Vision 2030

Sorghum

Directorate of Sorghum Research
Rajendranagar, Hyderabad, 500 030, A.P., India
Website: www.sorghum.res.in

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Compiled by:

Vilas A Tonapi, JV Patil, B Dayakar Rao, M Elangovan, B Venkatesh Bhat and KV Raghavendra Rao

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Sh. Harshal S. Gawali - Cover page & photo credits
Sh. K Sanath Kumar - Page layout

Foreword

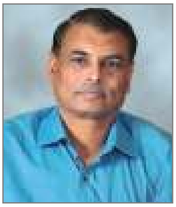
The diverse challenges and constraints such as growing population, increasing food, feed and fodder needs, natural resource degradation, climate change, new parasites, slow growth in farm income and new global trade regulations demand a paradigm shift in formulating and implementing the agricultural research programmes. The emerging scenario necessitates the institutions of ICAR to have perspective vision which could be translated through proactive, novel and innovative research approach based on cutting edge science. In this endeavour, all of the institutions of ICAR, have revised and prepared respective Vision-2030 documents highlighting the issues and strategies relevant for the next twenty years.

The Directorate of Sorghum Research, Hyderabad has been instrumental in developing high yielding varieties and hybrids of Sorghum as well as production and product development technologies. The ultimate challenge today is to provide technologies that will enable transformation of subsistence sorghum farming into a commercial and profitable production system that can compete at global level. This can be realized through realistic reassessment of crop research needs in terms of current and future demand, resolving specific production constraints, development of post-harvest processing and value-addition technologies, marketing strategies and policies that may result in additional income and employment without sacrificing overall goal of attaining sustainable food and nutritional security, especially of the sorghum farmers in dry regions and the urban poor.

It is expected that the analytical approach and forward looking concepts presented in the 'Vision 2030' document will prove useful for the researchers, policymakers, and stakeholdsers to address the future challenges for growth the development of the agricultural sector and ensure food and income security with a human touch.

13th June, 2011
New Delhi

(S Ayyappan)
Secretary, Department of Agricultural
Research & Education (DARE) & Director General,
Indian Council of Agricultural Research
Krishi Bhavan, Dr. Rajendra Prasad Road,
New Delhi 110 114



Preface

In India, research on sorghum as an agricultural commodity is carried out at the Directorate of Sorghum Research (DSR), Hyderabad and at 18 centres of All India Coordinated Sorghum Improvement Project (AICSIP) located in 10 sorghum growing states. While DSR is mandated to conduct basic and strategic research, it also supports and coordinates development of cultivars and management technologies under AICSIP. The overall idea 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" production system. Therefore, we are sharply focusing on resolving commodity-specific production constraints, matching agricultural and processing technologies to market opportunities which provide additional farm income and creating off-farm employment especially in the semi-arid tropical sorghum growing regions in India to usher total food and nutritional security. Sorghum research program in the country has embarked on developing capacity to evolve strategies for resolving the constraints that hinder increased adoption of improved technologies. Therefore, the purpose of this Vision 2030 is to reorient our strategies in the context of changing domestic needs and globalization.

The popularity of nationally released sorghum hybrids (CSH 1 to CSH 25), varieties (CSV 1 to CSV 23), forage hybrids (CSH 20 MF and CSH 24MF) and sweet sorghums (CSV 19SS, CSH 22SS and CSV 24SS) are a standing testimony of success of Indian sorghum program not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in the incorporation of resistance against major pests and diseases. Our major thrust is to create demand for kharif grain for non-food sector, particularly for feed, bio-fuel, starch production and beverage industries, and to provide value-addition to kharif grain and stalk.

We place on record our thanks to Dr. S Ayyappan, Secretary, DARE and DG, ICAR, Dr. Swapan Kumar Datta, DDG (CS), and Dr. RP Dua, ADG (F&FC) for support to the Sorghum programme. This document has been made possible because of the valuable inputs from RAC, IRC and QRT, and my colleagues in DSR and AICSIP. I specially appreciate the efforts of Drs. Vilas A. Tonapi, B Dayakar Rao, M Elangovan, B Venkatesh Bhat and KV Raghavendra Rao in the preparation of this document. The technical and editorial support from HS Gawali, K Sanath Kumar and others are also gratefully acknowledged.

17th June 2011 (JV Patil)
Hyderabad

Preamble

The major challenge facing sorghum research and development in India is to provide technologies that will enable the agricultural sector to affect transformation of "subsistence farming" to a sustainable "market oriented" enterprise successfully competing with rest of the crops. This requires that sorghum research programs, in addition to resolving commodity production constraints, need to focus more on matching agricultural and processing technologies to market opportunities, which provide additional farm income and create off-farm employment in agriculture-related enterprises. Sorghum is largely a key dry- land crop of resource-poor farmers. Therefore, we need to develop capacity to develop strategies for resolving the constraints, which inhibit the increased use of improved technologies in a cost-effective manner to realize higher productivities and profitability to the resource poor farmer across dry-lands in India. As agricultural policies increasingly follow regional and international patterns with 'markets' playing a dominant role, this will require that farmers increase productivity to remain competitive in national, regional and international markets. Likewise, agricultural inputs and technologies will follow a similar regional and international pattern.

Other issues which the Agricultural sector has to reckon with include the increasing population (with a significant proportion living in urban areas); and environmental degradation caused in part by inappropriate agricultural practices. All these can be handled well through networks/projects aiming at developing technologies to solve production and other constraints of farmers. India now produces about the same amount of 7.29 million tonnes of sorghum grain from much reduced area of 7.69 million hectares (TE 2010), what it used to produce from 18.59 million hectares (TE 1970) in 1970's. Sorghum area has come down from 11.52 million hectares to 3.31 million hectares in kharif and from 7.06 million hectares to 4.39 million hectares in rabi. The productivity of kharif sorghum has increased from 530 kg/ha in TE 1970 to 948 kg/ha in TE 2010. This was possible only through productive hybrids and varieties and improved production technologies developed by our program. In the last four decades, productivity has gone up by 74.64% in case of kharif, and 91.08% in rabi sorghums. This has enabled the country to spare 7.66 million hectares land (in many cases fertile land even with supplementary irrigation facility) for the horizontal spread of commercial crops such as oil seeds, pulses, soybean and cotton and even maize during 2010

It is estimated that India may be able to produce about 15.6 million tonnes of sorghum by 2030 AD from the existing area of 7.69 million hectares (TE 2010), with the current cumulative growth rate (CGR) for sorghum productivity, especially in the light of envisaged favorable governmental policies. The popularity of nationally released sorghum hybrids (CSH 1 to CSH 25), varieties (CSV 1 to CSV 23), forage hybrids (CSH 20 MF and CSH 24MF) and sweet sorghums (CSV 19SS, CSH 22SS and CSV 24SS) are a standing testimony of success of Indian sorghum program not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in the incorporation of resistance against major pests and diseases. Our major thrust is to create demand for kharif grain for non-food sector, particularly for feed, bio-fuel, starch production and beverage industries, and to provide value-addition to kharif grain and stalk.

Our past research efforts have been highly rewarding in enhancing the productivity of kharif sorghum. The recent focus on enhancing the productivity of rabi sorghum initiated with the release of few cultivars is expected to give boost to rabi grain production in the years to come. We also intend to achieve higher productivity of forage sorghum, as the area under this has increased significantly. Quality of grain, fodder (green) and stover will also be pursued with more vigour. Diversification of both genotypes and end-uses will be continuously emphasized. Sorghum has to face the stiff competition by other cereals under better soils and rainfall where cash crops have replaced sorghum during kharif. However, the fact that sorghum being a C4 is a high biomass producer and relatively tolerant to several stress factors make it difficult to replace it in least-endowed areas, especially in the climate change scenario. We also hope to overcome the issue of profitability of sorghum production by research and extension on value addition, marketing research and liaison with the user industries. Simultaneously, we will vigorously pursue other avenues such as growing sorghum as a biofuel crop for which we have done significant work, in addition to promotion of sorghum as functional health food.

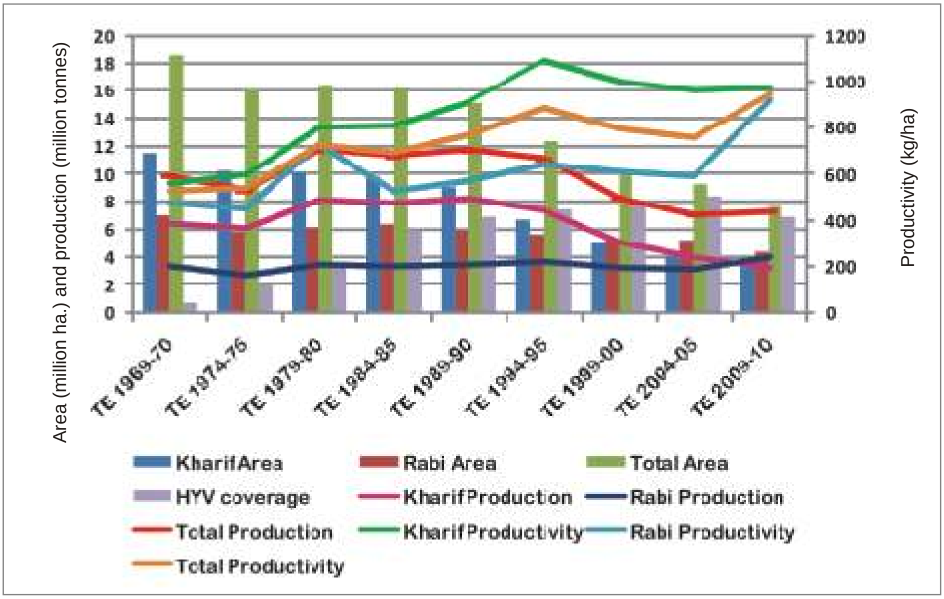
The economic gains that may be augmented by addressing earmarked benchmarks will result in significant improvement in productivity, disease and pest resistance and increased foreign exchange earnings through export promotion and enhanced improvement in the economic levels and rural livelihood of sorghum cultivating resource-poor farmers. All these are expected to translate sorghum farming into a healthy and prosperous proposition, justifying the public support for sorghum research in the country. Therefore, the main purpose of revisiting this perspective plan document on sorghum is to lay the foundation that determines the nature of the strategy, road map and plan of action to undertake basic, strategic, applied and anticipatory research in relation to the decisions driven by market forces and on and off-farm production constraints.

