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Global Sorghum Improvement Research and Its Relevance to India

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Summary

Region specific-production environments and product requirement coupled with the associated biotic and abiotic yield constraints has led to the adoption of different breeding strategies and selection criteria in sorghum improvement programs in major sorghum growing regions where sorghum is important for food security and sorghum-based economies. In India, initial landrace selection strategy to exploit natural variability was gradually shifted to pedigree breeding and hybrid breeding with a major focus on grain yield, early maturity and resistance shoot fly and grain mold in rainy season and resistance to shoot fly and terminal drought in postrainy season. Several high yielding varieties and hybrids have been developed and released/marketed for both rainy season and postrainy season adaptation in India. In China, breeding programs were aimed at improving grain yield and grain quality (low tannin and high protein) to meet animal feed demand and fodder yield to meet dairy industry demand. Sweet sorghum research was also given adequate emphasis, especially for silage preparation to improve the quality of fodder fed to dairy cattle. Because of large-scale adoption of hybrids compared to India, there has been a quantum jump in sorghum productivity in China unlike India. Development of high yielding, and midge resistant and drought resistant hybrids suitable for animal feed was the major objective of sorghum improvement research in Australia. In USA, improvement of grain yield and grain quality with midge resistance for animal feed use has been the major breeding objective. The yield levels in USA have increased by more than three folds due to the adoption of hybrids. In Africa, sorghum production is still at subsistence level, the African national sorghum improvement programs aimed at improving sorghum for grain yield and grain quality for food use, and resistance to drought. In countries like Nigeria, apart from food-quality grain cultivars, identification/development of cultivars suitable for brewing industry also received adequate priority. Apart from grain yield and grain quality, resistance to major production constraints such as Striga, leaf blight, and stem borer were target traits in breeding programs to stabilize production in African countries. In Latin America, improvement of grain yield and grain quality for animal feed use and fodder yield for dairy cattle were major breeding objectives.

The global sorghum improvement programs have tremendous impact on sorghum research and sorghum productivity in India. Several hybrids developed in India during 1960-1980 are based on exotic/their derived A-/B-lines, especially USA and African countries. The adoption of hybrids helped enhance stagnated yield levels due to cultivation of pure-line varieties. Several resistant sources to major abiotic (terminal drought) and biotic (shoot fly, midge, grain mold etc.) yield constraints and forage germplasm identified at ICRISAT, in collaboration with NARS have been extensively used in Indian NARS sorghum improvement programs to develop grain and forage sorghum varieties and hybrids less susceptible to these constraints. Some of the varieties developed by ICRISAT in partnership with NARS are popular among farmers in India. Apart from these, the trait-based hybrid parents developed at ICRISAT have *been extensively used by both private and public sector scientists to develop and market/release numerous hybrids for commercial cultivation in summer, rainy and postrainy seasons in India. Farmers now have wider cultivar options than ever before and these have contributed to cultivar diversity and sustainable production systems. The future priorities of sorghum improvement research in different regions/countries considering the current farmer and industry need, product diversification to find new niches and production constraints are emphasized.*

Introduction

Sorghum [*Sorghum bicolor (L.)* Moench] – a major cereal of the world after rice, wheat, maize and barley, is a staple food for millions of poorest and most food-insecure people in the Semi-Arid Tropics (SAT) of Africa, and Asia. Being C_4 species with higher photosynthetic ability, and greater nitrogen and water-use efficiency, sorghum is genetically suited to hot and dry agroecologies where it is difficult to grow other food grains. These are also areas subject to frequent drought. In many of these agroecologies, sorghum is truly a dual-purpose crop; both grain and stover are highly valued outputs. In large parts of the developing world, especially in Asia, 50 percent of the total value of the crop, especially in drought years (FAO and ICRISAT 1996). In countries in Africa, sorghum is predominantly grown for food purposes, while in USA, Australia, China etc., it is grown for livestock feed and animal fodder purposes. Unlike in other parts of the world, sorghum is grown both in rainy and postrainy seasons in India. While the rainy season sorghum grain is used both for human consumption and livestock feed, postrainy season produce is used primarily consumption in India. Sorghum also offers great potential to supplement fodder requirement of growing dairy industry in India because of its wide adaptation, rapid growth, and high green fodder yields, and good quality (Pahuja *et al.* 2002).

