybrid seed production and marketing of sorghum and pearl millet hybrids In fact, the largest volume of hybrid seeds sold earlier was for sorghum and *bajra* hybrids. Later the area under millet crops reduced to 20 – 22 million hectares. The reduction has been more drastic in case of kharif sorghum and small millets. This has been largely due to change in food habits and their limited role in market economy. The investments in R&D on these crops have also been limited. While the private sector plays no attention to ragi and small millets, the public distribution system supplies wheat and rice at subsidized prices. These are some of the reasons for the millets being called orphan crops. Even though, the area under millets diminished, in view of their multifarious uses, the potential is very high. Millets crops now stand at a critical juncture. Keeping in view the present situation, there is a need to reorient millet R&D programmes both structurally and functionally as millets as a group stand distinctly as climate smart crops which have a significant role to play in the climate change scenario and also as crops which are highly drought tolerant and can usher in food, feed, fodder, nutritional and livelihood security to all in dry land ecosystems as "MIRACLE NUTRI-CEREALS" providing nutritional and health security to all, which in fact is the need of the hour. In addition, it is apt time to critically evaluate their role in the conservation of bio-diversity, human and animal nutrition, industrial uses and therapeutic diets in the form of functional foods in relation to requisite Mandate of Indian Institute of Millets Research (IIMR) and AICRPs on Millets.

Vision: Ensuring Climate resilience, Nutritional Security and equitable prosperity through Millets

Mission: Promote growth of Millets by developing and disseminating value added technologies to create markets for long-term economic sustainability of millet production systems

Mandate of IIMR

- Conduct basic and strategic research to increase productivity of millets, their diversified utilization, and enhancement of profitability.
- Develop of economic and ecological millet based cropping systems and sustainable rural livelihoods for cropping system stability, food security and poverty alleviation.
- To collect, evaluate, conserve and use novel and value added germplasm and conduct critical analysis of the millet collection for various nutritional and therapeutic attributes and their exploitation in conserving bio-diversity, nutrition, therapeutics, health and diversification of diets.
- Demand generation through diversified uses for food, feed, energy, potable alcohol and alcoholic beverages, starch and starch based products and through exports.

- To serve as a national centre for training and consultancy and outreach approaches on millets production, development, value addition and utilization.

Mandate of AICRPs on Sorghum, Pearl Millet and Small Millets

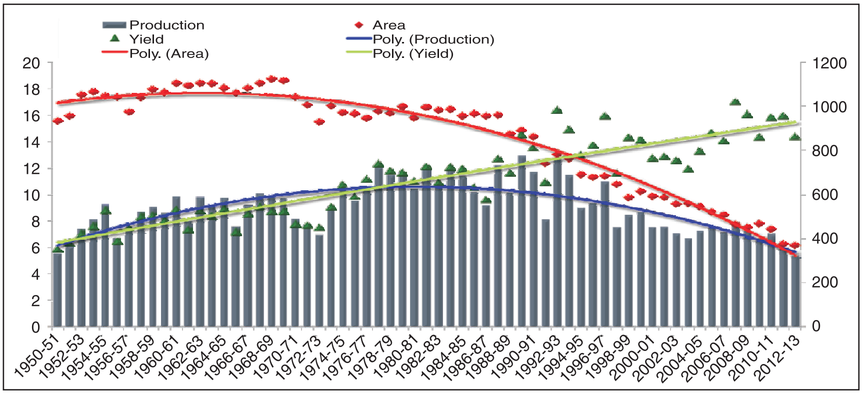
- To conduct coordinated multi-location programmes at the national level on sorghum, pearl millet and small millets improvement and utilization
- To develop superior hybrids, varieties and trait specific value added genetic stocks
- To evolve appropriate region and location specific crop management practices
- To promote linkages with seed production and developmental agencies for transfer of technology
- To document and disseminate research findings and exchange material for mutual benefit with bonafide collaborators and stakeholders.

Accordingly, IIMR would focus on resolving commodity-specific production constraints, matching agricultural, processing and value addition processes and technologies to market opportunities which provide additional farm income and creating off-farm employment especially in the semi-arid tropical Millet growing regions in India to usher in total livelihood, food and nutritional security. Therefore Millets research program in the country will embark on developing capacity to evolve strategies for resolving the constraints that hinder increased adoption of improved technologies. The Vision 2050 reflects strategies of IIMR in the context of globalization to complement and compete to augment adequate additional returns for research from both public and private stake holders by enhancing competitive edge to pave way for food, feed, fodder, nutritional and livelihood security across Millet production agro-ecologies, thus justifying amply the need for public and private investment in Millets Research and Development.

Millet Improvement and Current Scenario

Sorghum

Sorghum is one of the main staple food for the world's poorest and most food insecure people across the semi-arid tropics. Globally, sorghum is cultivated on 41 million hectares to produce 64.20 million tonnes, with productivity hovering around 1.60 tonnes per hectare. With exceptions in some regions, it is mainly produced and consumed by poor farmers. India contributes about 16% of the world's sorghum



Area, Production and Yield of Sorghum in India
(Area: in million hectares; Production: Million Tonnes and Yield Kg per hectare)

production. It is the fourth most important cereal crop in the country. In India, this crop was one of the major cereal staple during 1950's and occupied an area of more than 18 million hectares but has come down to 6.61 million hectares in 2013. The decline has serious concern on the cropping systems and the food security of these dry land regions of the country.

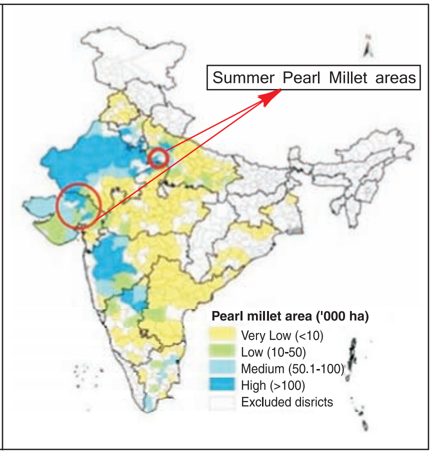
Thus, All India total sorghum production has registered a constant growth rate of 0.10% per annum during the period 1969-70 to 2012-2013 which can be mainly attributed to negative production of kharif sorghum rather than positive growth in rabi sorghum production. Though, kharif sorghum yield growth rates were relatively higher, it could not offset the declining growth rates in production, as the growth rates in kharif sorghum area were negative and high. Just opposite is true in case of rabi sorghum where the area decline was not sufficient to undermine the yield growth, thus resulting in positive production growth rates. The overall increase in productivity of kharif is far more than rabi sorghum. However, the loss in both area and production is greater in kharif sorghum than in rabi. The coverage with high yielding varieties (HYVs) of sorghum is nearly 80% in kharif and potential under moderate input is also high (4-6 tonnes per hectare). The area loss may be due to the fact that the expansion in irrigation which has made other crops such as rice, sugarcane, cotton, etc., more attractive and remunerative thus rendering sorghum to be less competitive. The decline in consumption demand of sorghum grain was also a major factor for the decline in area. The increased productivity of sorghum has not been able to compensate the loss in area turning the production to be negative. However, the suitability of the improved varieties of sorghum to specific regions and local farming conditions remain unresolved. But sorghum is finding a niche area under rice fallows, under the zero tillage conditions, grain productivity as high as 7 to 8 tonnes per hectare has been realized, and now it occupies a prime area of more than 45000 hectares and is expanding further, where kharif hybrids are prominently grown. The major thrust, in future, will be on enhancing area of sorghum in non-traditional areas and greater emphasis on alternate uses of sorghum and its utilization as a major food, feed, fodder, and fuel (bio-energy) for industrial utilization.

Pearl millet

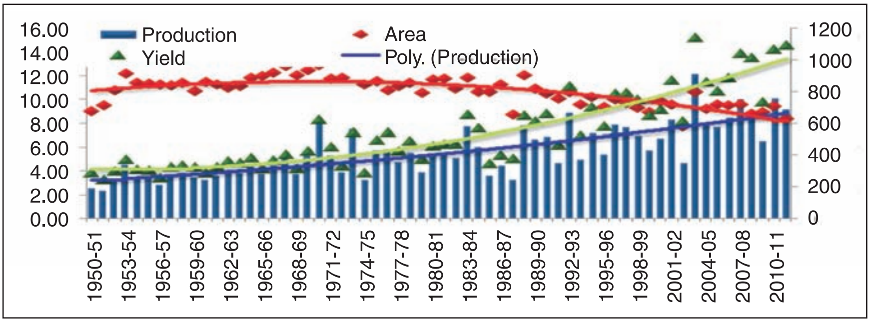
Pearl millet is a major warm-season cereal grown on about 30 million hectares worldwide, largely in the arid and semi-arid tropical regions of Africa (18 million hectares) and Asia (10 million hectares) with India accounting for largest area (>9 million hectares). The diversification of cultivar base with mostly dual-purpose hybrids has led to 24 kg/hectare/year of grain yield increase during the last 15 years as compared to only 5.2 kg/hectare/year of yield increase during the pre-hybrid phase of 1950-1965. Development of improved crop cultivars is just one major component of technological interventions to enhance food and nutritional security. Improved crop management technologies with potential to substantially increase pearl millet grain yield have been developed.

Some of the agronomic interventions will also have significant effects on improving nutritional quality. Laboratory tested processing technologies and alternative food products have been developed,

Area - 9.1 m ha in 2011-12
Importance – Grown for food, feed and fodder
Current market size (hybrid) – 18000 MT
Hybrid coverage - 68% (rainy), 100% (summer)
Market share – private 82%, public 18%
Major hybrid markets – rainy and summer
Trait preference – High grain & fodder yield, DM, blast, heat and lodging tolerance
Key issues – Downy mildew, blast, heat stress and drought stress
No. of hybrids - >150
No. of companies - > 45

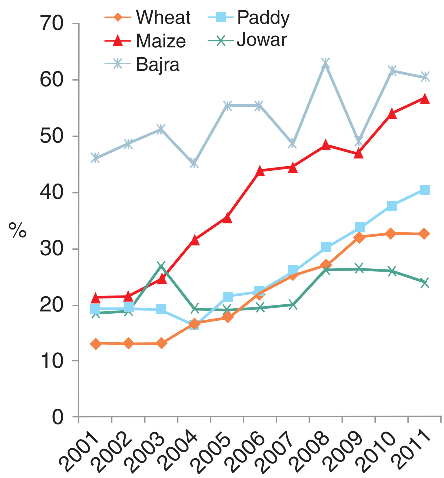


Overall scenario sustaining pearl millet production and productivity in India which have been shown to further enhance the bioavailability of these micronutrients. These technologies need to be tested for their commercial feasibility. Thus, an integrated approach of crop improvement backed with improved crop management, grain processing, and food products development; and appropriate policy support will enable pearl millet to play its rightful role in enhancing food and nutritional security.



All India trends in area, production and yield of pearl millet
(Area: in million hectares; Production: Million Tonnes and Yield Kg per hectare)

- **Stronger genetics:** superior products have driven growth @ 24 kg/ha/year in last decade.
- **Breeding for Disease resistance** – no DM epidemics in last 25 years
- **Highest seed replacement ratio** – Pearl millet has highest (60%) seed replacement rate as compare to other cereal crops.
- **Faster product ramp up**– average product life cycle is 5-7 years



Key drivers of pearl millet productivity improvement

Small millets

There are six different small millets grown in India which include finger millet (*ragi*), foxtail millet (*kangni*), kodo millet (*kodo*), proso millet (*cheena*), barnyard millet (*sawan*) and little millet (*kutki*). The area under these crops during the last 6 decades has significantly shrunk from 8 million hectares in 1949-50 to around 2.3 million in 2012-13 This is also reflected in diminishing production, from around 4 million tonnes produced in late forties to around 2.5 million tonnes in 2011-12. The loss of area is very severe in all small millets other than finger millet. However, in the last 15 years, the finger millet also has lost ground and area has come down from 2.4 million to 1.2 million hectares and likely to lose further in the coming years.

Area (million hectares), production (million tonnes) and productivity (Kg/ha) of small millets *vis-à-vis* other millet crops in India*

Crop/Year	Category	1955-56	1965-66	1975-76	1985-86	1995-96	2005-06	2012-13
Sorghum	Area	17.36	17.68	16.09	16.10	11.33	8.68	6.18
	Production	6.73	7.58	9.50	10.20	9.33	7.63	5.33
	Productivity	387	429	591	633	823	880	863
Pearl Millet	Area	11.34	11.97	11.57	10.65	9.32	9.58	7.20
	Production	3.43	3.75	5.74	3.66	5.38	7.68	8.74
	Productivity	302	314	496	344	577	802	1214
Finger Millet	Area	2.30	2.70	2.63	2.41	1.77	1.53	1.11
	Production	1.85	1.33	2.80	2.52	2.50	2.35	1.59
	Productivity	800	492	1064	1049	1410	1534	1428
Small Millets	Area	5.34	4.56	4.67	3.16	1.66	1.06	0.75
	Production	2.07	1.56	1.92	1.22	0.78	0.47	0.43
	Productivity	388	341	412	386	469	443	571

Source: Agricutural Cences, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Government of India.

Despite reduction in area, total production is not much affected. As regards productivity is conserved, finger millet has kept pace with most other major dry land crops in compound growth rates(CGR) for yield while the other small millets have shown little progress. By and large, the low productivity of these crops is largely due to meagre attention received in terms of inputs; water and technology backup which is further compounded by low value status of grains. The bulk of small millet production in India is of finger millet (80%) and the remaining from kodo millet, little millet, foxtail millet, barnyard millet and proso millet in that order. Small millets in India are grown in Karnataka, Andhra Pradesh, Maharashtra, Tamil Nadu, Orissa, Jharkhand, Chhattisgarh, Madhya Pradesh and Uttarakhand. They being the components of traditional farming system one could see well evolved cropping systems. Agricultural progress in India has been technology driven. In the endeavour, rapid and efficient dissemination of technology in the target areas is very critical. Wheat, rice and cash crops because of their importance have got greater attention of development agencies.