Contents

Sorghum improvement and current scenario

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 production. It is the fifth 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 7.69 million hectares (TE 2010). The decline has serious concern on the cropping systems and the food security of these dry land regions of the country.

All India total sorghum production has registered a constant growth rate of 0.10% per annum during the period 1967-68 to 2010-2011 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.



Change in proportion of kharif & rabi sorghum areas, production, productivity and HYV Spread in India (1970-2010)

The overall increase in productivity of kharif is far more than rabi sorghum. However, both the loss in 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 t ha-1). In the rice fallows, under the zero tillage conditions, grain productivity is as high as 7 to 8 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. Further, same production from lesser land was possible due to HYV technology thus sparing land for commercial alternatives. Of course the decline in consumption demand of sorghum grain was also a major factor for the decline. 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. The major thrust will be on enhancing alternate uses of sorghum and its utilization as a major food, feed, fodder, and fuel (bio-energy) for industrial utilization.

Sorghum Improvement

Organised sorghum research, its national co-ordination and net worked technology evaluation were initiated on a modest scale during the late 1960's. The All India Co-ordinated Sorghum Improvement Project (AICSIP) network with 18 main centres spread over thirteen State Agricultural Universities in ten major sorghum growing states, played the key role on evaluation and identification of superior cultivars and production technologies. Sorghum is one of the earliest crops where in cytoplasmic male sterility system was deployed to fix yield heterosis. First commercial sorghum hybrid, CSH 1, was released in 1964 using the parental lines bred in USA and supplied by the Rockefeller Foundation. Indian sorghum breeding since then steadily gained competence and moved to the vanguard. It generated a completely new genetic variability based on zera zera, feterita and durra germplasm, developed superior parental lines and produced high yielding hybrids possessing nationally preferred grain and agronomic attributes. While sorghum research was being carried out during pre-independence years, concerted research effort on productivity enhancement and a national effort to popularise technologies promoting high productivity was initiated in 1962 with the establishment of Accelerated Sorghum and Millet Improvement Project (ASMIP). ASMIP was the fore-runner of the All India Co-ordinated Sorghum Improvement Project (AICSIP) which was established in 1969. A modest genetic enhancement programme undertaken under AICSIP with a total of fourteen scientists located at IARI, New Delhi and Cotton Breeding Centre, Coimbatore proved to be highly rewarding. In 1970, AICSIP was shifted from New Delhi to IARI Regional Station, Hyderabad. The Off-season nursery programme located at Coimbatore was also simultaneously brought to Hyderabad. During this period only fifteen scientists were engaged in research on sorghum and in the co-ordination work of AICSIP. A substantial improvement in the productivity of kharif sorghum through high yielding hybrids and in the production technologies that enabled the harvest of high yield were achieved during this period. These research contributions stood in good stead for the eventual elevation of the erstwhile IARI Regional Station into the present National Research Centre for Sorghum. NRC for Sorghum was established in 1987 by upgrading IARI Regional Station. The erstwhile National Research Centre for Sorghum was later upgraded to Directorate of Sorghum Research (DSR) in 2009 with a mandate to lead national sorghum research in basic and strategic areas for promoting productivity, utilisation and sustainability of the crop. When established, the DSR had approved scientific cadre strength of 33. With the establishment of its Rabi Centre at Solapur, the scientific strength was enhanced to 40 during VII Plan. The post-NRC and DSR for Sorghum period has witnessed rapid growth in the number of technical and administrative personnel, infrastructure such as laboratory buildings, farm support system, regional research centre, off season nursery facility and research management support systems in the areas being researched. Formal short-term research collaboration with International Crops Research Institute for Semi Arid Tropics (ICRISAT), Hyderabad was established during 1990-91.

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. Since CSH 1, 25 more hybrids were added hither to centrally released (5 more in pipeline). A few more hybrids adapted to specific regions were released at State levels. Hybrids, CSH 1 to CSH 25, are a standing testimony of success of Indian sorghum breeding not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in the incorporation of acceptable levels of resistance against major pests and diseases. The hybrids played a major role in pushing up productivity and production, particularly in the case of kharif sorghum. Among the kharif hybrids, the role played and being played by CSH 1, CSH 5, CSH 6, CSH 9, CSH 14 and CSH 16 needs special mention. While CSH 5 and CSH 6 had a yield potential of 34 q/ha, this potential was raised to 40 q/ha in CSH 9. It is now further advanced to more than 41.0 q/ha in CSH 16, CSH 23 and CSH 25, with distinctly superior quality grain, and fodder (stover).

Breeding could also identify high yielding varieties CSV 1 to CSV 20 and many more varieties were also released in various states. Some of these varieties are dual-purpose type. By and large, varieties encountered less acceptability among farmers. Better preference was received by dual-purpose varieties such as CSV 10, CSV 13, SPV 462 and CSV 15 in some restricted pockets. A major advantage of varieties over hybrids was their relative better grain quality and multiple resistance or tolerance against major pests and diseases. The dual-purpose varieties CSV 15, CSV 20 and CSV 23 could establish higher grain and fodder yield potential than our potential hybrids released earlier.

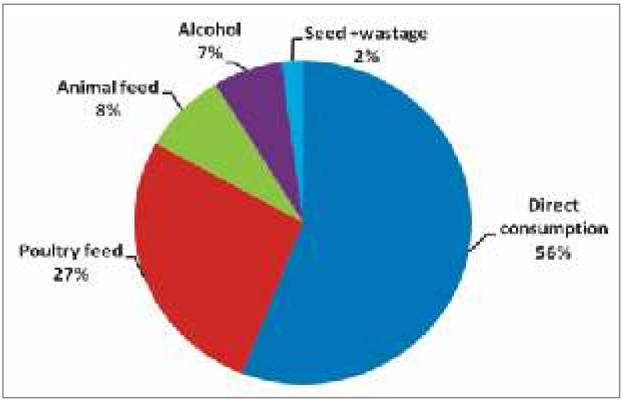
HYV-driven productivity increase, unfortunately encountered certain limitations. The reduced maturity duration of the HYVs led to its high vulnerability to grain mold damage during kharif. Building reasonable resistance against grain mold is found difficult. These biological limitations seriously restricted 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 disadvantage. The administered pricing of oil seeds, pulses and fibre crops also added an advantage to these crops over sorghum under rainfed conditions. With the advent of irrigation in some parts of kharif sorghum area shifted farming to commercial crops. These factors caused limitations, which seriously affected the profitability from the crop and its competitiveness over few other dryland crops.

Improvement of rabi sorghum did not receive as much emphasis and effort as the kharif sorghum until the nineties. Six hybrids and five varieties were hitherto centrally released for rabi. In rabi sorghum, the fodder yield given is even more importance than that in 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 to suit different receding soil moisture regimes and certain levels of thermo-insensitivity are essential in rabi cultivars for better adaptability. Grain quality is also as much important as the grain yield. The quality benchmark is that of the popular land race, 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 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 during rabi (dry season) without irrigation.

Unlike the case of kharif sorghum, biological and environment limitations posed difficult hurdles in rabi sorghum productivity. Limitations in the maneuverability of rabi adapted genetic variability to gain yield heterosis, high vulnerability of non-rabi adapted variability to biotic stresses are causing hurdles in the progress of 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 threshold at the current growth of demand appears around 6-8 million tonnes grain. 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 make rabi sorghum production more profitable and economically sustainable despite its very low yield (grown with stored moisture only).

Sorghum Utilization

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 such alternate uses requires promotional research in these areas, cultivar development suiting to the specific use 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 predicts a 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, in the Indian neighbourhood. Its domestic price since last five years is steadily declining over international as well as domestic prices of maize. There is a growing opportunity for sorghum export oriented sorghum production as the international sorghum prices are growing at 3.88% per annum over past 5 years.



Utilization of kharif sorghum grain as a raw material in various industries

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 too 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 while its usage is quite sporadic in starch industry. At present poultry feed sector is using

Pattern of utilization of kharif and rabi sorghum grain for various uses

Utilization patterns	Type	Demand (million tonnes)	
		Qty utilized in 2008-09	Estimated utilization 2011-12
Direct use/human consumption	a. Rabi b. Kharif (partly)	4.0 0.1	3.5 0.7
Sub-total (a+b)		4.1	4.2
Other uses 1. Poultry feed 2. Animal feed 3. Alcohol 4. Seed +wastage	 Kharif Kharif Kharif Kharif+ Rabi	 2.0 0.6 0.49 0.15	 3.18 1.30 2.50 0.20
Sub-total (1+2+3+4)		3.20	7.20
Total Production		7.31	11.40

approximately 2.0 million tonnes annually; animal feed sector uses about 0.60 million tonnes followed by alcohol distillers (about 0.49 million tonnes). The major user poultry feed sector largely depends on maize which constitute 30-35% of poultry ration. Sorghum is used when maize is in short supply and priced up to 20% higher than sorghum. The estimated utilization in 2010-11 shows that poultry feed industry is going to be the major industry which will absorb huge quantity of sorghum (3.18 million tonnes), followed by dairy feed industry (1.3 million tonnes). This estimate is made with the current trends, but if government policy on allocating food grain to potable alcohol making is pronounced, 4 million tonnes may need for brewing industry alone.

Sorghum 2030

Sorghum 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 sorghum 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 "to promote economic growth by generating and disseminating ready-to-use technologies which create markets, respond to current and future economic demands, and maintain the long-term sustainability of the agricultural resource base." The major output of the strategy is coherent and focused research programmes by DSR (ICAR) which not only target 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 Improvement Programme (AICSIP) under its umbrella , we hope 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 sorghum production and productivity. We believe 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.

Vision

Our vision is to transform subsistence farming of sorghum into a globally competitive one through cost-efficient and environmentally production technology, value-addition and marketing to meet significant food, feed, fodder, fuel (bio-energy) requirements of the country.

Goals

The focus in line with the vision could yield the expected gains in terms of enhanced production and stability of sorghum 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, grain mold and leaf disease resistance, head bug, midge, stem borer and shoot fly, IPM, grain quality and acid and saline-soil adaptability, including low and high temperature tolerance. 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 above objectives following strategic goals are relevant:

1. Enhancing and sustaining sorghum productivity and global competitiveness.
2. Improving the end-product quality and cost-effectiveness of sorghum production systems.
3. Improving use-efficiency of natural resources and purchased input.
4. Reducing avoidable yield losses and further stabilizing yield gains without impairing the environmental quality.
5. Making sorghum farming remunerative under a range of ecologies.
6. Effective transfer of improved technologies.
7. Promotion of sorghum 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 sorghum 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 increases farm income, and improves nutrition needs of the poor. It also releases more favorable agricultural lands for the production of cash crops, benefiting farmers enabling strengthening benefits to aid sustainable national development goals over the longer term strategic plans. Three impacts of DSR and the accompanying AICSIP can be judged from:

1. Increased incomes due to more efficient production technology.
2. Decreased risk due to technologies which stabilize production.
3. Lower prices to poor consumers and industries using sorghum resulting from decreased unit costs of production.