Production constraints

The yield and quality of sorghum produce is affected by a wide array of biotic (pests and diseases) and abiotic stresses (drought and problematic soils). These are shoot fly (India and Eastern Africa), stem borer (India and Africa), midge (Eastern Africa and Australia) and head bug (India and Western & Central Africa [WCA]) among pests; grain mold (all regions), anthracnose (WCA and Northern India) and *Striga* (all regions in Africa) among diseases; drought (all regions) and problematic soils – saline (some parts of India and Middle-East countries) and acidic (Latin America) – which together (except saline and acidic soils) cause an estimated total yield losses to the tune of US$ 3032 million (*www.agbiotechnet.com/pdfs/0851995640).* Sorghum grain productivity was dismally low (0.7 t ha^{-1}) because of these production constraints and the use of traditional cultivars (low-yielding) and traditional production practices during early 1970's.

Region specific-production environments and product requirement coupled with the associated biotic and abiotic yield constraints has led to the adoption of different breeding strategies and selection criteria in sorghum improvement programs in major sorghum growing regions where sorghum is important for food security and sorghum-based economies. In this article, we have made an attempt to trace the breeding objectives, strategies and achievements accomplished in global sorghum improvement programs and their impacts on Indian agriculture.

Sorghum breeding in India

India unlike other countries has two sorghum producing seasons-*Kharif* (rainy season June/July-September/October) and *Rabi* (post rainy) season (October-December/January). Therefore, different cultivars are required for each season as production conditions and production constraints are quite different (Rana, *et al.* 1997). Natural selection and domestication by farmers over thousands of years has resulted in the development of numerous varieties, which are highly local in their adaptation. Later, sorghum improvement switched over from farmers' selection to trained plant breeders as a result of which improved varieties were developed through pure line selection from principal local varieties cultivated by farmers. Subsequently, limited inter-varietal hybridization among local landraces followed by selection has contributed towards combining the then existing levels of grain yield with juicy stems to improve forage quality. Since the emphasis was on specific adaptation in the given region, several varieties were released within the states. E.g. Saonar, Rankel, Aispuri, Maldandi and Dagadi selection in Maharashtra and the Nandyal, Guntur and Anakapalli series of Andhra Pradesh. Inspite of these efforts, noticeable changes in yield levels were not marked (Rao, 1972).

After the discovery of stable and workable cytoplasmic-nuclear male sterility (CMS) system (Stephens and Holland, 1954) and as a result of the efforts under the accelerated hybrid sorghum project initiated by Indian Council of Agricultural Research (ICAR) during the year 1962, fourteen hybrids were released starting from CSH 1 released in 1964, CSH 2 in 1965, CSH 3 in 1970, CSH 4 in 1973, CSH 5 in 1974, CSH 6 in 1977, CSH 9 in 1981, CSH 10 in 1984, CSH 11 in 1986 and CSH 14 in 1992, all for rainy season. The program also released varieties for rainy season such as Swarna (1964), CSV 11 (1984), CSV 13 (1987) and CSV 15 (1993), but the varieties are not popular with farmers (Reddy and Stenhouse, 1994). However, the popularity of the hybrids by farmers in rainy season is indicated by the increased acreage under hybrids over the years starting from 30 percent area in 1981, 56.3 percent in 1985 and 95-100 percent in 1993 in Maharashtra state alone (Rao, 1972; Rao, 1982; Vidyabhushanam *et al.*; 1989). A few hybrids viz., CSH 7R (1977), CSH 8R (1978), CSH 12R (1986), CSH 13R (1991-1992), CSH 19R (2000-2001) and varieties e.g. CSV 7R(1974), CSV 8R(1979), Swathi (1988), CSV 14R (1991) were released for post rainy season. CSH 7R and CSH 8R hybrids failed to make any mark because of low fodder value and high heterotic response for harvest index leading to lodging (Rao, 1982). And other cultivars could not spread and make any effect on raising post rainy season productivity (Murty, 1994).

High yield with matching grain quality and boldness, resistance to shoot fly and fodder yield equal to that of the popular local variety M35-1 under receding moisture conditions are the traits which the farmer look for in post rainy season cultivars (Rana *et al.*, 1997). Best quality sorghum comes from *rabi* varieties; so good grain quality will be required in the hybrids if they are to be accepted (House, *et al.* 1997).