Coarse cereals have slower dissemination of technology due to less importance accorded by the development agencies, cultivation in unfavourable environments and lower apparent superiority of the improved technology under stress environments. Thus, the exploitation of available technologies has been limited and there is a vast untapped potential or productivity potential in different coarse cereals crops. The potential available in different agroclimatic zones for the various small millets based cropping systems makes it evident that there is still large potential available in the technology recommended now and which could be bridged through the appropriate development strategies. Technological dissemination and development strategies should focus on specific technology package for different farming situations, and intensive extension education on the package. Rainfed farming production technologies, particularly water management and usage, greater coverage under improved cultivars, efficient water use, integrated nutrient and pest management and good crop husbandry can result in a rapid progress in small millets productivity, provided appropriate guidelines are formulated and implemented for comprehensive development of these crops in harmony with other components of cropping systems. On farm experiments, frontline and other demonstrations need to be conducted on an extensive scale. Seed production and supply is not satisfactory in small millets.

The coverage under high yielding varieties is very poor in those areas where vagaries of monsoon are high resulting in uncertain production. In many states *ragi* and small millets seed production and supply is non-existent. Therefore, it is necessary to evolve a mechanism for assured production and supply of newly bred varieties. The evolution of such a mechanism is also necessary for the efficient conduct of central minikit programme as well as State/Centrally Sponsored Developmental activities. This can be further expanded and scope enlarged. Since seed is a critical input every effort should be made for efficient production and supply of seeds. Special seed programmes including Un- conventional methods of seed supply is also to be encouraged in coarse cereals. Involvement of Non-Governmental Organisations (NGOs) working in tribal/hill and remote dry land areas should be encouraged to undertake production and supply of truthfully labelled seeds. If necessary, seed subsidy has to be enhanced and its scope needs to be enlarged. On farm adaptive research conducted under NATP in Karnataka, Tamil Nadu, Andhra Pradesh, Orissa and Madhya Pradesh on intercropping of pigeon pea/ field bean/black gram with small millets have shown enhanced grain yield as well as higher monetary returns to the farmers besides augmenting

Compound growth rates of area, production and yield of millets for various periods

Crop	Area (Million hectares)	Production (Million Tonnes)	Yield (Kg/Hectare)
SORGHUM			
1970-2000	-1.74	-0.07	1.70
1970-2013	-2.33	-1.11	1.27
1980-2013	-3.04	-2.13	0.96
1990-2013	-3.23	-2.66	0.62
2000-2013	-3.78	-1.74	2.11
BAJRA			
1970-2000	-0.91	0.93	1.85
1970-2013	-0.85	1.51	2.38
1980-2013	-0.90	1.99	2.91
1990-2013	-0.79	2.11	2.93
2000-2013	-1.12	2.45	3.60
RAGI			
1970-2000	-1.48	0.24	1.74
1970-2013	-1.92	-0.59	1.35
1980-2013	-2.47	-1.18	1.32
1990-2013	-2.43	-1.59	0.86
2000-2013	-2.90	-1.57	1.37
MINOR MILLETS			
1970-2000	-4.45	-3.64	0.85
1970-2013	-4.67	-3.87	0.85
1980-2013	-5.13	-4.14	1.04
1990-2013	-4.71	-3.72	1.04
2000-2013	-4.75	-1.26	3.65
TOTAL MILLETS			
1970-2000	-1.65	0.11	1.63
1970-2013	-1.91	-0.25	1.47
1980-2013	-2.29	-0.59	1.54
1990-2013	-2.22	-0.65	1.29
2000-2013	-2.56	0.15	2.37

Note: Above figures are in % per annum**;** *Source:* IIMR, Hyderabad, 2014

(Area: in million hectares; Production: in million tonnes Yield: Kg per hectare)

the legume production that also helped in minimizing the protein malnutrition. This technology can be further taken to other states as a developmental strategy to augment the pulse production in the country.

Evidently the growth rate in the area of total millets in India is on decline for all the possible periods during last four decades due to decline in the growth rates of area in minor millets, sorghum, and finger millet. The rate of decline is slow in case of pearl millet. In pearl millet the yield growth rates are high which sheltered the effect of rate of decline in area keeping growth in production on positive side. The situation in case of all other millets including production growth is negative due to inability of positive gains attained in yield to subside drastic decline in growth in area. The reason in the positive growth in yield is primarily due to the enhanced crop improvement R&D efforts by the IIMR and coordinating centers constantly striving to keep positive growth. The positive growth in yield during 2000-2013 is the highest for all millet crops except in finger millet.

Background Information About R&D and Utilization

Sorghum

With the release of CSH 1, the first commercial hybrid in 1964, sorghum became the second crop after maize in developing high yielding hybrids using cytoplasmic-genetic male sterility system. After CSH 1, 30 more hybrids at central level and a few at state levels were released as adapted to specific regions. These hybrids played a major role in pushing up productivity and production, particularly in the case of kharif sorghum. Among the kharif hybrids CSH 1, CSH 5, CSH 6, CSH 9, CSH 14 and CSH 16 need special mention as CSH 5 and CSH 6 had a yield potential of 34 q/ha which was raised to 40 q/ha in CSH 9 and further raised to 41.0 q/ha in CSH 16, CSH 23, CSH 25 and CSH 30 with distinct superiority in grain and fodder quality. High yielding varieties CSV 1 to CSV 30 at central level and many more at states level were released. Some of these varieties are dual-purpose type. By and large, varieties were less acceptable to farmers. Better preference was for dual-purpose varieties such as CSV 10, CSV 13, SPV 462, CSV 15, CSV 20, CSV 23 and CSV 27 in some pockets. The short duration variety CSV 17 is gaining popularity and is expanding in area. A major advantage of varieties over hybrids was their relative better grain quality and multiple resistance/tolerance to major pests and diseases. The reduced maturity duration of the HYVs led to its high vulnerability to grain mold damage during kharif. Building reasonable resistance against grain mold is difficult. These biological limitations seriously restricted the economic advantage of their high yield. The government policies on production, pricing, procurement and distribution of cereals favoured fine cereals and placed coarse grains such as sorghum at a disadvantageous position.

Improvement of rabi sorghum did not receive as much importance as kharif sorghum until the nineties. Six hybrids and five varieties were hitherto centrally released for rabi. In rabi sorghum, the fodder yield is even more important than kharif sorghum. From this point of view, a progressive success was achieved from the first rabi hybrid CSH 7R to the latest hybrid CSH 19R. Unlike the kharif cultivars, higher levels of resistance against major pest (shootfly) and disease (charcoal rot), stringent maturity duration requirements to suit different receding soil moisture regimes and adequate levels of thermo-insensitivity are essential in rabi cultivars for better adaptability. Grain quality is also as much important as the grain yield, with quality benchmark being *Maldandi* (M 35-1). In adaptability criteria such as shoot fly resistance as well as the grain quality aspects, the varieties are superior to hybrids. The three rabi varieties released, CSV 8R, CSV 14R, CSV 18 and *Swathi*, were better received than the rabi hybrids such as CSH 7R and CSH 8R. However, the recently developed hybrids CSH 13 R, CSH 15R and CSH 19R are more productive, but the acceptability among farmers is not high as they do not want to invest on hybrid seeds every season during rabi (dry season) without irrigation. However, the new range of soil depth specific varieties like CSV 26 and *Phule Anuradha* for shallow soil, *Phule vasudha* and *Maulee* for medium soils and CSV 22, CSV 29 and *Phule Revathi* for deep soils have achieved niche area with greater productivity and quality in relation to *Maldandi*.

Unlike the case of kharif sorghum, biological and environment limitations posed difficult hurdles in rabi sorghum productivity. Some of the newly developed varieties could gain acceptability in certain deep soil pockets with assured soil moisture. The yield potential of newly bred cultivars is only marginally higher than M 35-1, the widely grown local cultivar. Hence, viable management methods to narrow down the existing gap between the production potential of local and improved cultivars and their farm yield could become a short term approach to increase rabi productivity. It appears that rabi sorghum may continue to enjoy increasing demand for its food and fodder preference. Thus, its area, particularly in Maharashtra and Northern Karnataka, may not decline substantially and possibly stabilize between 4.5 and 5.0 million hectares. While sorghum is largely used as a feed grain world over, its domestic cost of production and quality limitations made it less competitive to maize. The current feed production in the country under organized sector is 2.7 million tonnes which is projected to go up to 3.9 million tonnes by 2015 AD. Domestic grain based industries also need 2.0 to 3.0 million tonnes grain. Generation of novel alternate uses requires promotional research in these areas, including cultivar development to suit specific end uses and economic competitiveness through high productivity and lower

cost of production. The latter two considerations may also brighten up the chances for kharif sorghum to emerge as an export feed grain.
Utilization of sorghum in India

Unlike the case of kharif sorghum, biological and environment limitations posed difficult hurdles in rabi sorghum productivity. Some of the newly developed varieties could gain acceptability in certain deep soil pockets with assured soil moisture. The yield potential of newly bred cultivars is only marginally higher than M 35-1, the widely grown local cultivar. Hence, viable management methods to narrow down the existing gap between the production potential of local and improved cultivars and their farm yield could become a short term approach to increase rabi productivity. It appears that rabi sorghum may continue to enjoy increasing demand for its food and fodder preference. Thus, its area, particularly in Maharashtra and Northern Karnataka, may not decline substantially and possibly stabilize between 4.5 and 5.0 million hectares. The demand at the current growth appears to be around 6-8 million tonnes. This may, however, change in relation to the production and pricing of fine cereals. Rabi sorghum is highly valued as fodder during lean months. All these factors make rabi sorghum production more profitable and economically sustainable despite its very low yield (grown under conserved moisture only). While sorghum is largely used as a feed grain world over, its domestic cost of production and quality limitations made it less competitive to maize. The current feed production in the country under organized sector is 2.7 million tonnes which is projected to go up to 3.9 million tonnes by 2015 AD. Domestic grain based industries also need 2.0 to 3.0 million tonnes grain. Generation of novel alternate uses requires promotional research in these areas, including cultivar development to suit specific end uses and economic competitiveness through high productivity and lower cost of production. The latter two considerations may also brighten up the chances for kharif sorghum to emerge as an export feed grain. Global projection on future coarse grain demand for feed is at 2.4% annual growth rate while its expected production growth rate is only 2.0%. This demand-supply gap and expected low coarse grain reserve trends are favouring a long term increase in the international market price of coarse grains. Sorghum contributes to nearly 10% of the current international trade volume of about 135 million tonnes coarse grains. Sorghum has a growing market in Asia. Its domestic price since last five years is steadily declining than that of maize. There is a growing opportunity for export oriented sorghum production as the international sorghum prices are increasing at 3.88% per annum over past 5 years.

The utilization of kharif sorghum grain as a raw material in various industries is increasing, given the limited prospects of rainy season (kharif) sorghum for human consumption. Post-rainy season sorghum is a highly valued food grain, and expensive to be used as industrial raw material. The main industries currently using sorghum in India are the poultry feed, animal feed and alcohol distilleries. At present poultry feed sector is using approximately 2.0 million tonnes sorghum annually; animal feed sector uses about 0.60 million tonnes sorghum followed by alcohol distillers (about 0.49 million tonnes). But if government policy on allocating food grain to potable alcohol making is implemented, 4 million tonnes of sorghum may be needed for brewing industry alone. The likely scenario by 2050 AD for millets is depicted below.

Pattern of utilization of sorghum and pearl millet grain for various alternate uses

Utilization patterns	Type	Demand (million tonnes)		
		Qty utilized in 2008-09	Projected utilization 2050	
			Scenario II	Scenario III
Sorghum				
Direct use/human consumption	Rabi	4.0	4.83	10.76
	Kharif (partly)	0.1	0.97	2.15
Sub-total (a + b)		4.1	5.79	12.92
Other uses				
1. Poultry feed	Kharif	2.0	4.39	9.78
2. Animal feed	Kharif	0.6	1.79	4.00
3. Alcohol	Kharif	0.49	3.45	7.69
4. Seed +wastage	Kharif+ Rabi	0.15	0.28	0.62
Sub-total (1 + 2 + 3 + 4)		3.20	9.91	22.08
Total production		7.31	15.70	35.00
Pearl millet				
Household consumption	Kharif	3.49 (44%)	5.63 (25%)	9.38 (25%)
Sub-total (a + b)		3.49	5.63	9.38
Other uses		4.36 (55%)	16.65 (74%)	27.74 (75%)
1. Poultry feed	Kharif			
2. Alcohol	Kharif			
3. Others (Animal feed, Seed +wastage)	Kharif	0.08 (1%)	0.23 (1%)	0.38 (1%)
Sub-total (1 + 2 + 3)		4.44	16.88	28.12
Total production		**7.93**	**22.50**	**37.50**

Pearl millet

Pearl millet is a multi-purpose cereal grown for grain, stover and green fodder on about 30 million hectares, primarily in the arid and semi-arid regions of Africa and Asia. Although its productivity in these environments is low, its ability to tolerate drought, heat and low soil fertility makes pearl millet attractive crop species. It responds well to improved moisture and soil fertility conditions. In terms of annual production, pearl millet is the sixth most important cereal crop in the world. India is a major pearl millet producing country with an area of more than 9.0 million hectares and production of about 8.74 million tonnes in 2012, where five states (Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana) account for nearly 95% of the pearl millet cultivated area.