Hence, it is emphasized 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 farmer, 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. DSR/AICSIP is committed to this paradigm, as reflected in the following opportunities:

1. Collaborative research endeavors, such as area, product and zone-wise activities and joint projects.
2. Transition from generic research and training efforts to joint research partnerships to build skills and capacities.
3. Exchanges of scientists among ICAR, AICSIP, NARS, and advanced national and

international research institutes.

4. Participatory research methods development.
5. Networks as mechanisms for research collaboration and partnerships.
6. Consideration of gender issues across the research agenda.
7. Modeling effective outreach programmes.
8. Reorientation and implementation of priorities in current programmes in the context of WTO, PVP, IPRs and TRIPS.

Our envisaged mission is to alleviate poverty, sustain food security, and protect the environment through genetic conservation and enhancement; natural resources management, and putting across socio-economic and policy issues. 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 stabilizing technology, whereas matching technology to achieve high yield potential for high input environments is being developed.

Major output indicators

It is envisaged the planned research and pilot extension activities would result in following outputs:

1. Production of region- and end-use specific cultivars and package of practices to increase profitability and stability of production.
2. Management strategies for improving rabi sorghum productivity.
3. Improvement of roti making quality and shelf-life of grain sorghum through biotechnological applications.
4. Evaluation/improvement of dual-purpose sorghum and make available indigenous cultivars liked by farmers.
5. Developing sorghum as an efficient biomass and bio-energy crop and providing value addition to the rain damaged kharif grain for creating industrial demand.
6. Total grain quality management of kharif sorghum.
7. Application of biotechnology in enhancing resistance through marker-assisted selections and transgenics; integration of classical and molecular breeding.
8. Crop modelling applications to validate different management strategies for optimal production and assessing the profitability of sorghum under climate change scenario.
9. Farmer participatory varietal selection for improving rabi sorghum production.
10. Development of national database on rainfed, irrigated and rabi sorghum for research, planning and policymaking.

Scope and duration

New research programmes are dependent on the progress made during the previous plan based on centre's inter-disciplinary projects, the changing scenario of demands for agricultural commodity, and both opportunities and threats posed to sorghum by changing global scene including domestic and international trade. The availability of new and revolutionary research tools for sorghum 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 the institute at its headquarters and its two substations are meant to compliment established discipline-oriented investigations under AICSIP. The proposed road map encompasses following programs essentially:

1. Genetic resource management, diversification to complement and support applied research of AICSIP and DSR
2. Genetic enhancement for resistance to stress factors in relation to climate change
3. Strategic research on sorghum production, protection, use and marketing including socio-economic aspects and industrial liaison.
4. Biotechnological applications, alternate uses and food, feed and fodder quality and safety
5. Networking and strategic services including, technology exchange, and national and international linkages, and industrial liaison
6. Knowledge management, support to ICAR programs, projects and values

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 AICSIP centres will carryout most of the applied work across the country; DSR will conduct basic and strategic research with futuristic perspective and lead national R&D on sorghum. Our past research efforts have been highly rewarding in enhancing the productivity of kharif sorghum. The recent focus on the productivity of rabi sorghum is expected to give results very soon. However, we need to achieve more in forage sorghum due to enormously increased area, and because of its cultivation in different seasons, and diverse conditions of soil, climate, and water supply. Quality, in addition to diversification of both genotypes and end uses of the produce will be emphasized. We will have to face the stiff competition by other cereals, and the challenges for export. We hope to overcome these by research and extension on value addition, marketing research and liaison with the user industries. This vision document is relevant till the year 2030. The pertinent goals, approaches and performance measures are given in Annexure 1.

Mandate

ICAR has two units for conducting sorghum research in India. One is the Directorate of Sorghum Research located at Hyderabad (DSR) which deals mainly with basic and strategic research issues. The other is an All-India Coordinated Sorghum Improvement Program (AICSIP) with 18 centers spread over 10 states and a small management entity at DSR (coordinating unit) to conduct applied research and pilot extension activities in a network mode.

Mandate of DSR

1. Conduct basic and strategic research for increased productivity and profitability of sorghum farming.
2. Collect, conserve, evaluate and document germplasm and elite breeding stocks and act as national repository of sorghum germplasm.
3. Develop and popularize alternate uses of sorghum, and re-orient sorghum research towards market and export promotion.
4. Organize and monitor coordinated multi-location programmes on sorghum improvement and utilization, and serve as a national centre for training and consultancy.
5. Promote national and international linkages to develop cutting-edge technologies and mutually beneficial interaction with developmental agencies and industries in both public and private sector.

Mandate of AICSIP

1. Develop superior hybrids and varieties combining high yield and acceptable quality of grain and fodder, wider adaptability and resistance to major pests, diseases and abiotic stress factors for each zone
2. Evolve appropriate crop management practices and formulate efficient sorghum-based cropping systems for sustainable sorghum production in each zone
3. Conduct investigations on key or potential pests and diseases of sorghum and identify and evolve elite sources of resistance to develop suitable integrated plant protection strategies for increasing stability of production
4. Promote research and extension to meet local needs within each state through SAUs and other partners

Issues limiting sorghum development, adoption and utilization

Grain deterioration of kharif sorghum: Design of high yielding kharif genotypes with reduced maturity duration enhanced their vulnerability to serious grain deterioration 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 present damage by molds.

Progress in grain productivity sans demands: Deterioration of grain quality by moulding 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 for grain as feed or industrial raw material and value-addition to kharif sorghum and the low MSP imposed restrictions on production and profitability to the farmers. This led to partial diversion of sorghum area to more profitable alternate crops wherever such diversion is possible.

Denial of farmer-friendly public policies: Farmer friendly public policies on production and procurement available to the producers of fine cereals are denied to sorghum farmers. The MSP on kharif sorghum per se failed in its objective due to absence of governmental intervention to ensure this price to the producer. Farmers were also left high and dry whenever they faced economic losses inflicted by aberrant weather (drought-induced crop failure or rain-induced mold damage) and glut from rare over-production. This lack of public concern on sorghum production seriously reduced its per capita consumption, affected its overall production, profitability to the producer and forced farmers to gradually replace sorghum with economically attractive alternate crops which command higher MSP.

Lagging rabi sorghum productivity: We have not fully succeeded in developing high yielding rabi sorghum cultivars which could replace the low yielding landraces. Unlike the kharif sorghum which has wide variability, good heterotic expression and allows manoeuvrability in production management, rabi sorghum has narrow genetic variability, low heterotic expression and environment-imposed harsh limitations under heterogenic production regimes. This disadvantage of rabi sorghum as well as a consideration that a major breakthrough in sorghum production could be achieved through productivity improvement of kharif sorghum which had occupied two-third of sorghum area relegated rabi sorghum improvement to a low priority.

Need for greater thrust in forage sorghum improvement: Progress in developing high yielding quality forage sorghum cultivars is not commensurate with their demand from a rapidly expanding dairy sector. Progress achieved in productivity, forage quality and resistance against leaf diseases in high yielding multi-cut cultivars is not substantial since the release of the first sorghum-sudan grass derivative SSG-59-3 in 1978 which is still being used as a national check in all-India evaluations. Lack of focus, concerted efforts, and involvement of adequate variability in breeding material and interdisciplinary approach and inadequate use of off-season nursery facility for breeding are major reasons for the slow progress. While the area for this use of the crop is steadily increasing, the R & D based impact on productivity and quality is negligible.

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. It is leaf spot and rust that are important in forage sorghum. This vulnerability in the case of kharif cultivars is largely due to utilisation of exotic genetic variability for re-styling plant architecture and increasing productivity. In the case of rabi sorghum cultivars, it is due to introgression with kharif elite breeding material as well as reduced deployment of rabi adapted genetic variability. While complete immunity against these pests and diseases is not available, there is enough scope to build fair level of tolerance against most of these pests and diseases by conventional breeding and high resistance against grainmold and major pests by biotechnological approach and gene pyramiding. Genetic resistance in conjunction with other components of integrated plant protection management could offer lasting low cost solutions.

Need for new dimensions in nutritional and quality improvement of grain and forage: There was no focused and sustained research effort to improve the nutritional quality of grain used as food or feed and of feed quality of forage in protein content, digestible dry matter and palatability. Failure to undertake 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 restricted its demand. Similarly, the feed value potential possible in forage sorghum remains largely untapped due to the emphasis on production of biomass rather than bulk with quality. Complexities associated with improving quality, higher resources, specialised manpower and inter-disciplinary team work required for such research and a possible slow pace in achieving success also favoured a low priority for this research.

Absence of optimised technology choices for less favourable production situations: Limitations in the production technologies of rabi sorghum and kharif sorghum under harsh semi-arid conditions are restraining productivity advances under these production systems. Optimised conservation of the limited soil moisture to maximise productivity with nutrient use efficiency is a challenging task. This research demands innovation, development of cultivars suited to specific production situations, specialised expertise and infrastructure support. An expected slow success from this research encouraged more emphasis on quick result yielding a less complex kharif production system under favourable situations. The increase in the proportion of kharif area under less favourable production situations demands better prioritisation for research on this production system.

A narrow sorghum production strategy: The only goal of sorghum research hitherto is augmenting production to meet the domestic food needs and without a vision on possible export surplus and at the export market available in Asia. The latter goal required a production strategy to produce graded feed grain confirming to the international trade standards and at globally competitive production cost. Not only the national average yield of kharif sorghum is far below the productivity levels in several major sorghum producing countries but the cost of production also is higher than that of several sorghum exporting countries

Inability to exploit available genetic variability: Notwithstanding the lead shown by the national sorghum improvement programme in collecting, classifying and cataloguing national genetic variability, not adequate importance had been given to exploit variability.