Strong research program at ICRISAT's Patancheru center indicated that both A_1 and A_2 cytoplasmic nuclear male sterility (CMS) systems can be utilized when they are based on *caudatum* race and hybrids using landrace pollinators rather than improved restorers were comparable to the released hybrid CSH 13R and significantly superior to the popular landrace variety, M35-1 and released hybrids CSH 12R and CSH 13R for grain yield and grain quality, respectively (Reddy *et al.* 2003).

Intensified efforts are underway on post rainy season (*rabi*) sorghum improvement for higher grain and fodder yields with acceptable grain quality in both Indian national program and ICRISAT's Patancheru programs. Efforts are also being continued on *Kharif* hybrids and new male sterile seed parents with resistance to improved qualities including exploitation of different sources of CMS systems, and continued use of germplasm.

Rainy season sorghum's ability to compete efficiently with other crops in the future would depend on productivity growth, i.e., evolution of hybrids with higher yield potential, closing the yield gaps, reduction per unit cost of cultivation and creating demand for domestic and export markets (Rana, *et al.* 1997). Grain mold is an important biotic constraint of rainy season sorghum caused by a complex of fungi affecting the yield and quality of the grains. Therefore, genetic enhancement in grain mold resistance and value addition through genetic means would augment food and feed uses and ultimately increase the economy (Rana, *et al.* 1997). Alternatively, it is essential to work on the diversified uses of crop surpluses and mold damaged and discolored grain (Reddy and Stenhouse, 1994). The technologies to convert molded grains into various products such as sugars, alcohol, starch, semolina and malt products (Somani and Pandrangi 1993) would enhance industrial uses of sorghum and consequently the economy.

Sorghum Breeding at ICRISAT

The establishment of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in 1977 at Patancheru, Andhra Pradesh, India (which is now being called as (IAC) with sorghum as one of its five mandate crops for research aimed to improve productivity and stability of sorghum for food use in the SAT of the world. Improvement for yield potential and resistance to droughts, *Striga*, grain mold, downy mildew, charcoal rot, shoot fly, stem borer, midge and head bug with wide adaptability received equal attention up to 1980. Target materials aimed were populations and varieties. Both recurrent selection methods and pedigree were followed equally. In resistance breeding programs, emphasis was given to standardizing screening techniques and identification and breeding of improved resistance sources. The initial emphasis on red grain types up to 1975 was gradually shifted to white grain types by the end of 1970's.

During 80's, major emphasis was given for regional adaptation and breeding for resistance to biotic stresses (grain molds and insect pests only) in white grain background. Work on drought, downy mildew, charcoal rot and *striga* was discontinued. Work on improvement of male sterile lines for grain yield and grain food quality traits were also initiated.

Initially, several populations were introduced from USA, West Africa and East African programs and were reconstituted with selection. Later on several high yielding good grain bred-lines and *zera zera* landraces (*caudatum*) were extensively involved in breeding at IAC, and *guinea* local landraces along with *caudatum* derived lines at ICRISAT West African center (Reddy and Stenhouse, 1994).

During 1985-89, major thrust was given for specific adaptation and trait based breeding for resistance traits. By late 1980's many National Agricultural Research Systems (NARS) had enhanced crop improvement programs and were involved in planning of crop improvement programs of International Agricultural Research Center (IARC) aimed at specific adaptation. Thus, global sorghum improvement program reoriented itself to develop materials suited for 12 productive systems (PS) in Asia, six in Western Africa, six in Eastern and Southern Africa and five in Latin America. As a result of this reorientation, at ICRISAT's Asia center (IAC), strategic research on the development of techniques and intermediate products for utilization in partnership with NARS programs was given emphasis during 1990-1994.

Accordingly, an extensive program of diversifying breeding new *Milo* cytoplasm male sterile lines for earliness, introgression with durra and guinea races, incorporating bold and lustrous grain characters, and resistance to striga, shoot fly, stem borer, midge, head bug, grain mold, downy mildew, anthracnose, leaf blight and rust was carried out (ICRISAT 1993).

With a major objective of trait specific breeding, novel populations or trait-specific gene pools for bold grain and high productive tillering were developed. Test crosses involving post rainy season 'landraces' progenies as pollinators were examined for their fertility restoration ability under cool nights and for productivity in post rainy season. Variability for restoration was quite significant indicating the possibility of selection within and of hybrids than bred-restorer hybrids (Reddy and Stenhouse 1994).