It is quite interesting to compare the improvement in pearl millet productivity achieved during the last 28 years (1985-2013) than that achieved during 1960-85 period. During first 25 years (1960-85) of hybrid development, the crop productivity increased @ 6.3kg/hectare/year. This increase went up to over 20kg/hectare/year in next 25 years. The greater rate of improvement in pearl millet productivity during last 25 years is due to several reasons. Firstly, a far greater number of availability of pearl millet cultivars provided a wide range of choice for their cultivation in various agro-ecological regions. A total of 43 cultivars were released during 1960-85 in comparison to 112 hybrids/varieties released till date. As a result, there have been no major disease epidemics during last 25 years against quite a few prior to 1985. Secondly, involvement of private sector in seed production, distribution and marketing has helped provide quality seed of hybrids to farmers. Thirdly, greater adoption of production technology along with high-yielding hybrids proved synergistic in further augmenting the productivity gains. Pearl millet productivity has gone up from 0.54 tonnes per hectare during 1986-90 to 0.93 tonnes per hectare during 2006-13 registering a growth of 73% improvement, which is highest among all food crops. This extent of improvement in pearl millet productivity has resulted in 40% improvement in its grain production from 7.16 million tons in 1994-95 to 10.05 million tonnes in 2012-13, in spite of 13% decline in crop area from 10.22 million hectares to 9.10 million hectares in the same period. Pearl millet showed more percent increase in production and productivity over the two major cereals rice and wheat in the 10th and 11th Five year plan period in spite of decrease in area. But when we compare the consumption pattern of pearl millet with rice and wheat during the period 1993-94 to 2009-10, it shows a steep decline in both rural and urban areas. Between 1972-73 and 2004-05, the annual per capita consumption of pearl millet at the all India level declined sharply by 67 % (4.1 to 1.4 kg) in urban areas and by 59% (11.4 to 4.7 kg) in rural areas of India . It was also estimated that at the all India level during 1999-2000 about 54% of pearl millet production was used as food and the remaining 46% was used for other uses. By 2004-05, the utilization for other uses increased to 55% while food use declined to 44% (Basavaraj *et al*, 2010). Another revelation from Parthasarathy et al also suggest that the trends in utilization of pearl millet for other uses (alcohol and poultry feed) have increased in the recent years to about 70% of the production in Rajasthan and Haryana.

All India Coordinated Millet Improvement Project (AICMIP) was established in the year 1965 with its headquarters at the Indian Agricultural Research Institute, New Delhi. The headquarters of the project were shifted to Pune in 1977. Later on pearl millet was separated from the rest of the millet crops and the All India Coordinated Pearl Millet Improvement Project (AICPMIP) was established in 1985 with its headquarters at Pune as an independent coordinated project. The ICAR shifted, in July 1995, the headquarters of AICPMIP to Jodhpur in the state of Rajasthan, the state which occupies nearly half of pearl millet area of the country. AICPMIP has a network of fourteen centers in Rajasthan, Maharashtra, Uttar Pradesh, Karnataka, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana, Tamil Nadu and Gujarat. The AICPMIP centers pursue mandated activities in pearl millet improvement, production and protection. The AICPMIP has played a pioneering role in developing a diverse range of improved breeding lines and parental lines of hybrids. These lines have been used extensively to develop and commercialize a large number of hybrids. These hybrids are currently cultivated on approx. 50% of the total pearl millet area of 9-10 million hectares. Hybrids maturing in 80-85 days, when cultivated as an irrigated rains/summer season crop in parts of Rajasthan, Gujarat and Uttar Pradesh, have been reported to give as high as 4000-5000 kg per hectare of grain yield. With adaptive and nutritional features of pearl millet combined with high yield potential make it an important cereal crop that can effectively address the emerging challenges of global warming, water shortages, land degradation and food-related health issues. AICPMIP has also developed production-protection technologies specific to agro-eco regions of different states. The HYVs cover about 50% of total pearl millet area, which is highest among coarse cereal crops. Area under HYVs is highest in Gujarat where almost whole area (>90%) has come under hybrid coverage. Although Rajasthan has the highest area under pearl millet, adoption of HYVs in this state has been very low (25-30%).

Small millets

Research efforts in India have been in progress since the beginning of the 20 the century. But, the launching of coordinated crop improvement programs during late 1950s and 60s has contributed significantly by way of developing new superior varieties and concomitant production and protection technologies in all small millets. The release of these varieties and production packages for general cultivation has helped in 5 fold increase in grain production from 50 to 250 million tonnes in the country. It is generally seen that this increase has largely come from two major crops –rice and wheat- and less from dry land crops such as millets and more so from small millets. The small millets have been the last priority crops in the agriculture developmental agenda in the country. Finger millet among small millets has received a little more attention than the rest especially in the southern states. Before the launching coordinated project in 1950s and 60s; the crop improvement in small millets was confined to a fewer states such as Tamil Nadu, Andhra Pradesh, Karnataka and Uttar Pradesh. The emphasis was on varietal improvement through selection of better types from local cultivars. In Tamil Nadu, Millet Research Station was established in 1923 at Coimbatore under the erstwhile Madras Presidency and the work later extended to Anakapalle (AP) and Hagari (Karnataka). Finger millet work in Karnataka dates back to 1900, initiated at Bangalore especially on finger millet and in Uttar Pradesh at Kanpur and Gorakhpur in 1944. As a pre-requisite to millet improvement, the inheritance of qualitative and quantitative characters, period of anthesis, pollination and crossing methods were studied at Coimbatore. The first finger millet variety released in the country was H 22 as early as 1918 in Karnataka. Interest in finger millet improvement got a fillip in Karnataka during 1950-60 and several new varieties such as Aruna, Udaya, K1, Purna, ROH 2 and Cauvery were released. Similarly, many varieties were released in other small millets also in many states. This included little millet variety Co 1 (1954); foxtail millet varieties Co1, Co2, Co 3 (1943), H1, H2 (1948), T 4 (1949); kodo millet varieties PLR 1(1942, T 2 (1949), Co 1 (1953), proso millet variety Co 1 (1954) and barnyard millet varieties T 46, T25 (1949). During fifties, with food production remaining stagnant and with raising population the importance of millet crops to Indian agriculture started gaining recognition, as they formed the important constituents of dry land agriculture. Project for intensification of research on cotton, oil seeds and millets was launched during this period with several centres working on millets. The first attempt to collect the germplasm of millets in the country was made in 1961 under the PL 480 project on "storage, Maintenance and distribution of millets germplasm resulted in the collection of nearly 3000 genetic stocks of various small millets, 718 in finger millet, 584 in kodo millet, 431 in little millet, 615 in foxtail millet, 250 in proso millet and 399 in barnyard millet.

Small millets have always been of local and regional importance and as a result have attracted little attention both at national and International level. Millets in general, started receiving with attention with the launching of All India Coordinated Millets Improvement Project (AICMIP) in 1969. Small millets improvement received the major boost during 1978-79 with the establishment of five crops specific lead research centres in the country under IDRC assistance. They were Almora in Uttarakhand (barn yard millet), Dholi in Bihar (proso millet), Dindori in Madhya Pradesh (Kodo millet), Semiliguda in Orissa (Little millet) and Nandyal in Andhra Pradesh (foxtail millet.) The IDRC project continued till 1985 and the "All India Coordinated Small Millets Improvement Project" (AICSMIP) was established in the year 1986 with head quarters at The University of Agricultural Sciences, Bangalore. The centres that were functioning under IDRC project became part of AICSMIP. With the inception of separate AICRP, research on small millets has been getting focused attention for developing varieties and other agro production and protection technologies suitable to different regions. Small millets are known for their suitability to dry land areas, hill and tribal agriculture and contribute to food and nutritional security of the disadvantaged regions. The work is multi-disciplinary and applied in nature in AICRP on Millets and IIMR will be taking up basic and strategic research apart from value addition and industrial utilization initiatives. In the past small millets scientists hardly had access to germplasm and worked with a handful of local collections which lacked diversity.

The germplasm conservation activities further gained momentum with NBPGR, New Delhi, playing a key role in augmenting the small millets collection. Recognizing the importance and conservation and easy access to germplasm, AICMIP established a separate germplasm unit at Bangalore in 1979. This is recognized as National Active Germplasm Site (NAGS) by ICAR/NBPGR and has the mandate to assist in collection, conservation, evaluation and documentation of small millets germplasm in the country. Presently the unit at Bangalore is maintaining one of the largest collections of more than 15000 accessions of 6 small millets (7122 in finger millet,2821 foxtail millet,1537 kodo millet, 939 proso millet,1657 little millet and 988 barnyard millet)in the country. It is envisioned that while single crops such as rice and wheat can succeed in producing food security for India, millets will do more. They will contribute immensely to securities of food, nutrition, fodder, fibre, health, livelihood and ecology, especially in changing climate scenario as they are very less water requiring drought tolerant nutri-cereals as potent functional foods.

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Challenges

For centuries, sorghum and millets have been important staples in the semi-arid tropics of Asia and Africa. These crops are still the principal sources of energy, protein, vitamins and minerals for millions of the poorest people in these regions; these “coarse” cereals which in fact are “nutritious” cereals. They perform well in harsh environments where other crops grow or yield poorly. The growers in developing countries are a multitude of smallholder farmers including India. They are grown in traditional agricultural systems with limited water resources and usually without application of any fertilizers or other purchased inputs. Sorghum or great millet (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R. Br.) and finger millet (*Eleusine coracana* (L.) Gaertn.) are the three major millet crops cultivated in larger areas of India. In low external input areas (dryland), the impact of improved cultivars on crop productivity has been limited. Sorghum and millets fall in the latter category. Uncontrolled population growth leading to conversion of agricultural land for other purposes, urbanization and government policies have pushed sorghum and millet cultivation into drier, more marginal lands. However, with demographic and agro-climatic transitions and the brighter prospects for alternate and new end-uses for sorghum and millets using new technology can perhaps help realize the importance of these crops for national economy where livelihood in dryland, nutrition, fodder and resource conservation (mainly water) are factors of immediate importance.

Issues Limiting Sorghum, Pearl Millet and Small Millets Development, Adoption and Utilization

Sorghum is a major food and fodder crop for dryland farmers in India and elsewhere. One of the major reasons for lower yields in this crop is due to the problem of insect pests such as stem borer and shoot fly, and diseases such as grainmold, ergot, and drought. Similarly, in pearl millet, the important losses of yields are mainly due to fungal diseases such as downy mildew, ergot and rust. One pearl millet hybrid, HB3, which was adopted widely in India during 1960s was devastated by downy mildew and had to be withdrawn from cultivation. Blast caused by the fungus *Magnoporthe grisea* is the most important disease of finger millet. In India, the disease appears regularly every year causing annual yield losses as high as 50% in disease endemic areas and in favourable seasons. Classical breeding for blast resistance in small millets has not been rewarding, apparently due to the polygenic control of host resistance, significant environmental influence and the high level of variability present within the pathogen.

Sorghum

Grain quality deterioration of kharif sorghum

Designing of high yielding kharif genotypes with reduced maturity duration enhanced their vulnerability to grain molds leading to serious problem of grain deterioration, decline in grain quality and market acceptance leading to low profitability to the producer despite high productivity. Protection of grain from mould damage through conventional breeding is a formidable challenge due to the multiplicity of fungal species involved, structure of grain, absence of high level of resistance, complex genetic basis of resistance, and association of available resistance with hard grain texture and coloured pericarp. Biotechnological approach using antifungal genes offers hope to achieve faster solution to conquer damage by grainmolds. Deterioration of grain quality due to molds became primary reason for the decreased preference of kharif grain as food. Consequent non-expansion in demand for use as food, failure in creating diversified uses imposed restrictions on production and profitability to the farmers. These reasons led to partial diversion of sorghum area to more profitable alternate crops wherever such diversification and higher profitability is possible.

Vulnerability of HYVs to biotic stress

High yielding cultivars are more vulnerable to major pests such as shootfly, stemborer and earhead bug and major diseases like grainmold and charcoal rot. Leaf spot and rust that are important in forage sorghum. Immunity against these pests and diseases is not feasible. However, there is a need to build fair level of tolerance against most of these pests and diseases by conventional breeding and by biotechnological means through gene pyramiding.

New dimensions in nutritional and quality improvement of grain and forage

Research on grain processing, improving the limiting nutritional constituents, energy value and such other attributes which may impart value-addition to grain as food or feed or industrial raw material may improve sorghum demand.

Denial of farmer-friendly public policies

Farmer friendly public policies on production and procurement available to the producers of fine cereals have been denied to sorghum farmers. This lack of policy and public concern seriously affected its overall production, profitability to the producer and forced the farmers to gradually replace sorghum with economically attractive alternate crops which command higher MSP.

Seed supply system

To fulfil the emerging needs for seeds, identification of appropriate new regions for large scale seed production through seed village concept, and development of self sustainable community seed systems to usher in seed security in village clusters requires earnest initiatives. Development of cost effective molecular tests for seed purity should also be the priority.

Pearl millet

Pearl millet is the major cereal crop grown in the hottest, driest areas of the world where, rainfed agriculture is practiced. It is also very tolerant of acid soil conditions. Additional advantages of pearl millet include its excellent ability to ratoon following green fodder harvest, and the ease with which it can be transplanted compared to sorghum and maize. Finally, pearl millet, especially cultivars with medium or small grain size, stores better than either sorghum or maize. Downy mildew, smut, ergot, are often cited as the most important problems and issues to be addressed, in order of importance. Hence major research thrust need to be on:

- Downy mildew resistance; tolerance to drought and heat; and micronutrients (iron and zinc)
- Emphasis on dual-purpose hybrids, greater attention on hybrid development for the driest A_1 zone
- Development and promotion of green forage hybrids
- Application of biotechnology in breeding for downy mildew resistance; tolerance to drought and heat

Overcoming vulnerability of HYVs to abiotic and biotic stresses

Response of pearl millet to moisture stress at various growth stages has clearly established that yield losses are maximum when moisture stress coincides with grain filling stage, which is commonly referred to as terminal water stress. Various physiological and morphological traits have been examined as alternative selection criteria to further enhance tolerance to terminal drought. Conventional approaches to improve drought tolerance in pearl millet have a very short history and attempts have met' with some success. Various novel approaches have been attempted in pearl millet for enhancing yield under drought environments. These include use of adapted germplasm, genetic diversification of adapted 1andraces through introgression of suitable elite genetic material, and exploitation of heterosis to amalgamate drought tolerance and high yield. Genetic differences in tolerance to salinity and high temperature at both seedling and grain filling stages have been established and screening techniques standardized. The germplasm and breeding material with a higher degree of tolerance to high temperature and salinity have been identified in order to use them in breeding programs. When the rains end early, millet produces very little grain or leaf. Plus, up to a third of the crop is often lost to downy mildew. The genes that help plants withstand the three main threats - heat, drought and mildew - could vastly improve harvests. They are already being used in India by government and international research laboratories.

Improving and enriching quality of pearl millet stover and residues

Indeed it is the need of the hour to produce hybrid parent lines with enhanced stover quality suitable for use in commercial hybrid seed production through conventional and modern breeding techniques to determine the effects of individual stover quality Quantitative Trait Locus (QTLs) to improve on fodder quality of pearl millet stover for higher animal productivity and to promote the use of improved parental lines to public and private seed companies.