Lessons learnt, suggestions and options

Rabi sorghum: Both high grain and fodder yield under receding moisture situation are essential requirement. The resistance to shootfly, charcoal rot, drought and cold are important for adaptation in rabi. Bold, round and lustrous grain and higher flour recovery add to the consumer acceptability. Research on rabi sorghum to enhance productivity requires gene pools, breeding lines and parental lines with different adaptation niches from those of kharif sorghum, higher dependence on rabi adapted genetic variability, specific emphasis on grain quality and fodder yield, evolution of high yielding cultivars with maturity duration suiting to different growing conditions defined by soil depth, water retention capability and nutrient use efficiency and situation specific crop production management techniques which may facilitate yield optimisation under varied nutrient use soil moisture regimes. Possible development of genetically engineered cultivars with resistance to shootfly may offer opportunity to advance rabi planting and avoid problems associated with terminal moisture stress and low temperature. Due to paucity of complete data base on several aspects of rabi sorghum such as its genetic variability, limits to dry matter production and partitioning, yield components and those which are easily manoeuvrable for achieving quick yield improvement, gene pools effecting higher levels of heterotic expression, breeding behaviour for grain quality, biotic and abiotic stresses, control and correction of low temperature induced seed set and production problems, nutrient use efficiency among genotypes and under variable receding soil moisture regimes, etc. It is important that such database is generated to strengthen the rabi sorghum research strategy. The immediate option, however, is improvement of rabi sorghum productivity with the available scientific understanding on breeding and production management. Due to high demand for rabi grain for food use and better profitability to the producer, this research demands high priority, additional manpower in relevant disciplines and expanded infrastructure commensurate with the task and time frame.

Kharif sorghum: Even with an achieved production potential of 4.5 tonnes grain/ha with only moderate inputs, the highest state average yield is only 1406 kg grain/ha in Maharashtra and less elsewhere. Therefore, further genetic enhancement for productivity may have little relevance in the immediate future without high degree of resistance to grainmold. Research on augmentation of economic benefit from the achieved productivity potential by preventing grainmold damage and yield loss from major pests, expansion of demand for the grain for food and alternate uses and increasing profitability from kharif sorghum is to precede further increase in productivity. In the absence of the latter strategy, the decline in kharif area would continue. Incorporation of grain mold resistance as well as resistance to major pests in high yield background could be achieved by combination of conventional or biotechnological breeding. Expansion of demand for grain could be achieved by rendering it mold free, by introduction of processing technology and through promoting its use as feed and industrial raw material for starch and alcohol production. Increase in profitability to the farmer would be possible by a combination of demand expansion, increased productivity at farm level at low unit output cost, value-addition to the crop with sweet stalk and high biomass yield and favourable public policies. Specialised kharif sorghum farming for grain export to international market is another emerging option.

Sorghum for industrial uses: Sorghum, particularly kharif sorghum with high productivity potential, has capability to emerge as a commercial crop of industrial importance. With progress in the overall economic well-being of the nation, empowerment of households below poverty line with adequate purchasing power, growth in dairy and meat production and shift in the food habit to increased intake of animal-derived food, a phenomenal demand for cheap coarse grain is expected to emerge in the country. Sorghum along with maize would be favoured coarse grains. Suitability of grain to produce good quality potable alcohol may persist as long as it continues to be a competitive raw material. The chances are brighter as the policy of blending ethanol with petrol as biofuel, molasses existing a raw material will not be able to cater the total raw material requirement from biofuel production alone as the expansion programme is envisaged in more than 10 states in the country. We can introduce this crop as a supplement to sugarcane for its utilisation as an alternative raw material for ethanol production.

Fodder and forage sorghum: During the last 30 years the role of sorghum as a major source of fodder has not diminished while its importance as a forage crop has increased. While there is a scope for dual purpose cultivars in certain regions of the country in the immediate future, growing dairy industry may require cost-effective and efficient fodder or forage production system for supply round the year. This offers vast scope for developing high yielding, good quality cultivars for forage and similar cultivars for fodder supply. As fodder production is slowly become commercial, the dual purpose cultivars may be found yield limiting and this may shift the option to fodder sorghum cultivars. Apart from biomass yield, sugar content, protein content and digestible dry matter may assume importance in cultivar development.

Harnessing science & cutting-edge technologies

The growth in demand for food, fodder and bio-energy caused by expanding populations and dynamic patterns of their utilization has put sorghum in an opportune position. To produce maximum from limited available land, the onus for these 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 making use of cutting-edge technologies of genomics, proteomics and other tools and knowledge of modern biology.

Biotechnology, transgenics and molecular markers, and bioinformatics

Trait based approach for the genetic improvement of sorghum would make use of cutting-edge technologies of plant biotechnology and molecular biology to develop genotypes with improved performance in terms of combating stress during crop growth and storage, and enhanced quality of the produce. The programmes are planned to integrate several new technologies and weave them seamlessly into sorghum improvement activities to achieve more quick, precise and directed genetic advance. The traits to be addressed are those which are under complex genetic and environmental control, have limited genetic base or variability and useful novel traits. These also include those traits which cannot be solved by other approaches of crop improvement.

Sorghum genomics have 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 relevant improving 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 resource is envisaged to unravel the expression of battery of genes and the mechanisms of their regulation. The advent of affordable next-generation sequencing holds immense possibilities for increasing our understanding of complexity of genetic control of traits of interest, only limited by our imagination. Besides, the unexplored but potential gene pool of the wild relatives would be introgressed for improving agronomic performance of cultivated sorghum. The challenges of adventuring into the exciting task introgressing useful traits from related cultivated species such as sugarcane and maize would be addressed.

Molecular-marker technology would be extensively used to greatly improve the efficiency of sorghum breeding programmes. Molecular markers have started to demonstrate their usefulness into practical plant breeding by facilitating the identification, characterization, and manipulation of the genetic variation for important agronomic traits via quantitative trait loci mapping. The use of marker-assisted selection is contemplated especially in cases where phenotyping presents a challenge. State-of-the-art SSR technologies are already deployed for this purpose and the newer makers (such as SNP, DArT) would be developed which would be the major platform for marker-assisted breeding in future. Primarily, they would be utilized to select for traits that are otherwise difficult to measure or that require particular conditions for their expression. This also helps in finding chromosome regions and/or genes that influence important traits. 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. The progress in improving these traits had been limited by using other approaches. The transgenics would also help in alleviating the effects of abiotic stresses, augmenting the quality of grain, fodder, stalk, etc. using appropriate candidate genes. Research in functional genomics of sorghum would pave way for identifying the sorghum candidate genes for such manipulations.

Important offshoot of the adoption of new technologies which we want to capture is integration and management of biological information generated by the different research platforms. Applying genomic technologies in complex trait dissection would generate vast amounts of data. Versatile bioinformatics resources and databases that capture as well as provide information across research platforms and that are easily usable would be in place. This also necessitates seamless exchange of information with collaborators, public databases, procuring high throughput bioinformatics tools and data storage and analysis facilities.

Ensuring environmental sustainability

Environmental resources are the fundamental inputs of agriculture. The conscious or unconscious abuse of these resources can throw entire societies into poverty. Neither these effects nor the migrations of peoples desperate to escape areas where the resources base has been degrades, are limited by national borders, this target has particular relevance to the drylands where poverty is a driving force behind short-term exploitation of environment to satisfy pressing food needs. Arresting this trend, and even reversing it, is only possible through research and development which considers both the biophysical and socioeconomic dimensions of production systems to make new technologies relevant, practical, and adoptable. These, we are sure, will deliver benefits to the farmer by making sorghum production and utilization a profitable proposition.

Promoting bio- and nutritional security as a means of prosperity

Contemporary food systems are global networks of supply chains. Food contamination is becoming an increasing concern for a variety of reasons. Detection of contaminants requires accurate testing and tracking systems for food as it moves from farm to port, from one nation to another, and from distribution warehouses to retail outlets. This system will require the creation of a new cadre of researchers with special competencies to address potential food contamination around the globe. Additional research priorities include bio-fortified foods, which need to be developed to meet critical nutritional requirements for children to develop strong and healthy immune systems.

Participatory approaches in research

1. Intensified consultation and exchange of ideas among DSR, AICSIP, ICRISAT, NARS (including NGOs and private sector) and farmers.

2. Enhanced cohesion and coordination within research partnerships, leveraging additional joint resources to advance the common agenda.

3. Increased sharing of responsibility for local dissemination of technologies, resulting in more divers, locally attuned applications of global principles and prototypes.

4. Improved knowledge of gender issues and other social constraints and of opportunities through enhanced, holistic information flows from both female and male agriculturalists

Post-production issues and public-private sector involvement

Problems in seed supply are commonly identified as key constraints affecting the rate and level of adoption of new varieties. These reduce the payoff to national crop improvement programs. For the most part, these constraints relate to market conditions and associated seed production and trade policies. Hence, there is a need to identify options for strengthening seed multiplication and trade based on issues of national seed policy, commercial profitability, and the opportunity to exploit alternative seed supply systems such as NGOs and farmer groups. One component of this work seeks to identify opportunities for strengthening informal seed supply systems including direct seed trade between villages and between farmers. In addition, significant gains in productivity can be derived from linking policies favoring the liberalization of fertilizer markets and strengthening of a more competitive fertilizer trading systems with stronger sets of fertility management recommendations. Several of the identified research objectives will lead to commercializable products. An effective linkage will be established for effective partnership. This will cover effective exchange of prebreeding material, parental lines, genetic transformation and marker protocols etc.

Sensitization efforts in the context of WTO, PVP, IPRs and TRIPS

DSR has embarked on major sensitization efforts to have preparedness for new IPR regime in the form of training programmes to scientists, NARS partners and private and public seed sector. Our capacity building initiatives on “Biodiversity and IPR in relation to agrarian and seed sector reforms in India”, are already reflected in perfecting the intricacies of IPR, plant variety protection, licencing and entrepreneurship on public - private partnership platform.