From 1995 onwards, partnership mode of conducting research to develop improved intermediate product at ICRISAT, Patancheru, India, and finished products (varieties and hybrids) at other ICRISAT locations in Africa were being emphasized. Accordingly, the objectives of the program at present are breeding resistant (to biotic and abiotic stresses) seed parents and restorer lines, developing specific new gene pools and novel plant types and identifying and using molecular markers. However, breeding programs in Africa will continue to develop high yielding cultivars (varieties and hybrids) with resistance to *striga*, and head bug appropriate in the region. ICRISAT, working in partnership with NARS helped release 194 cultivars in several countries in Asia (50), Africa (110) and Latin America (34) (Reddy, 2004).

Sorghum breeding in United States

Initial sorghums introduction in the United States were tall growing and late maturing. Later farmers found early-maturing heads of Giant Milo, which gave rise to a cultivar called 'standard *milo*'. During 1900, a farmer in Oklahoma selected Dwarf yellow *milo* from standard *milo*, the seed of which were distributed to farmers around Chillicothe, in northern Texas. Texas Agricultural Experimental station and United States Department of Agriculture (USDA) began research efforts at Chillicothe in 1905. An early white Milo was selected from the yellow *milos* in about 1910. Short stature *feterita* and *hegarie* cultivars were selected and released in Texas by 1920 (Rooney and Smith, 2000).

Recognizing that natural hybridization gave rise to usable and improved types, H.N. Vinall and A.B.Cron began the second phase of grain sorghum improvement in 1914, with the deliberate hybridization of *feterita* from Sudan with Blackhull *Kafir*. Chiltex and premo cultivars were released from that cross in 1923. J.C Stephens and J.R. Quinby released Boniter from a cross of Vinall and Cron's Chiltex, a *hegaria* type, and Quadroon, from a *milo-kafir* combination. J.B. Sieglinger also working with *milo-kafir* combination in Oklahoma, released a variety 'Beaver' in 1928 which had desirable characteristics of erect heads, lacking the curvature of peduncle that was characteristic of many of the milos besides being short statured, suitable for mechanical harvest (Rooney and Smith 2000). Perhaps, Sieglinger's greatest contribution came with the release of Wheatland in 1931, also a derivative of *milo-kafir*. In 1937, W.P. Amrtin selected root and Stalk rot (Periconia circinata) resistant variety from Wheatland and released it as Martin's Milo in 1941. This cultivar proved so popular that it was the number one cultivar in the United States until the development of hybrids in 1950's.

The discovery of a cytoplasmic-nuclear male-sterile (CMS) system (Stephens and Holland, 1954) quickly led to the development of commercial sorghum hybrids. Scientists in Texas, Oklahoma and Kansas released several improved hybrids during this phase of grain sorghum improvement (Rooney and Smith, 2000). The greatest yield increases came early on, although higher-level yield plateau was soon realized. Later improvements were smaller yield increments, disease and insect resistance and quality. Yields in the United States improved over 300% from 1950 to 1990 (Rooney and Smith 2000) because of the adoption of improved hybrids and agronomic practices.

Sorghum breeding in Australia

Australia's first grain sorghum breeding program commenced at the Biloela Regional Experimental station in 1941 (Henzell 1992). Currently the public sector breeding program is based at the Queensland Department of Primary Industries (QDPI), Hermitage and Biloela Research stations. This program is coordinated with and complements breeding programs in the private sector. The major objectives of QDPI program include; grain yield, grain quality and resistance to lodging, drought, midge and disease.

Grain Yield

The variety 'Alpha' was the first major contribution of the Bilolela breeding program being released in 1946/47 by Dr. L.G. Miles (Henzell, 1992). In May 1958, seed pf parents of several hybrid grain sorghums was introduced from the USA, which paved the way for hybrid development, and several hybrids were released during 1960's (Henzell 1992). However, they showed a relatively small increase in yield although it varied with the region. Maximum yield advance due to breeding during the 30 years since 1960 varied from 0.3% per year for the Darling Downs to 0.6% per year in the south Burnett.