Nutritional and quality improvement of grain and forage

Research on grain processing, improving the limiting nutritional constituents, energy value and such other attributes which may impart value-addition to grain as food or feed or industrial raw material may further improve pearl millet demand.

Small millets

The most urgent and the strong context for giving such a priority to millets, is provided by the coming decades of climate Change which confront us with three challenging scenarios. The first is rising global warming; the second, water scarcity that will acquire frightening proportions; and the third, the projected malnutrition that promises to engulf 70% of the Indian population, particularly the poor and the vulnerable sections. Being hardy and robust crops, millets can withstand

and survive harsh climatic conditions. This makes them an ideal solution to the challenge of climate change. It is forecast that with the onset of climate change, wheat which is a thermal-sensitive crop would be hard-pressed to survive. At the same time, rice fields with 2"of standing water and heavy inputs of chemical fertilizers as required under the Green Revolution model of cultivation will release methane, a greenhouse gas into the atmosphere, thus rendering rice an utterly unviable crop. Many recent studies have pointed out that 20% of diabetes suffered by the poor in India is caused by the rice distributed and consumed through PDS. So, if we are serious in confronting this problem, we should look at millets for a solution. They must not be seen just as a diabetic food or health food. They do not merely heal our wounds and illnesses, but have the ability to heal our planet. This is what makes them great food crops. Production of millets and small millets are subject to wide fluctuations and the area is declining. Excepting sorghum, pearl millet, and finger millet, no other millet have showed greater improvement in their cultivable area. The major challanges are: 1.Improvement of yield potential in finger millet (Hybrid technology for higher productivity, Improving biomass production and harvest index), 2. Development of genomic resources (Employing tools of comparative genomics), 3. Gene discovery & allele mining from small millet genetic resource (Water and nutrients use efficiency, Nutritional quality), 4. Improvement of nutritional quality (Grain and Fodder) and bio-fortification (Exploit with in species variability for nutrients, Improve bio-availability), 5. Crop improvement for resistance to biotic and abiotic stresses (Blast disease in finger millet, Shoot fly in little, proso and foxtail millets, and Tolerance to drought, temperature and salinity)

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Operating Environment

The emphasis on millet research has largely been on yield improvement through development of superior hybrids and varieties. Some attention was also paid to insect and disease resistance. With declining uses and areas under millet cultivation, it is necessary to have a relook at goals and objectives of future millet research both through genetic improvement and appropriate management and value addition to make millets as preferred industrial crops. In view of their greater role in bio-diversity, nutrition and health, livelihood enhancement and security the demand base for alternative uses needs attention, especially in relation to renewed millet improvement and development efforts at Indian Institute of Millets Research. The present operating environment needs to relook at various issues as analysed hereunder.

Millets: Biodiversity, Nutrition, Health and Sustainable Livelihoods

The shift to rice and wheat diets of the high input agriculture no doubt provides for more calories but not a balanced diet to the vulnerable groups. Added to this, the per capita availability and consumption of pulses has also come down. Due to marketization and influence of globalization, the consumption of refined/processed energy foods like carbohydrates, fats and fried foods, junk foods, etc., is on the increase. Hidden hunger due to lack of micronutrients, vitamins and other complements and several health and disease problems are attributed to poor nutrition which in turn is associated with a weak immune system and increases susceptibility to deficiency and infective diseases. Damage to the ecosystem through increasing chemicalization of agriculture aggravates the problem. Thus this lack of dietary diversification brings into focus the inter-related problems of biodiversity, nutrition and health in the overall issue of food security.

Demand Generation: Diversified Uses

Recognizing the decline in cultivated area and consumption of millets, attempts have been made to generate demand through multiple uses of millets in the areas of food, feed, forage, energy, industrial and other uses. The use of ragi malt has been in vogue since long. Researchers on sweet sorghum were initiated in late seventies. Now we have all the leads and best of the cultivars that will enable to take the cause of diversification, value addition and development of novel products and also functional foods, including second generation biofuel production to make millets as preferred industrial crops.

Dry and wet milling

Diversified uses for food, feed, industry, etc., require prior processing. Dry milling separates the kernel into its components, bran, germ and endosperm. Data is now available on varietal difference for various fractions. Wet milling involves hydration or steeping and milling carried out in water slurry in several steps to produce various kernel components. The components are used for various purposes like food, feed and industrial uses.

Food uses

Whole meal flour is used in traditional foods like *roti*. There is data on the use of millet flours in various kinds of traditional preparations. Blended/fortified foods such as sorghum-soybean, sorghum gram, etc., have been studied. In the present days of marketing atta, there will be scope for such blended flours. Blends of flours with sorghum/millet with known therapeutic value further fortified with quality protein like soymeal can provide both for urban and rural markets. Weaning foods with malted millet and processed with pulses, sesame etc., have been formulated. Varietal differences for kernel attributes like corneous and sturdy endosperm, kernel hardness, water absorption, swelling properties, gel consistency, dough characters, biochemical attributes like amylase activity, proteolytic activity, have been studied. Depending on the product requirements, special varieties could be bred with product orientation either for domestic or processed foods. It is time to orient breeding programmes towards specific food products.

Animal feed shortages: Feed grain industry/forage/silage

The feed grain requirements are projected to be more severe than food grains. The World Bank has projected a deficit of 2.6 mt of concentrate feed and 251 mt of roughages for all categories of animals.

The poultry feed industry

Commercial poultry feed manufacturers largely produce broiler feed. The layer feed is mixed by poultry producers. While maize is preferred in poultry feeds, sorghum has been the second candidate. The potential for replacement of maize at various levels has been shown in many studies. If maize prices are high, then they turn to sorghum. There is a need to consciously promote sorghum in poultry feeds. If productive yellow endosperm sorghum with high metabolic energy is bred, sorghum will find a more significant place in poultry feeds. Breeder of sorghum and millets should orient their studies towards meeting the needs of poultry feed industry. The high lysine and high betacarotene sorghums and the incorporation of the gene for tryptophan through genetic engineering methods would be important contributions in this direction. It is necessary to establish an interface with poultry feed industry and promote partnership studies and future efforts will be in this direction.

The dairy feed industry

Besides feed grains, green fodder, dry fodder, oil cakes, etc., are important constituting dairy animal nutrition. According to the estimates approximately 10 m t of dairy feed is produced in India by the commercial sector (i.e. about 2 mt by Non-Coop. CLFMA members, 2 mt by the cooperative sector, and 6 mt by the unorganized commercial sector). The feed grain industry has an organized sector, Compound Livestock Feed Manufacturers Association of India (CLMFA) and a cooperative sector. Cooperative feed mills are looked after by NDDB. About 50% of the feed rations are produced in the unorganized sector. Besides grain, green and dry fodders are also important in dairy nutrition. Sorghum can play a more useful role than maize. Dual purpose and sweet sorghum can satisfy the needs of both grain and forage. Hence there is a need to establish an inter-face with dairy nutrition researchers and organized feed manufacturers. The breeding programmes at AICRP- Sorghum stations will also be reoriented towards feed, feed formulations, green forages and roughages.

Sorghum for biomass and bio-energy

Sorghum is recognized as one of the best crops for biomass-energy-feedstock. The initiation of research on sweet sorghums was in this direction. The introduced sweet sorghums were highly susceptible for stem borer. Over a period of time highly adaptable varieties like SSV 84, CSV 19SS, CSV 24 SS and sweet sorghum hybrid CSH 22SS have been developed. The sugars and starches in sweet sorghum could be fermented to ethanol and the liquid cellulose could be gasified to methane. The concept of high energy sorghums is now gaining ground. Some work has also been initiated on 'high energy sorghums'. The sorghum project has now commercialized the production of ethanol through cooperative efforts with some sugar factories. The collaborative efforts will be further strengthened to take ethanol production to commercial heights. Opportunities to produce biomass energy crops round the year would be explored by paying attention to the photo and thermo insensitivity, pest problems, the demarcation of areas of cultivation and related factors. The recent national bio-fuel policy of Govt. of India states that an indicated target of 20% ethanol blending with petrol, viewed largely a measure of environmental sustainability and reduced dependence on fossil fuels will be implemented by 2017. The traditional route of producing ethanol as a by product of sugar industry will not meet this huge demand. Therefore, as demand for production of fuel ethanol, through renewable sources increases to unprecedented levels, feedstock for ethanol production will become more diverse. High biomass low lignin sorghum would be a best option owing to its wider adaptation, high water and input use efficiency apart from multiple uses. Therefore, sorghum being a water use efficient non-invasive crop having wider adaptability, if improved for biomass without significant trade-off on grain will meet the requirement of upcoming commercial lignocellulosic ethanol firms that has not only significant impact on sustaining the environment but also on livelihood opportunities of small farmers in semi-arid tropics.

Potable alcohol/alcoholic beverages

Alcohol is largely produced from molasses, about 65% for industrial use and 35% for human consumption, mostly as Indian made foreign liquor (IMFL). Grain based alcohol is qualitatively superior and the demand is on the increase. The kharif sorghums are ideal for this purpose, even if the grain is damaged due to rains. Of course, now there are methods to prevent damage due to rains and to obtain to clean grain. About 13 companies are licensed to produce grain based alcohol and the capacity is said to be 100 m tones. Varieties with high starch and low protein content and good storability are better suited for this purpose. The sorghum project has established linkages both with research laboratories and manufacturing companies and is working to realize genetic enhancement of kharif sorghum for alchoholic beverages. The potential for kharif sorghum is excellent in this direction and will be capitalized. Sorghums could also be produced in summer with high yields exclusively for potable alcohol. The by-product from alcohol production will be good animal feed. Sorghum has also the potential to be brewed into beer and this has been demonstrated. IIMR will establish links with breweries and explore extensive usage of sorghum in the beer industry.

Starch industry

Maize is the major source for starch industry. Cassava and sorghum could be alternatives. Besides starch, a number of downstream products like modified starches, dextrin, liquid glucose, dextrin monohydrate, sorbitol, calcium gluconate, citric acid, etc., and by-products like steep water, oil, cake, fibre, etc., are produced in the industry. Starch is largely used in the textile, paper and food industries. If starch recovery from sorghum is improved, sorghum could be a potential source. The endosperm attributes for starch and the germ for oil need to be improved by genetic manipulations.

Exports

Despite the fact, we are the second largest producer of sorghum; we do not find recognition in the export market. It looks, we may have comparative advantage to export sorghum to neighboring countries in the middle east (Saudi Arabia, UAE, etc.), Sri Lanka, and Japan and near east. The major producer and exporter of sorghum, USA, produce brown/red sorghums with tannins. We need to educate that our sorghums are one of better quality devoid of tannins which have anti-nutritional factors. We will also study the market requirements of these countries and direct our programme to meet specific export needs, including development of red sorghum and colured sorghum hybrids for different markets. The demand for feed grain is increasing globally and we need to study the potential markets and their quality needs. We might even develop specific areas for cultivation of export oriented feed grains.

Future Improvement of Millets

The various factors leading to the decline of millets in Indian agriculture have been deliberated in detail. Millet based agricultural systems need to withstand biotic and abiotic stresses because of their cultivation mostly in unfavourable soil and climatic conditions. Further they also need to adjust to changing economic (prices and income) and policy induced stresses as has been the case in India where subsidized wheat and rice are supplied through the public distribution system. With this background in view, we will embark on future approaches for millet improvement. Promotion of genetic diversity, cropping system stability and economic advantage or parity will become the major criteria. The genetic approaches should promote genetic diversity and cropping system performance and stability.

Kharif sorghum

The higher order yield of the currently available hybrids and varieties is around 4-5 tonnes/hectares. Average yields hover around one tonne per hectare only. The food use of kharif sorghum is declining. Marginal yield improvements at the experimental level without perceptible changes in grain quality or a major advance in insect resistance etc., do not make much difference. Shootfly resistance is being incorporated in sorghum cultivars of economic worth. Quality standards of both grain and forage to meet international standards are being addressed. Alternate uses of kharif sorghum in food products, feed grain, energy, nutritional and therapeutic foods, starch and other industrial products and exports, are being developed to have specific quality (chemical attributes) to render the processes and products more efficeint. Breeding goals and approaches will be product specific and will be developed at appropriate centres.

Rabi sorghum

In view of the lack of significant progress in improving rabi sorghum yields, more basic and fundamental genetic studies are warranted to understand the genetic processes involved in the improvement of yield and the adaptation processes. Studies on heterosis in diverse crosses, temperature implications, lodging, shootfly and shootbug resistances stability across early normal and delayed sowings in the respective regions need to be achieved. The non-senescence or 'stay green' trait has been exploited. However good progress has been made in evolving soil depth specific cultivars to enhance rabi sorghum yields.

Nutritional quality

In the past, the sorghum project carried out several genetic studies to transfer quality protein/high lysine trait from Ethiopian sorghums with shriveled seeds and also a purdue mutant. From the late, photosensitive Ethiopian sources, early dwarf high lysine types with shriveled seeds and normal plump seed types were developed. The transfer of high lysine to plump seeds was partially successful. The studies need to be continued using modern biotechnology tools. The β-carotene content in several yellow endosperm types was analyzed and the stability of carotene was also studied. The studies were not pursued. In bajra, there are beautiful golden coloured commercial types. The carotene content do not appear to have received attention. With the current interest in golden rice, it is time that the project initiates work on incorporating β-carotene in commercial types which will be valuable in both human and poultry nutrition. The minerals, micronutrient, vitamins, therapeutic attributes are important in millets, more so in *ragi* and small millets. It is time we start paying attention towards nutritional attributes.

Population improvement

For incorporation of multiple traits and traits governed by quantitative genes, population improvement procedures are ideal. Using the Maldandi source of cytoplasm and allowing 4-5 years of inter-mating and crossing with diverse types, selfing was practiced and fertile types were isolated. They were designated FR lines. Some of them were agronomically good. When some of the FR lines were crossed to male steriles, surprisingly they did not restore fertility. We had a feeling whether the restoration was apomictic. Development of improved populations for incorporating multiple, traits is certainly a useful adjunct. In bajra, renewed attention is needed for systematic population improvement programmes.