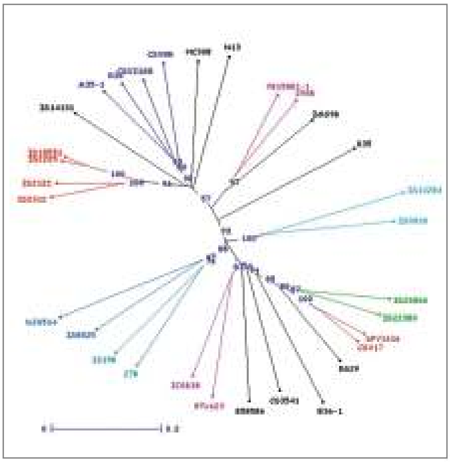
Internal human resource development strategy

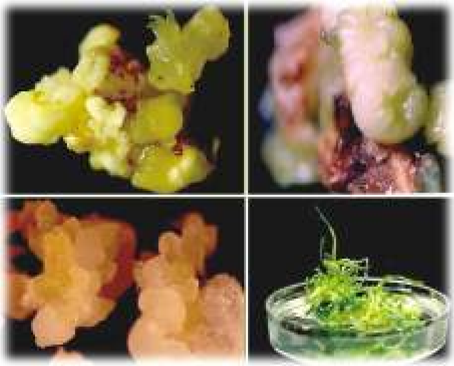
With the strategic re-focusing of the ICAR towards an entrepreneurial approach to research, stronger collaboration with NARS, development of DSR/AICSIP's internal human resources will be a critical success factor for the sorghum programme. To address these challenges, one major initiative that will be the attempting is in “right-shaping” of structures and skills to align with the competency needs of the new research priorities and project framework. Innovative and flexible re-sourcing mechanisms will be introduced to meet the short-and long-term needs for talent. Our focus will be to realize the shift from quantity to quality of staff members and their development, motivation, and retention. This will be based primarily on performance management, and introduction of performance related incentives. Greater emphasis will be placed on management development, to strengthen teamwork, in the sharing of accountabilities and authorities needed to manage the affairs of the Institute through a period of substantial challenge and change. Flexibility will be maintained to address the changing needs of the Institute.

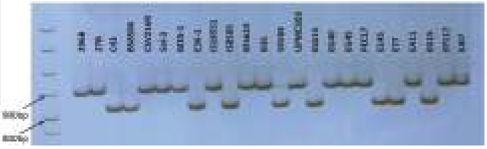
Effective outreach programs

For integrating research and outreach activities we need to have a practical model, which links learning, discovery and outreach, that can be adapted to the conditions of rural situations through promoting the integrated nature of stakeholder involvement in problem identification for research, followed by knowledge dissemination and grassroots adaptation of solutions.

We will also strive to participate more effectively in line with global trends. This alignment of extension systems with private sector interests and participation becomes increasingly important to increase uptake and adoption of technologies. Modern communication technology has enabled many farmers and agri-businesses in the world to have direct access to information and technologies that DSR and coordinated programs create and disseminate. This can be enabled to have access through the Internet and through direct communication with applied researchers and extension personnel. These models have the potential to increase direct technology transfer. The process of accessing information and technologies worldwide is equally applicable to producers and agribusinesses.







Status, strategies and framework for the future

Sorghum (*Jowar* or *Jonna*) is one of the most nutritious cereals, and is an important dryland crop grown in marginal lands with minimum inputs. It is now recognised worldwide as a smart crop capable of providing food, feed, fodder and fuel especially under moderate inputs, especially in water-deficit environments. It is also the base crop on which many inter- and sequence-cropping systems are built upon. Presently, it is grown in many states from Tamil Nadu to Uttarakhand, in the low rainfall areas. It is grown as green forage (multi-cut) crop in north-Indian plains where irrigation is available, and as single-cut forage mainly in drier parts of Western India. The southern India is yet to realize full potential of this crop as forage. The food types are grown during both the rainy (*kharif*; mostly in Madhya Pradesh and many south-western states) and the post-rainy seasons (*rabi*; in Maharashtra and the adjoining areas of Karnataka and Andhra Pradesh).

India now produces about the same amount of 7.29 million tonnes of sorghum grain from much reduced area of 7.69 million hectares (TE 2010), what it used to produce from 18.59 million hectares (TE 1970) in 1970's. Sorghum area has come down from 11.52 million hectares to 3.31 million hectares in kharif and from 7.06 million hectares to 4.39 million hectares in rabi. The productivity of kharif sorghum has increased from 530 kg/ha in TE 1970 to 948 kg/ha in TE 2010. This was possible only through productive hybrids and varieties and improved production technologies developed by our program. In the last four decades, productivity has gone up by 74.64% in case of kharif, and 91.08% in rabi sorghums. This has enabled the country to spare 7.66 million hectares land (in many cases fertile land even with supplementary irrigation facility) for the horizontal spread of commercial crops such as oil seeds, pulses, soybean and cotton and even maize during 2010.

Directorate of Sorghum Research and its associate All-India Coordinated Sorghum Improvement Project (AICSIP), both functioning under the ICAR umbrella are the lead agencies for sorghum research and popularizing of technologies in the country. So far, 25 hybrids and 25 varieties have been released nationally besides 51 state releases. These programmes have developed and tested several technologies for crop production, protection and utilization, all of which are now being adapted to various extent different parts of the country.

The major challenge facing sorghum research and development workers is to provide technologies that will enable the agricultural sector to affect transformation of "subsistence farming" to a sustainable "market-oriented" enterprise successfully competing with rest of the world. 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 cultivators, industries and exporters. Therefore, sorghum can be called as industrial crop rather than poor man's crop. Significant scope for export of hybrid seed for international markets is a new opportunity especially for all the entrepreneurs.

Kharif sorghum

In recent years, kharif sorghum has been in demand for industrial uses mainly as animal and poultry feed, ethanol industry (both grain and stocks) and as food item. Kharif sorghum is grown mainly in the states of Maharashtra (4.70 million hectares), Karnataka (1.59), Madhya Pradesh (0.60), Rajasthan (0.60), Andhra Pradesh (0.48), Tamil Nadu (0.48), Uttar Pradesh (0.27) and Gujarat (0.13). Introduction of hybrids witnessed a major change in Indian sorghum farming specifically in kharif season, which was traditionally formed with landraces. Hybrids, CSH 1 to CSH 25, are a standing testimony of success of Indian sorghum breeding not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in the incorporation of resistance and quality traits against major pests and diseases. Among the kharif hybrids, the role played by CSH 14 and CSH 16 needs special mention, but the recent releases such as CSH 25 and variety CSV 20 are even more promising.

Value-addition through diversified utilization: The value-addition through commercialization of the industrial applications of the sorghum grain as well as sweet sorghum technologies are assuming paramount importance in the wake of declining consumption demand and intensifying search for supplementary/alternate raw material by the various industries. Due to changing scenario of kharif sorghum turning into almost a commercial crop, it has a good potential to be used in various industrial uses. It has already established its ground with regard to use as cattle feed, poultry feed and potable alcohol.

Strategies for improving kharif sorghums: For any crop to become a viable industrial crop it needs to have two important traits. Besides having high yields (so as to be cost effective), the future kharif hybrids should have qualities which suit specific end-uses. Sorghum is being popularized for many food items like semolina, pops, noodles and vermicelli, which require specific grain (starch) qualities. Grain quality attributes are not only important for food industry, but also for feed and ethanol industry. Ethanol recovery depends on starch quality. The starch and protein digestibility depend on the starch-protein and starch-lipid complexes. Also, phytates which hinder availability of minerals and proteins in food and feed are warranted to be decreased. Grain hardness is one of the important criteria which in turn depend on starch quality of grain, for selecting good geneotypes for food and feed industry. For brewing industries, malts from sorghum varieties that have high diastatic power, amylase and starch contents are desirable. Conventional, mutation and molecular breeding approaches will be used to develop new varieties and hybrids for above mentioned specific end uses. Genes for high ethanol recovery/ ethanol efficiency are to be incorporated from germplasm lines to elite high yielding lines.

Rabi sorghum

Status: Rabi sorghum is an important dryland crop grown in the Deccan Plateau on ~5.0 m ha area in the states of Maharashtra (3.28 m ha), Karnataka (1.40) and Andhra Pradesh (0.36) with an annual production of >3.73 m tonnes. Because of their higher quality, large grain size and grain luster, rabi sorghum grains fetch higher market price for the farmers. Six hybrids and five varieties were hitherto released by the national programme. In rabi sorghum, the fodder yield is more important than that during kharif sorghum. High levels of resistance against major pest (shootfly) and disease (charcoal rot), stringent maturity duration are essential in rabi cultivars for better adaptability. Grain quality is also as much important as the grain yield. For food and fodder quality, the benchmark is that of the popular land race, Maldandi (M35-1). Recently released rabi varieties, CSV 14R and CSV 18 were better received by farmers. Rabi hybrids, CSH 15R and CSH 19R are more productive but farmers have not accepted hybrids under dryland conditions.

Strategies for improving rabi sorghums: Drought is one of the major production constraints responsible for destabilizing the rabi productivity. This discourages use of purchased inputs like hybrid seeds and fertilizers. Therefore, research on drought tolerance is now focused on development of early maturing rabi sorghum varieties and identification of QTL for terminal drought tolerant traits. Contrary to kharif hybrids, the heterosis in rabi hybrids is insignificant because the land races (which are low community performers) are used (mainly to maintain the consumer preferred grain size and lustre) in development of both parents, Introduction of higher grain size and lustre in the female parents of kharif hybrids by novel methods and hybridizing such female parents with rabi based R lines would increase the yield levels of rabi hybrids.

Forage sorghum

Status: Introduction of multi-cut sorghum hybrids, single-cut and dual-purpose sorghums which can be grown for quality green forage production in most of the states of India is helping to sustain livestock security. The multi-cut variety, SSG 59-3 (Meethi Sudan) with a potential of four cuts became popular due to its high green foliage, yield potential, regeneration and excellent forage attributes. Recently, the multi-cut hybrids, CSH 20MF and CSH 24MF have been released by All India Coordinated Sorghum Improvement Project (AICSIP). They are more tolerant to leaf diseases besides having higher productivity and dry matter digestibility (DM). The forage varieties, CSV 21F, Pant Chari 5, Pusa Chari 9, and Haryana Chari 6 are the popular single-cut forage sorghums with resistance to lodging and leaf diseases. These varieties also exhibited higher per-day productivity and improved DMD, and total soluble sugars (TSS) with comparable stalk crude protein content. Few other varieties released at the state-level also provided the base for varietal transformation in forage sorghum. Still private sector is dominating and marketing notified hybrids (MFSH 3, Harasona) as they target at relatively rich farmers and dairies in Western India. Nevertheless, there is a ready and growing market for high-yielding multi-cut forage sorghum hybrids to support the growing dairy business.

Strategies for improving forage sorghums: DSR has developed dual-purpose lines with brown mid-rib (bmr lines) which have higher digestibility. It is estimated that one percent increase in digestibility increases milk yield by five percent, leading to higher income to farmers. Further, DSR is aiming at developing both female and male parents with brown midrib (brown mid-rib gene is recessive) so as to develop hybrids with high stover digestibility. The forage and sweet sorghum hybrids are based on female parents of grain sorghum. Selecting grain MS lines with same maturity and slightly shorter in height as that of sudan grass pollinator is essential for good seed production. The high yielding grain MS lines with sweetness in stock and having stay green traits, crossed with sudan grass pollinator will give ideal forage hybrid with high stover digestibility. Utilization of unexploited germplasm especially Sudan grass having succulent stems, low HCN content and good tillering and regeneration habit is essential to diversify the genetic base of the hybrids.