However, the grain yield of subsequently released hybrids in 1986 was equal to the boot midge susceptible hybrids in the absence of midge in Queensland (Henzell *et al* 1992). A further increase in yield was evident in non-senescent hybrids, AQL40/RQL36 and AQL41/RQL36, which out yielded the mean yield of three check hybrids (Texas 610SR, pride and E57+) by 111.4 and 113.1 percent, respectively. The increased yield potential of these hybrids was due to their later maturity and therefore greater biomass (Miller, 1992).

Head type and grain quality

The open panicle type is preferred, principally because of its negative effect on the build up of head caterpillars, such as Heliothis (*Helicoverapa armigera*) and sorghum head caterpillar (*crytoblabes adoceta*). Grain with a red pericarp, a thin mesocarp; a relatively dense endosperm and low tannin content in most commonly selected for in Australia, each of these characteristics contribute to grain weathering resistance. No consideration has been given to selection for protein content, principally because there has been no clear demand from the grain consumers (Henzell, 1992).

Lodging resistance

Lodging caused by plant death under water stress during grain filling and the concurrent development of stalk rot diseases is one of the major production constraints in Australia (Henzell, 1992). In Australia and elsewhere (Rosenow *et al.* 1983), major advances have been made in breeding for lodging resistance under these conditions. This has been achieved because there is a genetic variation in sorghum for the rate of plant death under water deficit conditions. Breeders worldwide have therefore been selecting for the non-senescence (stay-green) trait.

In the QDPI program, the major sources of non-senescence have been KS19, to produce QL9, QL10, QL11 and QL12 and more recently B35 (Rosenow *et al* 1983) to produce QL40 and QL 41. B35 particularly has proved an excellent source of non-senescence such that hybrids based on QL40, but particularly on QL41, are highly non-senescent (Henzell, 1992), stalk-rot resistant (Dodman et al., 1992) and lodging resistant (Henzell *et al.* 1992).

Midge resistance

Host plant resistance to sorghum midge is a major objective of both public and private sector breeding programs in Australia (Henzell et. al., 1994). The aim was to develop germplasm with enhanced levels of and a broadened genetic base of midge resistance combined with other characters that are important for local adaptation (particularly stay green). Because of the polygenic nature of midge resistance, the breeding methods involve cycles of crossing, evaluation and selection of parents and additional crossing to commence a new cycle, with the occasional infusion of new germplasm. Some parents are used on the basis of other traits (stay green in B35, SC 35crosses). The use of such midge susceptible germplasm obviously slowed down progress in increasing midge resistance, but the approach has been to combine characters for local adaptation rather than concentrate on midge resistance alone (Henzell *et al.*, 1994). Midge resistant B-line Q39 developed using resistance sources SC108c, SC 165c, TX 2754 and TAM2566 are higher in resistance than each of these parents. Less progress has been achieved in developing R lines with high levels of resistance as in Q39. However, recently R lines with resistance at least greater than AQL39/RQ136 have been developed (Henzell *et al.*, 1994). Also, several improved midge resistant lines introduced from ICRISAT, Patancheru were exploited in midge resistant breeding programs.

Disease resistance

Breeding for resistance to Johnson grass mosaic virus (JGMV) was a major objective of QDPI program in 1970's (Henzell *et al.* 1982). It involved backcrossing the single dominant gene for resistance 'K' (discovered in the Indian variety 'krish') into locally adapted inbred lines. The lines QL3 and QL22 derived from JGMV resistant KS4 lines are dual resistant to JGMV and sorghum downy mildew disease (Henzell, 1992).

Drought resistance

Drought stress is by far the major constraint to sorghum production in Australia. Therefore, relatively a large portion of sorghum research is designed to address this problem. Of the several options for addressing this problem, selecting for drought resistance traits such as stay green in addition to yield per se has been the approach currently progress in Australia (Muchow, Borrell and Hammer 1996). Breeding for stay-green trait started in QDPI sorghum breeding program in 1984. The overall aim was to enhance and broader genetic base and to combine it with resistance to sorghum midge (Henzell, *et al.* 1997). The line Q41 derived from the cross QL33/B35 has a high level of stay green and crosses of it with QL38 and QL39 (Sorghum midge resistant lines) form the basis of female stay-green and midge resistant gene pool in QDPI program (Henzell *et al.* 1992). However, less progress has been made in developing such germplasm in the male population, although there are now some lines with moderate to high levels of stay-green combined with varying levels of midge resistance (Henzell *et al.* 1997).