Need for critical analysis and characterization of millet germplasm collection

Because of their evolution and adaptation to poorer soils and unfavourable agro-climatic conditions/environments, millets have developed unique attributed such as tolerance to drought, heat, adaptation to poorer soils and unfavourable conditions, nutritional and therapeutic values, processes of starch and vitamin bio-synthetics, etc. Some of these attributes have been discussed earlier. The germplasm collections of sorghum and *bajra* have been characterized for their morphological and physical attributes. Millet collections were, perhaps, not described. In the present context, the germplasm collections should be analyzed for such specific, physiological nutritional, therapeutic attributes and identify the genes controlling them and their bio-synthesis and gene markers characterizing such unique traits and processes. Such data bases will be of immense value to the improvement of millet crops by traditional as well as biotechnological methods and marker aided selection.

Public private partnerships (PPP)

Public-private partnerships are described as collaborative efforts between public and private sectors in which each sector contributes to the planning, resources, knowledge and capabilities needed to accomplish mutual objectives. Diversified use of millets for demand generation and improve incomes is market driven. They warrant collaborative research between agricultural research agencies, the concerned industry or even industrial research laboratories. Such collaborations, some of which have been initiated in the recent past, and more organized collaborative project could lead to the development of process efficiencies and marketable products. Some opportunities to be explored are in the areas of:

Dry and wet milling	Milling industry
Feed grains	Poultry feed and dairy feed manufacturing organizations with the private and cooperative sectors like NDDB
Ethanol	Sugar mills and ethanol manufacturing plants
Alcohol/beer	Breweries association
Starch and starch based production	Starch industry
Exports	Export organizations
Straw	Straw board manufacturers

Organizational Changes: Structural and functional

The All India Coordinated Research Projects for various millet crops were set up during mid and late sixties. Each of the coordinated projects was provided with a coordinating centre with a core staff of a project coordinator and 3-4 supporting scientific staff and an administrative unit. Each of the projects had cooperating centres in various states where the crop was important. Each of the centres was provided with scientists in major disciplines like breeding, agronomy, entomology, pathology, etc., depending on requirements. These centres carried out research and conducted coordinated trials. Trials were also organized in additional centres under the state research stations. Over a period of time, the number of centres increased under the respective projects. The sorghum project has been merged with the National Research Centres, which provides the research back up. Biotechnology also emerged as a discipline in some centres. The structure and functions of the projects remain largely the same. Now that Indian Institute of Millets Research will be a common platform for sorghum, pearl millet and small millets to address basic and strategic research and the AICRPs on sorghum, pearl millet and small millets which will be based at coordinated from IIMR Hyderabad will lead the way in millet research and development from 2014. In view of the changes that have taken in millet areas and their geographies, their significant role in biodiversity, nutrition and health, and the current emphasis on alternate uses; we are redefining the goals and objectives under each project. It is felt necessary to shift from the general improvement approaches, to projects with specified goals and inbuilt partnerships. This warrants both structural and functional changes for each of the projects and the respective programmes, centres and envisaged projects. The tools may very – conventional, biotechnological, biochemical or industry oriented.

Direct and indirect environmental benefits

Millets are staple cereal grain and fodder crops grown by subsistence farmers in the hottest, driest regions of e Indian subcontinent where rainfed crop production is possible. Enhancing the reliability of millet grain and straw yields in such environments will contribute directly and sustainably to the alleviation of poverty and improvement of food security of farm households. Sorghum, pearl millet and small millets, are more tolerant of high temperatures than other cereals, are the ideal crops for such conditions. Efficient breeding for drought-prone environments requires selection strategies that are sufficiently independent of the variation inherent in the natural environment to permit identification and use of true genetic differences. Molecular markers linked closely to traits such as Sorghum, Pearl millet and Small millets grain and stover yield during drought will provide increased reliability for selecting and breeding of these traits. Developing new drought- resistant varieties however only reduces risk if resource-poor farmers have reliable access to high-quality seed at low cost.

Coping with the effects of climate change, or risk from natural disasters

Predicted climate change scenarios indicate that water shortages and shorter effective growing season lengths will be increasingly likely thus increasing the need for short-duration crops such as sorghum, pearl millet and small millets with enhanced drought tolerance. Development of millets will not only able to withstand such conditions but also will be able to provide a usable yield increase with resilience for poor people inhabiting drier regions.

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Opportunities

The term millet includes a number of small-grained cereal grasses. Based on the grain size, millets have been classified as major millets which include sorghum and pearl millet and several small grain millets which include finger millet (*ragi*), foxtail millet (*kangni*), kodo millet (kodo), proso millet (*cheena*), barnyard millet (*sawan*) and little millet (*kutki*). The advantages of cultivation of these crops include drought tolerance, crop sturdiness, short to medium duration, low labour requirement, minimal purchased inputs, resistance to pests and diseases. Millets are C4 crops and hence are climate change compliant. There are varieties particularly in little millet and proso millet which mature in 60-70 days; yet providing reasonable and assured harvests even under most adverse conditions. India is a store-house of highly valuable genetic variability. Millets sequestrate carbon and thereby reduce the burden of green house gas. Millets have been called nutri-grains since they are rich in micronutrients like minerals and B-complex vitamins. Additionally millets are also rich in health promoting phytochemicals, and can be used as functional foods. Millet cultivation is the mainstay of rain-fed farming on which 60% of Indian farmers depend. They provide food as well as fodder and can be mix-cultivated (polyculture) with pulses and vegetables. Despite these attributes, millets are losing their pride of place in production and consumption in India, but there has been a greater revival of these crops in recent years.

Sustained Production of Millets

Though India is the largest producer of millets in the world, between 1961 and 2013, there has been drastic reduction in the area under cultivation of millets but due to productivity gains in some varieties, total production of millets showed some increase despite shrinkage of area.

Reasons for Decline in Area

Almost 50% area under millets has been diverted largely to soybean, maize, cotton, sugarcane and sunflower. A combination of factors like low remuneration as compared to other food crops, lack of input subsidies and price incentives, subsidised supply of fine cereals through Public Distribution System (PDS), and change in consumer preference (difficulty in processing, low shelf life of flour and low social status attached to millets), have led to shift from production of millets to other competing crops. There is a vast gap between productivity of millets in field demonstrations vs. farmers' field pointing to the need for robust extension activities, and transfer of state of the art farming practices, as well as access to good quality seeds to the farmers. Increasing marginalised cultivation is also an impediment to productivity. Demand for millets can be increased by: (i) Creating awareness regarding their environmental sustainability, nutritional and other health benefits, (ii) Making them available through PDS, (iii) Value addition, and (iv) Inclusion under feeding programmes like mid-day meal, Integrated Child Development Services (ICDS) feeding, and adolescent girls nutrition scheme (now under consideration of Ministry of Women and Child Welfare)

Estimates on Production Potential versus Demand

Estimated demand for millets by 2025 is 30-35 million tonnes. This has to be met by increasing productivity through choice of better varieties, good agronomic practices, effective extension activities and robust policy initiatives. A study by ICRISAT using CERES-sorghum and CERES-pearl millet crop growth models and historical weather data, rain-fed potential yields and water balance of sorghum (kharif and rabi) in different locations, showed that the total yield gap (simulated rainfed potential yield - farmers' yield) in production zones ranged from 2130 to 2560 kg per hectare for kharif sorghum, 280 to 830 kg per hectare for rabi sorghum and 680 to 1040 kg per hectare for pearl millet. This indicates that productivity of kharif sorghum can be increased by 3.0 to 4.0 times, rabi sorghum by 1.4 to 2.7 times and pearl millet by 1.8 to 2.3 times from their current levels of productivity. Thus assuming an average of 2.5 to 3.0 times potential yield increase as a whole for millets, and current area coverage, the achievable production potential can be three times i.e 45-55 million tonnes. This production potential is achievable by bridging the yield gaps not only through supply side factors such as high yielding crop cultivars, nutrient management and integrated pest management but also addressing demand side issues - value addition by processing, nutritional labelling, alternate industrial utilization and policy measures so as to make millets cultivation more remunerative. Breeding strategies should be redesigned to orient product-specific cultivars. With increased demand and profitability, there will be incentive for farmers to shift to millet cultivation even on better lands. Such a shift will be environmentally and nutritionally beneficial.

Biofortification

Bio-fortification means enrichment/value addition in crop through genetic manipulations. This seed-based approach is farmer-empowering and can go a long way in reducing deficiency of micronutrients, particularly iron, zinc and vitamin A (Beta carotene) in Indian diets. Priority is needed for research in biofortification, preferably using conventional breeding and molecular breeding methodologies. A major thrust is given to bio-fortification research in pearl millet under CGIAR funded research programme by ICRISAT. The aim of bio-fortification in pearl millet is to develop varieties/hybrids with high iron and zinc content.

Seed Production

There should be an adequate support for seed production of hybrids/varieties of both public and private sector through public-private partnership (PPP). This should be initiated through signing of MoU between State Departments of agriculture, seed agencies (NSC/SFCI/SSCs) and private sector seed companies. The State Seed Committees may identify the varieties/hybrids as per State-specific needs. Participation of All India Coordinated Research Projects on pearl millet/ sorghum/small millets may be made mandatory in such committees. To promote cultivation of millets as industrial crops, seed delivery systems, community-based services, post-harvest processing, input supply and marketing, coupled with awareness regarding advantages of millet cultivation need to be strengthened.

Nutritional and Health Value of Millets

Millets in general are rich source of fibre, minerals and B- complex vitamins. Among the millets, pearl millet (*Bajra*) has the highest content of macronutrients, and micronutrients such as iron, zinc, Mg, P, folic acid and riboflavin. Finger millet (*ragi*) is an extraordinary source of calcium. Though low in fat content, it is high in PUFA (polyunsaturated fatty acids). It is also rich in essential amino acids, like lysine, threonine, valine, sulphur containing amino acids and the ratio of leucine to isoleucine is about 2. The chemical score (percentage of the most limiting amino acid compared to a standard protein like egg protein) of finger millet is about 50 which is relatively better than other millets, Sorghum (34) and pearl millet (43). Millets are a treasure-trove of micronutrients like B-complex vitamins and minerals whose deficiencies in India are rampant. They also contain fibre and health promoting phytochemicals which function as antioxidants, immune stimulants etc., and thus have potential to mitigate degenerative diseases such as diabetes, CVD, cancer etc. whose incidence is rising in India. This makes millets important candidates as functional foods.

Bioavailability of Nutrients from Millets

High fibre content and presence of some anti-nutritional factors like phytates and tannins in millets affect bioavailability of minerals. Few studies in humans have suggested that absorption of iron tends to be lower from millets than from rice or even wheat. Thus, the advantage of having higher content of micronutrients may to some extent be nullified by lower bioavailability. More studies using state of art techniques and different methods of cooking are needed to examine the bioavailability of micronutrients including minerals and B-vitamins to assess their nutritional advantage in vivo. Processing can improve the bioavailability of nutrients as well as functionality. Limited studies show that bioavailability as well as functionality differs with the type of processing and preparation. More work is needed to optimise both of these. Effects of physiological status (pregnancy, lactation), age, and nutritional status should also be investigated. Absorption of vitamins and minerals tends to respond to body's demand. Dietary fibre has health benefits like good bowel movement, and reduction in blood cholesterol and sugar. Besides fibre, millets are also rich in health-promoting phytochemicals like polyphenols, lignans, phytosterols, phyto-oestrogens, phytocyanins. These function as antioxidants, immune modulators, detoxifying agents etc. and hence protect against age-related degenerative diseases like cardiovascular diseases (CVD), diabetes, cancer etc.

Effect of Processing on Nutrients

Milling, roasting, soaking, malting, germination and fermentation have been found to reduce phytic acid and tannin contents of millets. The nutrient content of millet grain is relatively poor after milling but the bioavailability of certain nutrients, such as iron improves considerably. Weaning foods prepared by roasting of finger millet have higher iron bioavailability. Popping or puffing of finger millet enhances protein and carbohydrate digestibility. Soaking of millet flour prior to heating can activate phytases and thereby improve zinc availability. Malting, finger millet reduces tannin content (brown millet) and phytate and improves ionisable iron and soluble zinc significantly. Malting of pearl millet and finger millet reduces protein content, but improves protein efficiency ratio (PER), bioavailability and has pronounced effect in lowering anti-nutrients. Feeding isocaloric diets differing only in the type of cereal, i.e. pearl millet, sorghum, wheat and rice to rats showed significantly higher absorption and liver zinc and iron for the pearl millet and wheat-diet fed groups, than rice or sorghum fed groups. The weight gain was also the highest in the pearl millet group compared to sorghum, wheat and rice-fed groups.

Designer Functional Foods

In recent years, the term functional foods have been used for foods that promote health through prevention of specific degenerative diseases. This effect is due to the presence of health-promoting and bioactive phytochemicals in plant foods. Some of the known nutrients-vitamins, minerals, essential fatty acids also have benefits in terms of prevention of degenerative diseases, besides their known functions of preventing nutritional deficiency diseases. The term nutraceuticals (like pharmaceuticals) is used for such bioactive compounds having protective effect against degenerative diseases, in isolated form. It is now recognized that harmful oxygen species like free radicals and peroxides damage cells and initiate the process of diseases. Being non-glutinous, millets are safe for people suffering from gluten allergy and celiac disease. They are non-acid forming, and hence easy to digest. They are also non-allergenic.

Epidemiologically lower incidence of diabetes is reported in millet-consuming populations. The diabetes preventing effect of millets is primarily attributed to high fibre content. Some antioxidant phenols in millets also tend to have anti-diabetic effect. Reports from India are sporadic. Sorghum is rich in phenolic compounds and antioxidants. Among minor millets, fox tail and barnyard millet have low glycaemic index (40-50). Many processed traditional foods have been prepared from minor millets and pearl millets. However systematic studies to validate their glycemic index are needed. Millets being high in fibre, antioxidants and complex carbohydrates are potential candidates for having beneficial effects against diseases. A few *in vitro* and animal studies support this view but well controlled studies in human are needed. In conclusion, millets have potential for protection against age-onset degenerative diseases. This is an area where more work is needed since these diseases are increasing in India. As the largest producer of millets, India can capture world market with appropriate validated functional foods.