Sorghum for dry fodder (stover): There is enormous demand for dry fodder, particularly during lean winter and summer seasons in the arid and semi-arid regions. Fodder (stover) demand is additionally linked to demand for milk and milk production. Sorghum fodder is the main roughage in the semi-arid regions of Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat and Rajasthan and the Bundelkhand region of Uttar Pradesh. It is estimated that sorghum fodder constitutes 20-45% of the total dry weight of feed of dairy animals during normal seasons and up to 60% during the lean summer and winter seasons. With increase in milk demand, the production demand for dry fodder is expected to rise. There is already an emphasis on the fodder component of the yield in parts of Tamil Nadu, Karnataka, Andhra Pradesh, Rajasthan, Gujarat and Uttar Pradesh. The extent of trade off between grain yield and fodder yield acceptable in a cultivar vary among different regions. This demand situation, however, did not receive adequate attention in the national sorghum improvement programme till recently. Earlier kharif HYVs yielded 80% more grain and 30% lesser fodder than the local cultivars. More favourable environment increases the percentage share of grain over fodder, while the reverse is the case under less-favourable environments. The inability of HYVs to give high fodder yield under less-favourable production systems is one of the reasons for their low adoption in such areas. However the recently released dual purpose types in Kharif (CSV 15, CSV 20 and CSV 23) and the improved rabi cultivars released at national and state levels will aid in meeting the dry stover demand in India to usher in fodder security.

Sweet-stalk sorghum

Status: Demand for renewable energy sources and biofuel which would minimize pollution are expected to rise rapidly in coming years. Sorghum, by virtue of its C4 photosynthetic system and rapid dry matter accumulation is an excellent bioenergy crop. Therefore, sorghum is expected to gain importance in the coming years in bioenergy farming. Ethanol is a clean burning fuel with high octane rating and it can be blended easily with petrol to the extent of 15-20%. Juice from sweet sorghum stalks can be competitive raw material to molasses for producing ethanol. Few factories have started using this (such as TATA's at Nanded in Maharashtra). This can also be profitable crop during summer with irrigation or during monsoon season. Till date the SSV 84 and CSV 19SS are the only national released sweet-stalked varieties. There are a few private hybrids in the market such as Madura and Sugargraze. Realizing the importance of high yielding superior sweet sorghum hybrids, the national programme could release the first sweet stalked sorghum hybrid, CSH 22SS which has attracted much attention internationally. Efforts are on for development of sweet stalked sorghums for various specific end-users such as production of alcohol, ethanol, and syrup. We provide consultancy services on commercialization of sweet sorghum for bio-ethanol production to sugarcane- based distilleries, biofuel industries, farmer groups, policy makers, and entrepreneurs.

Strategies for improving sweet sorghums: At DSR, we are developing cultivars for high stalk yield and sugar content combining tolerance to shoot pests (shootfly, stemborer, etc) and standardizing the crop production practices. Biotechnological tools are being used to develop shootfly and stemborer resistance. Ideal traits for good sweet sorghum genotypes are cane yield, juice extractability, high starch content and sugar content per se in the genotype. Photo-insensitive sweet sorghum genotypes with special leaves arrangement are required to grow them throughout the year. Developing sterile sweet sorghum hybrids on A3 and A4 cytoplasm where no translocation of carbohydrates to panicle take place and carbohydrates are retained in the stocks would be useful.

Production technology

Sorghum-based cropping systems in kharif

Status: Sorghum with redgram as an intercrop is found practicable in 2:1 or 3:3 row proportions. Alternatively the sorghum and fodder cowpea as an intercrop in the ratio of 2:2 is also 40% more profitable. Soybean is also becoming other important intercrop with sorghum. In the intercropping systems the yield of grain and fodder from the sorghum crop is similar to its sole cropping. Therefore, the gains from the intercrop are additional. In the deep black soils having adequate rainfall, sunflower or bengal-gram can be grown after kharif sorghum. Initially, early duration hybrids, CSH 6 and later CSH 14 became popular hybrids for intercropping.

Strategies to promote sorghum based cropping system: There is need for developing better yielding early duration hybrids. The early hybrids will also be useful for sequence cropping especially when two crops are taken in a year. The traits to be incorporated in high yielding background are earliness and suitable leaf geometry (leaf arrangement) so that the other crop takes advantage of solar light.

Sorghum as health food

Status: Recent research is discovering many new potential health benefits from sorghum, such as high anti-oxidant levels, improved cholesterol profiles of the consumer, and as a source of safe food for persons with celiac disease. Sorghum grain has high fibre content, moderate digestibility and rich mineral content compared to other cereals such as rice and wheat. Therefore, sorghum foods are recommended for diabetic and jaundice-affected persons and for fighting obesity. Being free from gluten, sorghum is the ideal food for celiac patients also. Sorghum is becoming popular as a part of multi-grain foods, snacks and sweets. Food recipes for breakfast, lunch, snacks and savouries are available. To create greater demand for millets, especially sorghum for foods, we are working through the National Agriculture Innovation Project (NAIP) involving public-private partnership. We also provide recipe books in several languages and training to entrepreneurs.

Strategies to promote sorghum as health food: High tannin sorghums reduce the risk of certain types of cancer when compared to other cereal grains. By introducing testa genes B1 and B2, levels of tannins can be increased in white coloured grain also. Some tannins however, are also known to bind with protein and make grain indigestible. Sorghum wax (with unique health properties) has sterols like policosanols which regulate cholesterol absorption and endogenous cholesterol synthesis thus helping in cardiac problems. Sorghum wax also has favorable composition of very long chain fatty acids (VLCFA) that have been shown to have benefits for human health. Genetic variability for sterols can be studied and superior lines to be utilized in breeding programme.

Potential niches

Status

Introduction of sorghum in rice-fallows: Introduction of sorghum in rice-fallows, especially in non-conventional areas when water is insufficient for second crop of rice, appears to be potentially promising with planting in late December to early January ensuring high quality grain for feed industry. It is gaining popularity among farmers in coastal Andhra Pradesh especially in Guntur and adjoining Krishna and Prakasham districts. The area of sorghum in rice-fallows has increased from 1000 ha during 2008-09 to 4000 ha in 2009-10 with an average productivity of 5.7 t/ha, which is the highest in the country. The hybrids like CSH 16 and others gave as high as 8 t/ha grain yield. As the water scarcity is becoming a major problem, there is a great scope of sorghum in rice-fallows.

Summer sorghum cultivation: There is an emerging trend for summer cultivation of sorghum apart from traditional kharif and rabi sorghum as an irrigated crop. It is being taken up with much enthusiasm in Nanded and Pune districts of Maharashtra and Bidar district of Karnataka. Usually kharif hybrids are opted because of their higher yields and the quality of the grain is high. Due to dry weather, grains age highly priced owing to its good quality (unlike during wet kharif, no grain deterioration caused by fungal infection). It has tremendous scope for export purposes. Summer sorghum essentially caters the needs of fodder during peak shortages.

Red sorghum for feed and exports: Specialized red kharif sorghum farming for grain export to international market is another emerging option. In order to meet the feed demand in high rainfall regions red grain sorghum may be targeted as potential raw material for poultry which imparts rich yellowness to yolk of egg. The red grain types have good demand in many countries for feed purposes. Red grain sorghums are relatively more tolerant to grainmolds because of the presence of phenols and red pericarp. At DSR we are screening and developing red grain sorghum cultivars with early maturity combining tolerance to grainmolds as well as resistance to major pests in high yield background.

Sorghum in present scenario of climate change and global warming: Climate changes may affect farming patterns with drought in kharif and heavy rains in rabi, therefore demanding the agriculture sector also to reduce its share of greenhouse gas emissions, at the same time safeguarding the soil through better farm management practices. Sorghum cultivation has better advantage as compared to rice cultivation in the present day scenario of climate change. Sorghum is C4 plant and utilizes CO2 efficiently, it does not produce as much greenhouse gases as rice does and also it utilizes fewer inputs (water + fertilizers).

Strategies to breed for potential niches: Till now the available sorghum cultivars have been tried for different niches. The sorghum growers in rice fallows are not interested in fodder as they feel that their cattle prefer rice straw. There is tremendous scope to make feed blocks and sell them to peri-urban dairies. The grain of sorghum is sold to Pune market, where the grain is mixed with rabi sorghum. The phenotype of cultivars suitable for this niche area is high grain yielding, medium in height and with bold luster grain. Summer sorghums need to be photo-insensitive, early and bold grain and should require less irrigation. In mold-prone kharif areas, red sorghums can be encouraged for feed as they have grain mold tolerance, less phytates in their bold grains, with high fat content so that they can compete with maize in poultry industry.

The climate change vis-a-vis sorghum productivity: The climate change may cause unpredictable drought and heat stress. So, it is necessary to have drought resistance (at various stages of growth) for kharif genotypes. Understanding the resistance mechanisms at various growth stages and utilizing it in breeding will be beneficial. Sorghum has capability to withstand drought at vegetative stage and it revives after it rains. Genotypes which efficiently utilize CO2 and withstand high temperatures will be useful in climate change scenario. Developing highly digestible sorghum stover and grain will help in reducing green house gas production from animals. Hybrids having good root system (roots to get established in unprepared soils) and performing superiorly in zero tillage will be the requirement in future.

Research in new frontiers

Status

Molecular breeding: The use of DNA markers in plant breeding has been called 'molecular breeding'. DNA markers that are tightly linked to agronomically important genes are used as molecular tools for marker-assisted selection (MAS). MAS involves use of a marker as a substitute for, or to assist in phenotypic selection, in a more efficient, reliable and cost-effective way as compared to conventional plant breeding methodology based mainly on eye-balling. At DSR, we are employing DNA markers for developing linkage map of sorghum, and for detecting QTL for a number of traits such as resistance to shootfly, grain mold, drought, and quality traits related to grain and fodder uses. Additionally, new mapping populations for foliar diseases, stem borer, stover quality, sugar content, and ergot are also being developed, and soon use of DNA markers to pyramid desirable complex traits will be routine in our breeding.