Sorghum breeding in China

Modern breeding of sorghum in China began in 1920's, and has progressed through 3 stages: (a) collection, classification and pedigree selection within the best local varieties; (b) cross breeding, using crosses between local varieties or local exotic for variety production; and (crosses). Utilization of heterosis, which has been the main method of breeding since 1965 (Zheng Yang, 1997). The major objectives of sorghum improvement research in China include; grain yield, multiple resistance to abiotic (low temperature and drought) and biotic (aphids and head smut) stresses, grain quality, grain feed and forages for livestock.

Breeding for high yield

Exploitation of heterosis was the main method of improvement of yield in China. Through a program of selecting the best introduced seed parents, and then evaluating Chinese bred pollinators, a series of hybrids have been developed starting in the 1970's. A progressive increase in yield has been accompanied with an improvement in quality traits. Average grain yield of sorghum during 1992-94 was 3-75 t ha^{-1} during 1962-64 before hybrids were released (Zheng Yang, 1997). The increase in yield due to utilization of hybrids is estimated at 30-40% with the remaining improvement being due to better cultivation conditions (Zheng Yang, 1997).

A survey of the Chinese sorghum genetic resources through test crosses made on A_1 cytoplasm showed that very few accessions were maintainers and most were partial or full restorers of male sterility, so these were mainly used to breed pollen parents. Through crosses of Chinese lines with introduced B-lines, new seed parents have been bred so that hybrids are now being tested that have adaptation and quality traits from Chinese germplasm in both parents (Zheng Yang, 1997).

Breeding for multiple resistance to abiotic and biotic stresses

Low temperature. Low temperature is an important stress factor, especially for northeastern China in both the seedling and grain filling stages. Some cold-tolerant local varieties have been identified using low temperature seedling treatment. The effects of low temperature on panicle differentiation and seed set,have also been studied (Zheng Yang, 1997).

Drought. The main factor that limits sorghum production is shortage soil moisture in semi-arid areas. Research on resistance to drought has been focused on breeding of sorghum, measures for increasing emergence rates in water-limited areas and methods to identify suitable genotypes. New male sterile lines and restorers with resistance to drought are being developed (Zheng Yang, 1997).

Aphids. There are two major kinds of sorghum aphids, the sugarcane aphid, *Melanaphis sacchariand,* the yellow sugarcane aphid, *sipha flava* which together cause yield losses of about 20% in years of epidemics. It was found that most Chinese sorghum varieties lack genetic resistance to aphids. Several new male sterile lines with high degree of resistance have been developed by the Sorghum Research Institute, LAAS (Zheng Yang, 1997).

Head Smut. Sorghum head smut caused by the fungus, *Sphacelotheca reliana* is also a serious disease. There are three different physiological races of the pathogen in China. Resistance to head smut is controlled by both major genes of 2 or 3 pairs and some minor genes (Yang Zhen and Yang Xiaoguang 1993). Among 10,083 germplasm accessions studied, 39 showed immunity to race 2 but only 3 accessions have shown resistance to race3 (Chen Yue and Shi Yuxue, 1993). Based on these sources, resistance breeding is in progress (Zheng Yang, 1997).

Breeding for quality

Chinese Kaolings are an excellent source of good grain quality types such as Xiang Yanai and Zhen Zhubai. However, they are not used directly in heterosis breeding due to low combining ability and poor restoration. The problem of hybrid sorghum quality for food has initially been solved in China, but nutritive composition is low and the traditional fragrance of original local varieties needs to be recovered (Zheng Yang, 1997).

Grain for feed and forages for livestock

Feed grain. Since sorghum is the main raw material of compound feeds for livestock and poultry; breeding for feed quality has now become one of the main objectives of sorghum breeding in China (Shi Yuxue et al., 1992). In order to increase the feed value of grain it is essential to select varieties and hybrids with low or tannin content (below 0.2%), higher protein level, a better balance of protein amino-acid composition (Zheng Yang, 1997).

Forages. Most forage sorghums can be classified as dual purpose in China, with the grain used for human consumption and stover for other purposes. At present, the focus is on breeding for high biomass coupled with good nutritional value and low HCN content (Zheng Yang, 1997).