Post Harvest Processing Technologies for Sorghum and Millets

Commonly used processing technologies for millets are: milling including decortications or seed coat separation and size gradation into semolina and flour, popping, malting, fermentation and cold extrusion. In recent years, contemporary food processing technologies such as extrusion cooking for Ready to Eat (RTE) foods and breakfast cereals, pasta and vermicelli-noodles and bakery products, malting & brewing, wet milling for starch preparation are employed for these grains. Cost effective dehuller for SAM has not been developed though small prototype models are available. Development of simple technologies for preparation of semolina and flours; composite mini malting unit, Hot-air-based High Temperature Short Time (HTST) unit for sand less popping are some of the areas of future research. Central Institute of Agricultural Engineering (CIAE), Bhopal has developed a millet mill for small millets which can be popularized in millet catchment areas. Milling to separate seed coat or decortication reduces fibre and nutrients but improves consumer acceptability. Bran is a good source of dietary fibre and edible oil. Deoiled bran from millets has the advantage of having lesser silica than rice bran. Products involving heat treatment (popping, flaking, expanded grains (murmura type) par boiling have better shelf life, since heating deactivates lipase. They also have better aroma and texture, and can be converted in to a variety of products which can be used as snacks or made into complementary food for feeding programmes. Grains like barley and finger millet are amenable to malting (sprouting). Malting increases the bioavailability of micronutrients and amylase, and reduces bulk by breaking down starch. Amylaserich foods (ARF) like finger millet malt are used in industry. Incorporation of 5% ARF is mandatory for energy-rich formulations used in states sponsored nutrition programmes. Texture and digestibility are also improved. SAM flours singly are not suitable for bakery products, but they can be mixed with wheat and converted to bakery products. Traditional foods like *roti* cannot be reheated but Mexican Tortillas can be. There is a tremendous scope for promoting SAM-based traditional (papad, murukku etc.) and contemporary foods (extrusion cooking-pasta, vermicelli, RTE foods etc.) as health foods because of their high nutrient and phytochemicals content.Several Home Science Colleges, industries, Directorates under ICAR, and NGOs are attempting to prepare and market traditional and contemporary millet-based foods. R&D work on parboiling of SAM is scanty even though the potential has been established.

Other Commercial Uses of Millets

Sorghum and millets are basically starchy grains and have potential for industrial level production of starches, dextrin and ethanol for food and allied applications. In most of the developed countries, Sorghum and Millets finds extensive usage as feed components for bird, cattle and pigs.

Recent Initiatives – A Value Chain Approach Initiative for Nutritional Security through Intensive Millets Promotion (INSIMP)

To promote cultivation and consumption of millets and millets-based products, the Government of India announced a programme under Rashtriya Krishi Vikas Yojna (RKVY), for INSIMP. The aim is to demonstrate improved production and post-harvest technologies in an integrated manner. Major millets such as sorghum, pearl millet and finger millet are covered. Apart from bringing more land under cultivation of millets, about 300 Post-Harvesting units have been established in the Andhra Pradesh, Gujarat, Madhya Pradesh, Mahrashtra, Tamil Nadu and UP. These units have increased the supply of raw material for value added products of Millets.

Creation of Demand for Millet Foods through Production to Consumption System Value Chain - A Consortium Spproach

The major objectives of this Public Private Partnership (PPP) project, mooted by the Directorate of Sorghum Research (IIMR), Hyderabad include : (i) Market-driven millets cultivation for specific end products, procurement and primary processing for continuous supply-chain management, (ii) Fine-tuning the technologies for development of millet food products and up-scaling, (iii) Nutritional evaluation and safety of selected millet foods, (iv) Consumer acceptability, price and market strategies and social and policy imperatives, and (v) Entrepreneurship and appropriate strategies to promote and popularize millets for commercialization through value-addition, branding as health foods. The consortium partners are National Institute of Nutrition (NIN), Sate agriculture universities (SAU's), private partners such as ITC and linkages with Defence Food Research Laboratory (DFRL), Central Food Technological Research Institute (CFTRI), CIAE, Central Institute of Post-Harvest Engineering and Technology (CIPHET) and Home Science Colleges. The e-choupal infrastructure of ITC was leveraged by IIMR to network hundreds of farmers in Andhra Pradesh and Maharashtra as stakeholders for technology transfer, and improvement of product-specific millets, and primary processing at farm level to value addition. Some entrepreneurship-driven manufacturing units were also set-up. Marketing was facilitated by ITC and nutritional and health studies were done at NIN. A host of sorghum based products were developed and entrepreneurship promoted. This is a promising approach which can generate income and improve access to products made from nutri-cereals.

Employment Generation for Women through Production and Marketing of Millet-based Processed Foods

Some Home Science Colleges have involved Self Help Groups (SHGs) in preparing traditional millet-based products, teaching quality control measures, packaging and labeling and hand-holding for local marketing. A successful case study is from the University of Dharwad, where women of North Karnataka are making *roti* (salted pancakes) from sorghum, and pearl millet, and supplying to hotels "Kharnavalis" retail and wholesale dealers, besides supplying to marriage and other social parties at the cost of Rs. 3-5 per *roti*. On an average each woman can prepare 50-60 *rotis*. A variety of other traditional and contemporary (noodles) millet-based products including small millets have been developed under projects like NAIP and IDRC. SHG women have been trained in their production and help is being given for direct marketing as quality control and market are major challenges. Such a venture can be successful if either a government institution or NGO provides supervision and marketing.

Strategies for Creating Demand

1. The production and consumption of millets must be augmented with appropriate policy initiatives.
2. Consortium-mode research may be pursued for validating the advantages of millets as health and functional foods.
3. Traditional and non-traditional, ready to use, convenience foods and foods that can be used for complementary feeding programmes may be developed with proven nutrient content and bioavailability mapping.
4. Millet-based complementary foods such as *khichdi, upma, roti* etc. in feeding should be introduced in feeding programmes such as MDM, ICDS etc.
5. R&D on millets as fodder and forage for livestock feed security may be strengthened.
6. Commercialize and promote millet-based processed ready to eat snacks and convenience foods through public private partnership.
7. Awareness regarding nutritional, health and environmental advantages may be created thorough known communication strategies.

Strategies for Enhancing Supply

1. Development of varieties/hybrids of Sorghum and Millets with better recovery capacity on reversal of dry spell for harsh environment/ drought prone areas.
2. Exploration of zero tillage for millets under rice fallows particularly for southern States.
3. Development of hybrids/varieties resistant/tolerant to salt/ high temperature. Strengthening breeding programmes through conventional breeding, marker-assisted breeding as well as biotechnology for biofortification and other traits such as varieties with better root architecture.
4. Validation of high productive technology under real farming situations.
5. Effective deployment of trait-specific germplasm available in gene banks for genetic enhancement.
6. Evolving strategies for better seed production with public, private, NGO partnership and establishment of seed villages.
7. Research for better post-harvest management for enhancing the shelflife of millets and prevention of wastage.
8. R&D for integrated toolkit for farm mechanization. CIAE Bhopal has developed a millet mill suitable for small millets. This should be tested in millet catchment area. Retro fitting of machinery used for rice/wheat/maize for millet foods processing.
9. Markets and entrepreneurship development through modern and innovative approaches.
10. Generation of scientific data to substantiate the claim of conservation of biological resources, low water consumption, agro-climatic limitations and high nutritious value of millets and their derivatives.
11. Promote production and consumption of millets through mixed/ relay cropping with legumes and vegetables in homestead gardens.
12. R&D work to generate evidence-based information on the phytochemicals with nutraceutical characteristics and authenticate their health potential including anti-diabetes, anti-inflammatory and hypo-cholesterolemic properties, through clinical trials and nutritional studies. Functional foods for diabetes and obese populations based on Sorghum and Millets will have good market. Measurements of glycemic index should be done using specified WHO-FAO protocol. Such studies must be extended to the best preparations/recipes from millets with functional properties, through proper clinical trials.
13. Studies to examine the bioavailability of micronutrients from different preparations of millets.

14. Breeding to improve the levels of lysine and tryptophan and also screening the germplasms for specific end uses such as milling, popping, malting and vermicelli noodles etc.
15. Setting up of a training-cum-demonstration centre for integrated processing of sorghum and millets.
16. Undertaking surveys of sorghum and millets foods and allied industries, for bringing out a directory and share knowledge base for modernization of the Sorghum and Millets processing industries.

Scientific, technological and behavioural engineering involving convergence of efforts of agriculture scientists, food technologists, home scientists, policy makers, and media is needed to revalorise millets. Some recent initiatives to rejuvenate millets from production to Consumption, include: "Initiative for Nutritional Security through Intensive Millets Promotion" (INSIMP), under the Rashtriya Krishi Vikas Yojna of Government of India, "Revalorising Small Millets in the Rain-fed regions of South Asia (RESMISA) funded by International Development Research Centre (IDRC) and CIDA (Canadian funds), and IIMR-led value chain development approach for commercialisation of millets. Millets are an important component of the National Agriculture Innovation Projects of ICAR, and All India Coordinated Project in Home Science, Other policy initiatives include: price and procurement support for millets, inclusion of millets in the Mid day meal programme and, promotion of Nutrifarms. Demand growth for food, fodder and bio-energy triggered by expanding populations and dynamic patterns of their utilization has put Millets in an appropriate and opportune position. To produce maximum from limited available land, the onus for these target increases heavily rests on technologically driven yield improvements. For this purpose, there is a need to make our genetic improvement programmes more efficient, effective, rapid and precise by making use of cutting-edge technologies of genomics, proteomics and other tools and knowledge of new biology.

Biotechnology, Transgenics, Molecular Markers, and Bioinformatics

Sorghum

Trait–based approach for the genetic improvement of millets would make use of cutting-edge technologies of plant biotechnology and molecular biology to develop genotypes with improved performance under stress during crop growth, and enhanced quality of the produce with extended shelf life of seed, grain and novel sorghum products. Genomics has made rapid advances during the past decade. The sorghum genome has been sequenced and important gene transcripts and regulatory mechanisms are being deciphered on large scale worldwide. Our national programme has already begun implementing precision-breeding using molecular marker-based selection for traits under complex genetic control such as resistance to shootfly, post-flowering drought and grain mold. Efforts are on to identify genes and alleles associated with abiotic stresses and quality using allele mining approach. The system has achieved a very high degree of success in producing genetically transformed plants for an array of genes of interest that add value to existing cultivars. In this background, it is proposed to explore and attempt the new technologies for improving relevant traits. The traits of interest to be addressed by new technologies include improving resistance to complex traits – biotic (shoot fly, grain mould, stem borer, aphids, etc.) and abiotic (drought, salinity), improving quality (grain for food, poultry and industry, fodder, stalk for ethanol production) and novel bio-products. In addition, research aimed at predicting heterosis and incorporation of apomixis would be pursued using new tools to help farmers realize the maximum yield potential at minimum cost.

The genetic diversity in sorghum provides an opportunity to search for new genes and alleles that are responsible for conferring desirable phenotypes. Genome profiling using molecular markers would provide a very large number of markers. Association mapping methods, joint linkage and linkage disequilibrium mapping, genetic finger printing and diversity analyses would pave way for effective utilization of sorghum germplasm for crop improvement. The development of large mutant population as a reverse genetic tool is envisaged to unravel the expression of battery of genes and the mechanisms of their regulation. State-of-the-art technologies would be utilized to select for traits that are otherwise difficult to measure or that require particular conditions for their expression. Further, they provide genetic fingerprints that measure relationships between different lines of sorghum and can be used to protect IPRs. Also, development of gene variant specific markers for major genes controlling adaptive traits would help in accomplishing requisite level of trait expression. It may be expected that genome-wide selection methods that incorporate marker technology into practical breeding processes would be routine in future. Another dimension of accomplishing traits of interest including novel ones in sorghum cultivars is the deployment of transformation technology to transfer the genes of interest or regulate the expression of host genes. The Bt transgenic sorghum already developed in the system not only holds promise as an important source of resistance to stem borer, but exemplifies the possibilities of incorporating new genes into sorghum for innumerable end-uses. A similar approach would be a major option for improving resistance to shootfly, grain mold, aphids, etc. if suitable candidate genes are identified. Research in functional genomics of sorghum would pave way for identifying the sorghum candidate genes for such manipulations.

Pearl millet

In pearl millet, the important losses of yields are mainly due to fungal diseases such as downy mildew, ergot and rust. One pearl millet hybrid, HB3, which was adopted widely in India during 1960s was devastated by downy mildew and had to be withdrawn from cultivation. Blast caused by the fungus *Magnoporthe grisea* is the most important disease of finger millet. In India, the disease appears regularly every year causing annual yield losses as high as 50% in disease endemic areas and in favourable seasons. Classical breeding for blast resistance has not been rewarding, apparently due to the polygenic control of host resistance, significant environmental influence and the high level of variability present within the pathogen. The first molecular marker-based genetic linkage map of pearl millet was built with restriction fragment–length polymorphism (RFLPs), the marker system of choice in the early 1990's. This map has served as the base for subsequent pearl millet marker-based studies. Genetic maps in pearl millet were constructed principally using 4 mapping populations. A total of 597 loci were mapped over the four crosses. The crosses with LDG-1-B-10 × ICMP 85410 and 81B x ICMP 451 were mapped most extensively with RFLP markers while SSR markers were mainly mapped in the latter two crosses and in the 81B x ICMP 451 population. In total, 13 loci were mapped in all four crosses, 37 in three of the crosses, 66 in two crosses and 302 loci were mapped in only one cross. Compared to sorghum, the work on mapping QTLs in pearl millet is less. Only few studies are available linking molecular markers with agronomically important traits. Among the target traits identified for improvement of pearl millet are breeding for durable resistance to downy mildew and enhanced drought tolerance.

Finger millet

Five mapping populations have been developed targeting mapping of drought and blast disease, the most important traits in addition to other agronomically important characters. Comparative genome mappings (CGM) of major crops have shown extensive synteny (conservation of genetic linkages) and co-linearity (conservation of gene order). This facilitates cross-referencing genetic information across groups of diverse species such as major cereals like rice, barley, wheat, maize, and sorghum, and millets. CGM helps in easy isolation of genes based on map-positions in other related species and also provides alternate allelic forms for transgenic breeding. This will be of increasing importance, as we want to decipher the action of QTL and their interactions for practical crop improvement. In this regard, the dense annotated maps and genome sequence in rice will play a crucial role in our research approach to other cereals like sorghum and millets. Considering the syntenic relationships among different cereals, it is desirable to use a set of the same or similar anchor probes in different crops so that opportunities to examine the relevance of selected genome regions in one crop can be readily tested in others. Comparative mapping has shown that two stay green QTLs identified in sorghum corresponded to stay green QTL regions in maize. Four QTL clusters controlling plant height and one QTL controlling flowering in sugarcane corresponded closely to four of the six plant-height QTLs and one of three flowering QTLs of sorghum respectively. A comparative analysis of the foxtail millet genome, pearl millet, and also rice revealed a simple relationship between the chromosomes. The integrated maps can help in range of applications including, identification of candidate genes, gene prediction, fine-mapping, and elucidation of metabolic pathways.