Transgenics research: At DSR we are developing and testing a number of transgenics and the one with Cry1B gene against stem borer has undergone field testing. Others for salinity and drought resistance, low HCN, and food quality trait are under development.

Strategies to speed-up molecular assisted breeding

Our strategy for use of molecular tools involves as many collaborators as possible so that we make quick gain with minimal investment. Outsourcing some works, such as marker analysis is routine so that scientists can spend more time on generation of materials, data analysis and product promotion.

Public research in the IPR regime: The public sector research in the changing IP regime needs to have institutional arrangement for protection of intellectual property through patents, copy rights, trademarks and plant variety protection. There is a need to systematically document entire process of varietal improvement encompassing pedigree database, material transfer agreements, stakeholders and their level of participation to impart due credit, and benefit sharing. It is necessary to assign value to the advanced genetic stocks, trait specific lines, hybrids / varieties, transgenics and other processes and technologies for their licensing and commercialization to channelize the licence fee and royalties back into research and developmental initiatives, including benefit sharing among the researchers and organizations.

Therefore, If, sorghum is to be promoted as an industrial crop (not just that of subsistence farmer and poor consumers), we require to develop cultivars suitable for specific end-uses. One of the important requirements is to gain high productivity so that the raw material for industry is cost-effective. Besides having high yield and resistance to biotic and abiotic resistance, cultivars need to have good grain and stover quality. Breeding by using conventional and molecular approaches for specific end uses is the need of the day. Strengthening seed delivery systems, community-based services including post-harvest, input-supply and marketing support and creation of awareness among people on health and other benefits of millet crops are also expected to promote cultivation of sorghum

Increasing export possibility: Despite having the largest area under sorghum, India could not emerge as a sorghum exporter. Three major reasons responsible for this are its domestic demand as a food grain, low national productivity, a non-competitive cost of production and government policy. Even after an expected further decline in kharif sorghum area, India would continue to be the country with largest area under sorghum. Rabi grain productivity and its domestic price may not allow a competitive edge for its export. The research towards the grain quality upgradations, lowering production costs and providing better storage and transportation could definitely find a place for Indian sorghum in International markets which would enhance its export competitiveness in the global sorghum market.

Dynamics of R&D strategies vis-à-vis governmental interventions

Initiative on Nutritional Security through Millets promotion programme" (INSIMP): DSR's efforts on sensitization of policy makers, planners through NAIP " Millets value chain project" resulted in a National brainstorming session on Promotion of millets which was jointly organized by DSR, NIRD and DMD in November, 2010, held at Hyderabad. The recommendations emanated from it and subsequent formation of taskforce by DAC, MoA paid rich dividends and it culminated in the form of Union government's support of Rs 300 Crores for the first time in a major way for the promotion of millets cultivation through a scheme entitled "Initiative on Nutritional Security through Millets promotion programme" (INSIMP) in 2011-12 under Rashtriya Krishi Vikas Yojana for promotion of millets as Nutri-cereals.

Scheme on INSIMP has been formulated to operationalize the announcement. The scheme aims to demonstrate the improved production and post-harvest technologies in an integrated manner with visible impact to catalyze increased production of millets in the country. Besides increasing production of millets, the Scheme through processing and value addition techniques is expected to generate consumer demand for millet based food products. DSR has been identified as nodal institution for operationalizing this initiative across the country. The Scheme will be implemented from Kharif 2011. Further, there are serious developments in the ministry to support millets consumption through its inclusion in PDS and also made millets available for school children in mid-day meal scheme. They are contemplating to develop a programme in Millets promotion to boost their consumption demand in the form of policy support in XII plan.

NAC recommendations on Food Security Bill: National Advisory Council recommendations on the proposed Food Security Bill envisage 35 kg of foodgrains at subsidised prices for 75 per cent of the population and 20 kg for the remaining 25 per cent of the population. In fact, the NAC recommendation is that the new law should provide a legal entitlement to subsidised foodgrains for at least 75 per cent of the population, which translates into 90 per cent of the country's rural population and 50 per cent of the urban population. This 75 per cent of the population is, in turn, divided into “priority households” who should have a monthly entitlement of 35 kg at a subsidized price of Re. 1 per kg for millets, Rs. 2 per kg for wheat and Rs. 3 per kg for rice and “general households” who should have a monthly entitlement of 20 kg “at a price not exceeding 50 per cent of the current Minimum Support Price” for the three grains. The recommendations are likely to become as food security Bill.

ICAR's plan on a mega research thematic area on Value addition through Health in XII plan: 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 DSR research priorities are to be reassessed in this context so as to merge with ICAR goals. Sorghum fits perfectly within this as it is a nutri-cereal 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 emanated from NIN's clinical trials supporting the positive results of sorghum consumption in reduction of lifestyle diseases such as diabetes the research on similar aspects. Since DSR is primarily a crop improvement institute there is a need to reorient our breeding strategies by strengthening breeding for end products which is 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. Further, shelf life enhancement of not only grain, but also of flour, rava and other products should 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 opting for them, the mass consumption will be promoted through policy interventions such as INSIMP which again has all India coverage offering end to end solutions for demand creation efforts are to be backed by the research efforts in the form of technology development on both processing machineries and products thereof meeting most of the rural producers and consumers 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.

The dynamics of Kharif and rabi will come into picture as most of the produce from rabi and good quality grain may be procured for PDS, efforts should be intensified for attaining higher yield levels in rabi. Molded Kharif grain will continue to form a source of raw material for industrial uses such as potable alcohol. The option to increase rabi yields may come from irrigated rabi cultivation with one or two protective irrigations and secondly spread of sorghum cultivation in rice fallows where the crop agronomy is to be standardized. The prospects of commercialization of sweet sorghum stalks will again depend on bioethanol pricing. However, R&D should be intensified on new generation of biofuels through high biomass and hemicellulosic means. Sorghum grain and stalks has greater potential in paper and pulp industry. The underlying factor for promotion of sorghum for various uses is that our research strategies must be discernable not to compromise with food security.

Long term perspective 2030

Following four production scenarios are worked out based on possible options/situations that are in front of us which are used for estimation for future.

Scenario one is existing situation and forms the bench mark. Scenario two deals with reduced area situation based on current trend in compound growth rate (CGR) for sorghum productivity for the past 15 years, and continuation of present trend of replacement of Kharif sorghums by more competitive and remunerative crops there is a possibility that there will be fall in the most productive and assured rainfall areas. The production predicted here is 9.83 million tonnes from a meager 6.6 million ha. The share of Kharif would be about 45% and rabi is 55%.

Third scenario deals with optimistic estimates based on expected yield levels the anticipated further improvement in productivity and coverage of HYVs. This scenario assumes the current area is retained superimposed with increased yields to

Scenario No.	Description	Production (million tonnes)	% increase over scenario
Scenario 1	Existing scenario	7.29	NA
Scenario 2	From reduced area based on existing trend	9.83	34.84
Scenario 3	Optimistic estimates based on expected yield levels	11.54	58.29
Scenario 4	Estimates based on Policy push	15.60	113.99

obtain 11.54 million tonnes. The contribution of Kharif is slightly higher than rabi (52%) unlike the scenario 3.

In the last scenario (4) an attempt is made to understand the impact of favorable Government's policy which has already started and going to further strengthened in XII plan in the form of support for production, processing and value addition. Creation of awareness is given more importance so as to generate consumption demand owing to nutritional merits of sorghum. Further, Government policies interventions in the form of inclusion of Sorghum in PDS is expected to fruition some area gains and we presumed it to the tune of 20% and computed likely production which has come to 15.6 m t, of which Kharif production will be 8.24 m t (53%) and remaining rabi production is expected to attain in the next 19 years. Area gains in favor sorghum may come from other crops which are less remunerative 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 favors Sorghum which with 1-2 Irrigations the yield may be doubled in rabi and assured water supply in Kharif sorghums too.

Sorghum cultivation and production: Projection up to 2030 AD

Ecology of production area	Scenario I			Scenario II			Scenario III			Scenario IV		
	Area (m ha)	Yield (Kg/ ha)	Produc-tion (m t)	Area (m ha)	Yield (Kg/ ha)	Produc-tion (m t)	Area (m ha)	Yield (Kg/ ha)	Produc-tion (m t)	Area (m ha)	Yield (Kg/ ha)	Produc-tion (m t)
Kharif	3.31		3.25	2.65		4.77	3.31		5.95	4.34		8.24
Assured Rainfall area	1.32	1378	1.82	1.06	3000	3.18	1.32	3000	3.96	1.95	3000	5.85
Non-assured Rainfall area	1.99	718	1.43	1.59	1000	1.59	1.99	1000	1.99	2.39	1000	2.39
Rabi	4.38		4.04	3.95		5.06	4.38		5.59	5.26		7.36
Rainfed Area	3.51	616	2.65	3.16	850	2.69	3.51	850	2.65	4.21	1000	4.21
Irrigated area	0.87	1597	1.39	0.79	3000	2.37	0.87	3000	2.61	1.05	3000	3.15
Total	7.69		7.29	6 60		9.83	7.69		11.54	9.60		15.6

Source: Estimates worked out for Vision document 2030, DSR, Hyderabad 2011

Thus, the maximum production gains will be attained through policy interventions as in scenario 4 to the extent of 114 % over the current situation. Such gains will push it for meeting food and nutritional security if the quality concerns are adequately addressed concerning Kharif sorghums.

Epilogue

Thus, sorghum production scenario is inter-linked with aspects conferring strength as well as weakness and threats to its sustainability. However, there are many opportunities for its enhanced production and profitability. Despite a declining per capita consumption of sorghum, it still remains the fourth major cereal staple and the cheapest grain accessible to the economically-deprived people especially in rural and remote areas. Resistance to grain mold and introduction of processing technology to facilitate easy cooking and consumption may greatly enhance the food value of kharif grain in addition to the preferred rabi grain. Transgenic approach is being adopted to incorporate superior dough quality in sorghum grain. Mapping populations are being developed to finally implement marker-assisted selection in developing cultivars with resistance to biotic and abiotic stresses and important quality-related traits.

The emerging role of kharif grain as feed in the domestic and international circuits is a viable and harnessable opportunity. Diversification and value-addition of kharif sorghum as a bioenergy crop has vast potential and great economic relevance in the context of huge annual national burden on import of fossil fuel. Genetic potential of this crop to provide cultivars with good malting quality, competitive starch production and good source of beta glucan may also receive recognition. There is hardly any other single dryland cereal crop which has all such potentials together. Thus sorghum is not only a drought hardy crop but also a treasure crop of the dryland farming.