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Goals/Targets

The diverse challenges and constraints as growing population, increasing food, feed and fodder needs, natural resource degradation, climate change, new parasites, slow growth in farm income and new global trade regulations demand a paradigm shift in formulating and implementing the agricultural research programmes. The emerging scenario necessitates the institutions of Indian Institute of Millets Research (IIMR) to have perspective vision which could be translated through proactive, novel and innovative research approach based on cutting edge science. In this endeavour, IIMR has revisited the immediate needs and priorities to prepare Vision-2050 document highlighting the issues and strategies relevant for the next three and half decades. Therefore Millets research program in the country has embarked on developing capacity to evolve strategies for resolving the constraints that hinder increased adoption of improved technologies to usher in food and fodder security in Millet growing regions of the semi-arid tropics in India. The mission, vision, mandate, perspectives and future is outlined to provide an overall perspective to have realistic impact assessment till date to take the lead forward in order to plan our future strategies.

Mission

The envisaged primary mission is "Promoting growth of Millets by developing and disseminating value added technologies to create markets for long-term economic sustainability of millet production systems." The major output of the strategy is coherent with focused research programmes by IIMR (ICAR) which not only targets technologies that respond to economic opportunities but also link producers to markets and make optimal use of existing technologies and technology providers. Through the goals and objectives of All-India coordinated sorghum, pearl millet and small millets improvement programmes under one umbrella of IIMR, it hopes to lead the way in adoption of the new strategy by applying revised criteria in prioritization of programmes and the specific activities under them, by helping the National Agricultural Research Systems to create strong linkages with producers, processors and markets of agricultural produce, and by working with other sister institutes to improve their capacity to carry out agricultural policy analysis and apply this analysis to influencing change in policies that negatively affect Millets production and productivity. IIMR believes that food security objectives can best be met by stimulating growth in market-oriented production systems which should generate additional cash resources for small holders and increase off-farm employment for rural and urban poor and also develop and capitalize on avenues for value addition and exports.

Vision

The envisaged vision is: "Ensuring Climate resilience, Nutritional Security and equitable prosperity through Millets". The focus of our targeted outputs on a given timeline is in tune with the stated vision that could yield the expected gains in terms of enhanced production and stability of millets under low to moderate-rainfall situations, increased resistance to drought and other environmental stresses to address the climate change, diversification of the genetic base including hybrid cytoplasm, grainmold and leaf disease resistance, headbug, midge, stemborer and shootfly, grain quality and acid and saline-soil adaptability in sorghum; and yield improvement, drought tolerance and downey mildew,rust and ergot resistance and value addition in pearl Millet; and Yield enhancement technologies and blast resistance, including exploring possibility of developing hybrids in finger millet and other small millets; including low and high temperature tolerance in millets. While grain production is the main focus, forage and stover uses and quality are also of equal priority. National priorities, networks and international linkages, support and technology exchange will be integrated in the research agenda. For accomplishing envisaged objectives following strategic goals are highly relevant:

1. Enhancing and sustaining Millets productivity and global competitiveness.
2. Improving the end-product quality and cost-effectiveness of Millet production systems.
3. Improving use-efficiency of natural resources and purchased input.
4. Reducing avoidable yield losses to stabilize yield gains without impairing the environmental quality.
5. Making Millets farming highly remunerative under a range of agro-ecologies.
6. Effective transfer and implementation of improved technologies.
7. Promotion of Millets as health-food, and as industrial raw material for potable and industrial alcohol, starch, and their products including those from the stalks.

8. Better utilization of stover by increasing its quality, processing and storage.

The higher sustained yields of millets achieved through improved germplasm, pest and disease management, and effective networking among cooperating centers will enable farmers to increase the volume and stability of production of this feed and foodstuff. This will enable increase in farm income, to improve food, feed, fodder and nutritional needs of the poor. By enabling increased productivity, sorghum will also release more favourable agricultural lands for the production of cash crops, benefiting farmers to aid sustainable national development goals across longer term strategic plans. Three targeted impacts of IIMR and the accompanying AICRPs on sorghum, pearl millet and small millets can be judged from:

1. Increased incomes from highly refined efficient production technology.
2. Decreased risk due to technologies which stabilize production in the climate change scenario
3. Lower prices to poor consumers and industries using sorghum and Millets resulting from significantly reduced unit costs of production.

Hence, it is our innate goal that research products must be understood and valued by those who use them, if they are to have impact. It is difficult to achieve this unless farmers, processors, traders and industry are involved in the identification of relevant research priorities, and in the research process itself. Partners often require assistance to develop necessary skills and capacities to function effectively. Therefore IIMR is committed to this paradigm, as reflected in the following opportunities:

1. Collaborative research endeavours, such as area, product and zone-wise activities and joint research and outreach projects and programmes.
2. Transition from generic research and training efforts to joint research and capacity building partnerships to build everlasting knowledge base, skills and novel product range useful for stake holders.
3. Participatory research initiatives, methods and joint product development.
4. Networks as mechanisms for research collaboration and partnerships.
5. Consideration of gender issues across the research agenda.
6. Modelling effective outreach programmes.
7. Reorientation and implementation of priorities in current programmes in the context of WTO, PVP, IPRs and TRIPS.

Effective research management is a necessary condition for the success of agricultural research systems. This includes identification of priorities, management of human and financial resources in support of the system, knowledge creation, knowledge application and technology generation. It also includes effective coordination of inputs at national, regional, and local levels within our systems. Linkages developed through this process can help promote collaborative research, as well as technology generation and transfer that lead to programs of mutual benefit. Since isolation constrains the potential of IIMR and AICRPs on sorghum, pearl millet and small millets, the twin programmes recognize the need to have more direct linkages with the stake holders to generate more impact from its technologies aiming to reduce poverty for the poorest of the poor. Our envisaged mission is to lessen poverty, sustain food security, and protect the environment through biodiversity conservation and enhancement; natural resources management; and with better socio-economic and policy perspectives, proposals and initiatives. The progresses in our crop improvement efforts till date have range of superior hybrids, varieties and diversified pre-breeding materials to offer. For low input environments we are developing yield enhancement technology, whereas matching novel technologies to achieve high yield potential for high input environments is being developed to address following priorities:

1. The demand for Millets grain as food is decreasing in India and forage/fodder use and grain as poultry feed is increasing. How do we get additional resources to meet this?
2. Our major research achievements so far have been confined to high yielding cultivars. However, the productivity increase is still alluding in Millets. What can we do about it?
3. New tools such as biotechnology, participatory breeding and information technology are increasingly available. How can we use them in combination with traditional methods in sorghum research?
4. The world's food situation is still not relatively secure. If so, how do we create food security in drylands and address the issue of "hidden-hunger" caused by imbalanced nutrition? How can we emphasize breeding for micronutrients, vitamin A and other essential amino acids?
5. How to develop sorghum and millets as multi-purpose all-season cash earners? How should we move forward?
6. The current thrust and future priorities in Millets research should ultimately have favourable impact on the poor by improving their farm income, health and well-being. Similarly, millets research and development should go hand in hand to win our war against hunger and poverty in the in the dry tropics to accelerate the cause of "grey to green" revolution in these areas.

Major Output Indicators

The major output indicators out of our planned research, pilot, and extension based outreach programmes should result in following deliverables:

1. Region- and end-use specific cultivars, technologies and package of practices to increase profitability and stability of production.
2. Management strategies for improving productivity.
3. Improved of food quality and shelf-life of seed, grain and novel food products through conventional and modern applications.
4. Improvement of dual-purpose sorghum and Millets to make available cultivars that enable both enhanced fodder and grain yield to the farmers.
5. Developing sorghum, pearl millet and small millets as efficient biomass and bio-energy crops
6. Total grain quality management of kharif sorghum and value addition to create industrial demand.
7. Application of biotechnology in enhancing resistance to various biotic and abiotic stresses through marker-assisted selections and transgenics; integration of classical and molecular breeding.
8. Crop modelling applications to validate different management strategies for optimal production while assessing the profitability from Millets under climate change scenario.
9. Development of national database on Millets for research, planning and policymaking.

Scope and Duration

New research programmes are dependent on the progress made during the successive plan periods based on centre's inter-disciplinary and network programs and projects, the changing scenario of demands for millets as agricultural commodity and value added products, opportunities and threats posed to sorghum and Millets by changing climate scenario, including domestic and international trade. The availability of new and revolutionary research tools for sorghum and millets research especially those of biotechnology is also factored into, while developing the new research agenda. The inter-disciplinary program areas to be undertaken for research and development at IIMR at its headquarters and its two substations and network partners are meant to compliment established discipline-oriented investigations under AICRPs. The proposed road map encompasses following programs essentially:

1. Genetic resource management and diversification to complement and support basic and strategic research at IIMR and applied research under AICRPs on sorghum, pearl millet and small millets

2. Genetic enhancement for resistance to biotic and abiotic stresses in relation to climate change
3. Strategic research on Millet production, protection, use and marketing including socio-economic aspects and industrial liaison.
4. Biotechnological applications, alternate uses and food, feed and fodder quality and food and biosafety
5. Networking and strategic services including technology exchange, and national and international linkages, and industrial liaison
6. Knowledge management, support to ICAR programs and projects and addressing stakeholder expectations

Genetic enhancement using novel and well-characterized germplasm to increase variation in the cultivars, and generation of production technology packages appropriate to realize increased yield potential in farmer's field will be our major activities. The closely associated AICRPs on sorghum, pearl millet and small millets will carry out most of the applied work across the country. IIMR will conduct basic and strategic research with futuristic perspective and lead national R&D on sorghum and Millets. Our past research efforts have been highly rewarding in enhancing the productivity of sorghum and Millets However, we need to achieve more in forage due to enormously increased area, and because of its cultivation across seasons, and diverse conditions of soil, climate, and water supply. Quality, in addition to diversification of genotypes and end-uses of millets will be emphasized. We will also devise strategies to enhance exports. We hope to overcome these by research and extension on value addition, marketing and liaison with the user industries. This vision document as outlined is thus highly relevant till the year 2050. ❑

Way Forward

There are many opportunities for enhanced production and profitability of sorghum and millets. Despite a declining per capita consumption of sorghum and millets, they still remain cheapest grain accessible to the economically-deprived people especially in rural and remote areas. Resistance to abiotic stresses, diseases and pests, and introduction of processing technology to facilitate easy cooking and consumption and development of novel, functional and designer foods for specific health needs of children, diabetics and malnourished will greatly enhance the food value of Millets. Therefore, we are developing strategies for resolving the constraints which inhibit the increased use of improved technologies in a cost-effective manner. The higher scope for industrial utilization, livestock development through quality forage and enhanced utilization of grain by poultry, and potable alcohol industries, and sweet stalk juice by biofuel industry will aid increased income to sorghum and Millet cultivators, industries and exporters. Therefore, sorghum and millets will then be called as industrial crops rather than poor man's crops.

Another dimension deals with emerging class of Health conscious urban people. ICAR is coming up with a mega Research theme on Health & Value addition which will have dual benefits of increasing farm incomes besides offering consumers a range of health and nutritive products. This has bearing on our research agenda and the focus of IIMR's research priorities are to be re-assessed in this context so as to merge with ICAR goals. Sorghum and Millets fits perfectly within this as they are nutri-cereals with high fibre and rich in minerals and vitamins. While many researchable issues such as processing for better shelf-life and bioavailability of minerals will be addressed, processing should become the means of eliminating inconveniences apart from reviving consumption. With findings that have emanated from NIN's clinical trials supporting the positive results of sorghum and Millets consumption in the reduction of lifestyle diseases such as diabetes, the research on similar aspects will be continued to provide sorghum and Millets their due niche position as a health food. Since IIMR is primarily a crop improvement institute there is a need to re-orient our breeding strategies by strengthening breeding for specific end-products which is a deviation from the past where the improvement of productivity levels were prime concern. Further, identification of genotypes suitable for end product characters and for higher recovery of processed products will also be taken up on priority. Also, shelf life enhancement of not only seed and grain, but also of flour, rava and other products will be on top agenda for value addition and sustainable market prospects. Though the promotion of sorghum through food processing may result in urban niche markets as health conscious urban class is opting for them, the mass consumption will thus get promoted through policy interventions such as INSIMP which again has all India coverage offering end to end solutions for demand creation efforts backed by the research efforts in the form of technology development on both processing machineries and products thereof meeting most of the rural producer's and consumer's needs alike and at much affordable cost. In wake of government's policy to include sorghum and millets in PDS, there is a need to ensure proper shelf life of grain/flour/rava the primary products which again a researchable issue to be addressed with regard to their placement in PDS and also in commercialization regime where the grain should not be lost in supply chain.

Limitations with Storage and Consumption of Millets

The awareness about the high nutritive values of millets is very low both among the producers and consumers. Besides, being small seeded and low priced commodity, the produce is not properly cleaned, graded and dried before they are brought to the markets, fetching low price to the farmers and poses storage problems. Besides, rains at the time of maturity/harvest also lead to poor quality of Kharif produce. The high fat, fibre, inert matters coupled with high moisture content/high humidity leads to infestation of insect/fungus during storage. Grains stored with high moisture content often develop Mycotoxins/Aflatoxin which is highly poisonous both for human and live stock. The shelf life of flour of millets is also low because of high fat content in the grains. The dark seed coat color of some millet such as ragi and bajra also possess problem in acceptance of food products of these commodities. Thus, enhancement of shelf life could be an important challenge to process grain to products and market them sustainability, which would be addressed on priority.