Future research on sorghum, therefore, will focus primarily on genetic enhancement to promote productivity as a food, feed, fodder and forage crop, and as an industrial crop for bioenergy. Conventional breeding while, may continue as the mainstay for this improvement, the tools of biotechnology would be most critical for greater success. New clients of future research would be not only farmers, but also industries. Constant contact with global trends on research and production would become a compelling requirement not only to keep the anticipated feed export competitive but also to maintain production for domestic needs sustainable. Research and production to the changing industrial needs, continuing research to constantly maintain the competitiveness of grain over alternate raw material, improving the bioenergy potential and by-product utilisation would also assume increasing importance. Appropriate public policies to promote the diverse economic potential of this crop are essential without which the very relevance of kharif sorghum may become questionable very soon. A lesson learnt in the past is that technology advancement alone in the absence of friendly public policies may not trigger economic sustainability of an agricultural production system.

Globalization and economic liberalization have opened up several new opportunities as well as challenges. While providing the appropriate climate for the private sector to utilize available and prospective opportunities, safeguarding the interests of Indian farmers protecting and conserving agro biodiversity and traditional knowledge are also of central concerns. A regulatory system of new type is, therefore, needed which will encompass quality assurance mechanisms coupled with facilitation of a vibrant and responsible public-private sector collaboration covering all the issues of intellectual property rights.

Productivity improvement as envisaged 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. India may be able to produce about 15.6 million tonnes sorghum by 2030 AD from 9.6 million hectares as per the estimated scenario for the year 2030 AD. Of this estimated, the production in kharif will be 8.24 million tonnes and 7.36 million tonnes in rabi. 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 farming into a healthy and prosperous proposition, justifying the public support for sorghum research in the country.

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Annexure 1: Strategic framework

Goal	Approach	Performance measures
Genetic resource management		
Sorghum genetic resources Management	Region, and trait-specific germplasm collected, characterized, collated, conserved	Trait specific Potential germplasm identified and used in trait specific breeding
Seed science & Technology		
Overcoming cold induced seed set in rabi, and ergot incidence in sorghum	Lines for cold tolerance screened, role of alternate hosts assessed; Crosses generated to develop RILs and QTL analysis done. Ergot control measures worked out.	Cold tolerant lines , Information on prevalence and spread of disease, Ergot resistant lines Information on most effective fungicide for ergot control
Seed longevity in sorghum	Combining abilities and nature of gene action for seed longevity ; Standardized seed treatments for enhanced seed longevity	Nature of gene action & better storers for seed longevity , Selection criteria to improve seed longevity and treatments for enhancing sorghum seed longevity
Wide hybridization, Genetic diversity and crop improvement		
Exploring sorghum species and novel variation for crop improvement	Technique to produce and record mutants of sorghum established; New mutants characterized for agronomic traits ; Advanced progenies and back crosses between sorghum, sugarcane and maize	Reproducible techniques; Agronomic traits and performance potential; Inter-specific sorghum hybrids developed and evaluated
Improving kharif and rabi grain productivity	Superior MS lines and R lines with better combining ability	Superior hybrids developed with high grain yield for kharif and rabi situations
Genetic enhancement of sweet sorghum for high sugar content (brix) and biomass	New germplasm and genetic stocks with high brix and biomass and stemborer tolerance	Lines with high brix, high biomass and stemborer tolerance identified; Diversified seed parents for stalk sweetness, biomass and stemborer tolerance
Genetic enhancement for t pest resistance	Sorghum genotypes with improved level of resistance to shoot fly, stem borer and other earhead pests	B and three R line derivatives with improved level of resistance; Complete phenotyping and genotyping data of the RILs obtained, and molecular mapping constructed
Development of parental lines for grain quality traits (high protein digestibility and grain size and grain yield using conventional and molecular approaches	Identification of lines with high grain yield and protein digestibility suitable for alternate uses	Parental lines and hybrids developed with superior protein digestibility and yield; SSR/genic markers identified and validated for use in MAS
Biotechnology and Molecular biology		
Use of DNA markers for identification of QTLs for shoot fly, drought, seed quality and grain mold traits	Complete phenotypic and genotypic data of the RILs for QTL identification; QTL with tightly linked markers identified	Major, epistatic QTLs identified and QTL x E effects understood; QTLs for shoot fly traits identified; Precision breeding with linked markers in marker-assisted improvement of elite genotypes for shoot fly resistance drought traits and grain quality identified

Goal	Approach	Performance measures
Comparative genome mapping in sorghum	Synteny map of sorghum and other cereals; Identification of common markers for staygreen trait; Validation of staygreen markers in sorghum	More number of PCR based markers identified to saturate sorghum map. Tightly linked markers for staygreen identified; Map based gene cloning attempted.
Establishing the role of volatile cues in oviposition preference of sorghum shoot fly, and mapping associated QTLs	Role of specific volatile blends in imparting shoot fly resistance identified; Variation in wax morphology and composition in resistant and susceptible genotypes studied and its role in imparting resistance understood; QTLs associated with volatiles and waxes will be mapped	Use of volatile cues as selection criteria to improve shoot fly resistance; Wax morphology and composition employed as a selection criteria; Use of linked markers for volatiles and waxes in marker-assisted improvement
Molecular basis of apomixis in sorghum	Genotypes with apomixis identified in sorghum; Cytomolecular basis of apomixis	Understanding apomixis in sorghum; Possible clues to develop usable form of apomixis in sorghum
Marker-assisted improvement of parental lines for Shoot fly, stay green, grain quality and cold tolerance	MAS improvement of sorghum for tolerance to terminal drought; Complete phenotyping and genotyping data of the RILs	Shoot fly resistant CSH 13 hybrid; Hybrids and varieties tolerant to terminal drought ; QTLs for MAS for grain quality; New RIL mapping population with variation for cold tolerance
Abiotic stress management in relation to climate change		
Improvement for drought and salinity tolerance; and adaptation to climate change	Impacts of climate change on growth, and productivity of sorghum adopting modeling framework quantified. Identification of mechanisms of salinity tolerance in sorghum	Key plant traits contributing adaptation to climatic stresses identified, and characterized for utilization in breeding program. Sorghum productivities across agro-ecological zones validated
Crop health and biotic stress management		
Loss minimization due to grain mold	Identification of resistant donors, new parental lines for major mold components and their combinations Elucidation of the path to floret infection and kernel deterioration for major mold pathogens; Molecular mechanisms of mold resistance	Resistant donor for each major mold pathogen identified. New information based on cytological and histopathological studies; Major reasons for resistance and susceptibility demarcated
Identification of improved and stable sources of resistant to shoot fly, aphids, stem borer and earhead pests (kharif and Rabi sorghums	Sorghum lines with resistance identified and registered; Phenotyping of MAS lines for resistant traits	Lines resistant to shoot and earhead pests identified and registered with NBPGR. Reliable trait conferring resistance to pest resistance identified for use in breeding program. Revalidation of economic losses caused by major pests in sorghum
Management of charcoal rot and seedling mortality in rabi sorghum	Genetic sources against CR; Integrated management of charcoal rot	New resistance sources resistance; Identification CR management strategy and crop loss estimations
Management of storage pests of sorghum	Post harvest loss under storage condition assessed and quantified; Identified lines resistant to major storage pest and mechanism of resistance understood; Cost effective storage pest management methods developed and demonstrated.	Losses estimation figures arrived under different storage conditions. Avoidable losses quantified for major storage pests of sorghum. Mechanisms of resistance understood. Eco friendly storage package developed

Goal	Approach	Performance measures
Impact of climate change on the bio-ecology of key sorghum pests	Life tables constructed at various temp, RH and Carbon dioxide regimes under laboratory conditions. Pest incidence surveyed in various agro-ecosystems and developed pest distribution maps.	Role of Carbon dioxide, temperature, and humidity on the life table parameters of key pests studied
Crop production and extension		
Standardizing and enhancing organic sorghum production	Suitable agro-climatic zones / markets / standards identified; Appropriate organic inputs identified and Organic production technology defined for enhanced sorghum production; Suitable regional specific cultivars for organic production identified	Enhanced organic sorghum production and productivity
Drought management in rabi sorghum	Existing data sets on climate, soil characterstics with rabi sorghum collected (Solapur, Bijapur, Rauri, and Parbhani) research station and simulate growth and yield components; Drought characterization of selected genotypes of rabi sorghum	Yield gaps identified; Soil water budget and crop growth in selected sorghum genotypes under benchmark rabi environments using simulation models
Assessment of performance and acceptability of new cultivars	Yield assessment of cultivars; Identifying suitable cultivar for lateral spread	Profitability and acceptability assessment of public –private seed sold in Indian market; Increased chances of acceptability for release of sorghum, use in breeding programme
Crop utilization, value-addition and popularization		
Improving sweet sorghum for high biofuel & biomass production	Germplasm accessions and genetic stocks characterized; Four big-mill tests; Eliciting farmers feedback responses on sweet sorghum cultivars	Sweet sorghum germplasm with improved stalk & quality traits ; Sweet sorghum genotypes for sugar & ethanol yields
Collaboration with TERI /Praj industries/ ILRI etc.	Released and advanced cultivars evaluated for biomass composition (cellulose, hemicelluloses, lignin, ash etc.)	Sweet sorghum genotypes with desirable biomass compositional traits (high cellulose, low lignin etc.) identified.
Sorghum foods	Genotypes screened to identify suitable for different products; Suitable processing technology; Sorghum genotypes with rich in antioxidants; Suitable additives for quality improvement; Packages for the improved shelf-life identified	Genotypes registered used in breeding; Process registered; Sorghum genotypes registered Process registered; Process for better shelf-life identified
Commercialization of sorghum	Commercialization of sorghum for industrial uses (poultry/cattle feed & potable alcohol)	Better genotypes identified and commercialized
Cultivar development and AICSIP interface		
Trials and nurseries and Off-season nursery management	Yield (all India) trials organized; Synchrony of parental lines documented	Diversified material ; Seed increase of advanced progenies Information on performance potential of test entries, best entries selection, propagation, registration, licensing and commercialization; Standardized seed production technology and new releases brought in seed chain
Research coordination and services		
Nucleus & breeder seed production; DUS characterization; Production of commercial seed under Mega Seed Project	Breeder seed supplied to indenters ; DUS traits of new lines; Popularization of new cultivars and revenue generation	Uptake of lines in seed production; Applications for PPV&FRA, and plant varieties protected Spread of cultivars, licensing, commercialization, revenue generation and benefit sharing