Commercialization

The market for health and wellness foods in India is estimated to be worth $7.5-10 billion by 2015 according to a study undertaken by the Tata Strategic Management group. The demand for fortified foods, whole grain, high fibre, low cholesterol, natural and organic foods will grow. The recent efforts of these public private partnerships under NAIP have led to commercialization of some millet products though scaling up is a challenge; however, they have proved the point of possibility of convenient millet foods on par with rice and wheat so as to offer choices to urban health conscious consumers. Similarly there are efforts from major private player such as Britannia industries Ltd through their nutria-choice segment and ITC's multigrain biscuits the millets appear to play a major role. In recent times Britannia Industries have entered a research MoU with IIMR (IIMR) on sorghum biscuits and bakery products which is again a land mark. Apart from big players there are many small scale players who produce extruded snacks from sorghum, and pearl millet in Mumbai, Rajasthan, Tamil Nadu and Andhra Pradesh. Among the millets, finger millet based malt is more acceptable product both in traditional and non-traditional consuming areas. Some of these products have premium prices and are acceptable as up market products cater to high income groups. Gluten-free sorghum products are commercialized by an entrepreneur based in Kolkata catering to celiac patients. Processed Small millets are commercialized in a big way by entrepreneurs from Nasik, Maharashtra and are being export. Though substantial studies are not attempted on the bioavailability of minerals in millets the general awareness that is being created across the country and world over that millets are nutri-cereals and offer promise to health seeking population who desire to keep lifestyle diseases at bay. IIMR alone has entered more than 12 MoUs with private partners. However, advocacy and policy prescription would take the consumption to greater heights that would generate not only demand for millets but also raise standard of living of the poor dryland farmers growing millets.

Value Chain Approach - A Success Story

Value chain on sorghum and Millets: Under National Agricultural Innovation Project (NAIP) sub-project on "Creation of demand for millet food through Production to Consumption System (PCS) value-chain" with support from the World Bank IIMR led consortium comprising of, National Institute on Nutrition (NIN), ANGRAU and ITC Ltd. at Hyderabad from December, 2007. This was one of major effort in millet promotion where the pilot scale testing is done to create demand for millet foods through interventions at on farm level, processing technologies, nutritional labeling, marketing and entrepreneurship development. Thus end to end solution is provided linking from on farm production to consumers and will enable upscaling through entrepreneurship development.

Interventions through Product Specific On-farm Production

The consortium with the help of ITC, its partner has established supply chain management in its place through it market assured e-choupal platform first time on pilot scale with sorghum farmers. The end product specific cultivation enabled the desired change in mindset of farmers that millets can be commercially grown under value chain approach. ITC provided backward integration by bulking and aggregation functions and linking farmers with rest of the value chain. Thus, the problem of supply of raw material (despite low marketed surpluses) for commercial production was resolved and value addition through these linkages made the success of all the stakeholders, especially our primary stakeholder, the farmer is biggest beneficiary through increased profitability per unit land they began to allocate better lands to sorghum cultivation which by all means an impact of the initiative, which may be replicated. The processing interventions at farm level have generated more awareness on commercialization of millets; it has high potential of generating employment in rural areas especially during the off season, more income from their produce and above all, positive impact in their overall farm practices changing their mindset from subsistence farming to commercialization. It will also provide them option to diversify from traditional typical farming.

Interventions on Nutritional Evaluation

NIN evaluated the effect of sorghum diet on growth of school children, among diabetes and studied that acceptability and growth in school children after consuming sorghum diet for more than 8 months in 'rice eating belt' and compared with controls. The growth of anthropometric indices was significantly better in sorghum group, the biochemical indices were also better for Hemoglobin, Calcium, Iron and Vitamin B12. Studies on GI show that low glycemic index for sorghum products ranged between 60 -70 while the glycemic load (~60-35) which were significantly lower than wheat control samples. These results were further corroborated with establishment of sorghum in reducing diabetes in terms of lowering of Gycosilated hemoglobin levels in subjects fed with sorghum processed products. Through these clinical trials, Glycosilated hemoglobin levels decreased from 7.9 to 7.3 g %; whereas Normal range <7.0 g %), corroborates the beneficial effects of sorghum among those ailing from diabetes. However, these results need to be validated further for large scale recommendations. However, in the pilot testing the findings are used for labeling of the commercialized products in the project. Similar studies and leads in millets will enhance their uptake and trigger initiatives in the direction of novel and nutritional designer foods.

Processing and Marketing Interventions

We Developed and standardized 18 sorghum based processed food through employment of various processing technologies such as flaking, baking, extrusion, milling, popping etc through retrofitting machinery to suit sorghum processing (as there are no available machinery suitable for sorghum). The shelf life is enhanced. Short listed six products i.e sorghum based Multigrain *atta*, *Jowar suji*, flakes, pasta, vermicelli and biscuits which were labelled and packed for marketing to the consumers. Thus consumers were offered with choice of convenient and health foods. NIN data was used to label them. They found to be nutritionally superior to the existing on shelf products that are based on refined wheat and rice. IIMR has launched sorghum products on their brand name "*Eatrite*" on a pilot scale in Hyderabad. Eatrite products are now marketed through "Heritage Fresh" and ITC retail chain stores in Hyderabad. Simultaneously we outsourced the event managers for popularization of sorghum products in urban markets. Massive awareness is created on sorghum as health and nutritious food through "Road shows" (100+) in public parks, malls, and institutes etc in Hyderabad and in exhibitions in creating awareness of sorghum to thousands of consumers through fabricated *Jowar Rath* in Pune, Bangalore, Jabalpur, Chennai, Coimbatore, New Delhi etc. We have also signed Memorandum of Understanding with 12 entrepreneurs It has also signed Research MoU with multi-national M/s Britannia Industries Ltd, Bengaluru for joint research to developed sorghum biscuits and bakery products of international standards. However, challenges loom around its success story such as sustainability, upscaling of the prototype technologies, Replication/Horizontal expansion and spread in the non-traditional consuming areas. Awareness on nutritional superiority is also a challenge. We are contemplating for horizontal expansion of marketing these products through private entrepreneurs either through technology licensing or brand franchisee MoUs. Innovative methods of popularization are being adopted to take the message across.

Entrepreneurship Development

In order to keep up the momentum and the sustainability of commercialization process, Entrepreneurship development of the stakeholders is necessitated through interventions in food processing and product development and nutritional evaluation. Creating sustainable value chain has been one of the greatest challenges for the social scientists and research institutions at large. Therefore the ultimate goal of entrepreneurship development programmes is to disseminate thorough knowledge of post-harvest management which includes linkage of farmers with market, processing, nutritional importance of sorghum, and marketing. The stakeholders were trained who includes progressive farmers, rural entrepreneurs, NGOs, SHGs, small and medium scale processors, women group entrepreneurs on topics such as Nutritional importance of sorghum and millets, Post Harvest Technologies of Sorghum/Millets, and Branding, Packaging and labelling. Similarly, another two projects under NAIP value chain mode were attempted by UAS, Dharwad and Raipur to study on small millets. These project's successful stories may be available as a model for integrated approach for millets promotion across the country. The INSIMP, a Government of India's scheme on millets promotion is an offshoot of policy sensitization of the efforts of IIMR led consortium which is now operating across the country for the third year.

Millets- Long-term Perspective 2050

Possible options for working out estimates for long term planning of sorghum production

Three production scenarios for sorghum and other millets are listed below based on possible options/situations for working out estimates for long term planning. This would help in strategizing the research priorities in the context of changing scenarios as cultivation scenario is highly dynamic due to various issues listed and explained in the preceding chapters.

Scenario No.	Description
Scenario - I	Existing scenario
Scenario - II	Optimistic estimates based on anticipated improvement in yield levels from existing area
Scenario - III	Estimates based on anticipated favourable Policy push

Millets cultivation and production: Projection up to 2050 AD

SORGHUM									
Ecology of production area	**Scenario I**			**Scenario II**			**Scenario III**		
	Area (m ha)	**Yield (Kg/ha)**	**Produ-ction (m t)**	**Area (m ha)**	**Yield (Kg/ ha)**	**Produ-ction (mt)**	**Area (m ha)**	**Yield (Kg/ha)**	**Produ-ction (m t)**
GRAIN SORGHUM									
Kharif									
Assured Rainfall area	1.32	1378	1.82	1.32	3000	3.96	2.00	3000	7.00
Non-assured Rainfall area	1.99	718	1.43	1.99	1500	2.99	3.00	1500	4.50
Kharif-Total	3.31	1048	3.25	3.31	2750	6.95	5.00	2750	11.50
Rabi									
Rainfed Area	3.51	616	2.65	3.51	1500	5.27	5.0	1500	7.50
Irrigated area	0.87	1597	1.39	0.87	4000	3.48	4.0	4000	16.00
Rabi-Total	4.38	1106	4.04	4.38	2750	8.75	9.0	2750	23.50
Grain Sorghum-Total	**7.69**	**1077**	**7.29**	**7.69**	**2750**	**15.70**	**14.0**	**2750**	**35.00**
PEARL MILLET									
Kharif, Rabi and Summer	9.00	1214	10.92	9.00	2500	22.50	15.0	2500	37.50
FINGER MILLET									
Kharif, Rabi and Summer	1.11	1428	1.59	1.11	2500	2.78	4.0	2500	10.00
OTHER MILLETS									
Kharif, Rabi and Summer	0.75	750	0.43	0.75	1500	1.13	2.0	1500	3.00
Total Millets-Grand Total	**18.55**	**1117**	**20.23**	**18.55**	**2400**	**42.11**	**35.0**	**2400**	**85.50**
MULTICUT FODDER SORGHUM									
Ecology of production area	**Area (m ha)**	**Green fodder Yield (tonnes/ ha)**	**Produ-ction (000 m t)**	**Area (m ha)**	**Green fodder Yield (tonnes/ ha)**	**Produ-ction (000 m t)**	**Area (m ha)**	**Green fodder Yield (tonnes/ ha)**	**Produ-ction (000 m t)**
Kharif, Rabi and Summer	18.70	92.0	17.20	18.70	100	18.70	27.0	110	29.70
SWEET STALK SORGHUM									
Ecology of production area	**Area (m ha)**	**Green cane Yield (tonnes/ ha)**	**Produ-ction (000 m t)**	**Area (m ha)**	**Green cane Yield (tonnes/ ha)**	**Produ-ction (000 m t)**	**Area (m ha)**	**Green cane Yield (tonnes/ ha)**	**Produ-ction (000 m t)**
Kharif/Rabi/Summer	-	-	-	-	-	-	1.0	150	6.67

Source: Estimates worked out for Vision document 2050, IIMR, Hyderabad 2014

Scenario–I: is existing situation with current levels of area, production and productivity which forms the bench mark for measuring likely improvement in respective parameters.

Scenario–II: deals with optimistic estimates with two assumptions. Firstly, current sorghum, pearl millet and small millets acreage will be retained. Secondly, there is going to be increase in productivity levels due to higher coverage of HYVs.

Scenario–III: assumes that the area under sorghum, pearl millet and small millets will impact positively due to favourable governmental policy (in the form of support for production, processing and value addition). Government policy is bound to be in favour of support for promotion of sorghum/millets due to increasing population growth rate and unmet demand for food consumption by the rice and wheat. Thus, it is expected that the Government policies are going to be strengthened for millet promotion during different plan periods. Further, it is expected that creation of awareness is being given more importance so as to generate consumption demand owing to nutritional merits of sorghum, pearl millet and small millets. The increasing incidence of lifestyle diseases which are linked with relatively poor nutritive composition of fine cereals especially rice, the promotion of nutri-cereals such as sorghum will be more pronounced owing to their superior composition of nutrients and minerals. It is also expected that millets as health food is being included in PDS which may gain some area under sorghum, pearl millet and small millets.

Overall, at least 88% increase in millet acreage over the current levels is expected to be attained by 2050 AD if policy push and demand creation trend is going to be continued, even otherwise with current acreage if continued with more productivity enhancement through R&D is in place the increase in production will be doubled Accordingly, the estimated production in sorghum with policy push and R&D enhancement will be 35.0 million tonnes, of which rabi production contribution alone will be 68% of total production. Similarly 37.50 million tonnes in pearl millet continue to top, 10.0 tonnes in finger millet, 3.0 million tonnes in other small millets with overall aggregate production of 85.50 million tonnes of sorghum, pearl millet and small millets put together by the end of 2050 AD. Area gains in favour sorghum, pearl millet and small millet may come from other crops which are less remunerative (sorghum, pearl millet and small millet demand is going to higher due to value addition for food and non food uses and due to their importance as functional health foods) and from areas where commercial crops like sugarcane cannot be continued due to lowering of water table making it difficult for them while it still favours sorghum, pearl millet and small millets which with minimal Irrigations will help to double the yields. Even from non-traditional rice-fallow areas as second crop. Another area that has not been taken into account at all is area under multicut fodder sorghum. The present acreage under multicut fodder sorghum is one lakh hectares. The seed yield productivity is 15 quintals per acre. Thus a total of 37, 50,000 quintals of seed is produced, which @ 20 kg per hectare as seed rate will crop 18.7 million hectares area under multicut fodder sorghum. The 6-7 cuts from each hectares yield 92 tonnes of green fodder to the farmer. With the policy push and ever increasing demand for fodder required by domestic and dairy industry suggests that with improvement in yields and commensurate with demand, the fodder sorghum area by 2050 will be 27.0 million hectares. Sweet sorghum if policy push through blending of ethanol with petrol is implemented with remunerative pricing on par with petrol, the area under sweet sorghum will capture 1.0 million hectares by 2050 AD across the country and will supplement the sugarcane molasses based ethanol for blending with petrol. It can be inferred from above that the maximum production gains will be attained through policy interventions as in scenario III for millets to the extent of more than 400% over the current situation. Such gains will enable meeting both food and nutritional security of millions. Thus productivity improvement may be within the realms of reality in the near future. Different genotypes suited to different growing conditions may be essential to bring in all-round increase in productivity. The economic gains that may be augmented by addressing envisaged benchmarks will result in significant improvement in productivity, profitability and even export earnings. All these are expected to translate sorghum and millets farming into a healthy and prosperous proposition, justifying the public support for sorghum and millets research in the country.

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Laser typeset at M/s Print-O-World, 2568, Shadipur, New Delhi 110008 and printed at M/s