Breeding for sweet stalks

The growing animal husbandry industry in China has resulted in increased demand for fodder resources. Sweet sorghum, being more tolerant to biotic (leaf diseases) and abiotic stresses (salinity, alkalinity and water logging), besides higher biomass producing ability with sweet and juicy stalks compared to maize, researchers and policy makers in China placed increased importance on the use of sweet sorghum as an alternative source for meeting the demand for animal fodder. In China, sweet sorghum is primarily used for silage preparation. Sweet sorghum silage mixed with maize silage is fed to dairy cattle. Mixed silage has excellent quality and higher digestibility and palatability to dairy cattle. Despite long history of sweet sorghum cultivation in China, limited efforts were made to improve sweet stalk sorghum systematically before 1970's. However, with the introduction of improved sweet sorghum varieties such as Rio, Roma, Ramada, and Wray from several countries, systematic sweet sorghum breeding program was initiated in Liaoning Academy of Agricultural Sciences in 1985. As a result, two sweet sorghum hybrids, Liaosiza No.1 and Liaosiza No.2 were developed and released during 1989 and 1995, respectively. These two hybrids have wide patronage from the farmers throughout the country.

Sorghum breeding in Africa

Sorghum is one of the major cereal staple grain crops that contribute to food security to millions of people spread across in several countries in Africa. The crop is grown as a rainfed crop in diverse environments across tropical and sub-tropical agro ecologies in Africa; from extreme lowland arid and semi-arid zones (of Libya, Sahel of West Africa and Botswana) to the sub-humid and humid low lands (of southern Guinea Savanna of West Africa) and the mid high lands (of Great Lakes Zone of East Africa). The semi-arid and sub-humid high lands are typified by high lands of Ethiopia, Eastern and Central Africa (ECA) and Lesotho (where sorghums are cultivated around Mokhotbug at an altitude of 2400 m). In all these regions, traditional cultivars are grown following traditional production practices. These diverse agroecologies with varying production systems have resulted in different production constraints affecting sorghum production.

Consequently, the national sorghum improvement programs in Africa had their own priority when sorghum breeding began in late 1930's replacing traditional farmer selection activities. This led to the identification of, selection and release of better landraces as "improved local selections". Breeders then began introductions and conversion programs using exotic germplasm. Some of these are still being used as checks in national and regional trials. At the same time, exotic germplasm lines were introduced, adapted and tested. Between 1948 and 1960, useful cultivars local varieties and exotic germplasm lines were used in hybridization program and initiated pedigree and bulk breeding programs. Population development and its improvement through recurrent selection were possible with availability of genetic male-sterility. The population improvement served as a long-term strategy to derive broad genetic-based varieties and complemented conventional breeding methods. Of the several available male-sterility inducing genes, ms_3 has been extensively used in sorghum population improvement program. These breeding methods are still continuing in many African countries.

Between 1930 and 1950, a multilateral collaboration in Eastern Africa involving Kenya, Uganda and Tanzania began (Doggett 1988). Greater prominence was given to wide adaptation and increased productivity. In the late 1970's, a regional approach to sorghum breeding initiated as result of such collaborations. The first of such regional approaches to sorghum breeding was the Organization of African Unity/Scientific Technical and research Commission (OAU/STRC) Joint Project 31 on Semi-Arid Food Grain Research and development in Africa (SAFGRAD), which was initiated in 1976. Subsequently, regional sorghum breeding approach began at different periods in three regions-East and Central Africa (ECA), South African Development Community (SADC) and West and Central Africa (WCA). These regional breeding programs were set up with the objective of tackling different production constraints specific to different regions. The breeding methodologies and strategies differed in these regions resulting in differential impacts, both of intermediate genetic products and cultivars on farmers' fields.

East and Central Africa

Sorghum improvement research in Eastern Africa began with the collection and screening of local germplasm in Kenya, Uganda and Tanzania (1930-50) (Obilana 2004). Useful local selections were identified; the popular ones are: Dobbs (from western Kenya) and L 28 (from Uganda) (Doggett 1988). With the sorghum gaining significance in Uganda and Tanzania, a program to breed for early maturing, white and brown grain 'bird resistant' varieties was initiated in Tanzania during 1948. The outcome of this program was the development of brown grain variety, SERENA. The variety was derived from the cross Swazi P1207 × Dobbs through pedigree breeding in 1956/57. The sorghum-breeding program in these three countries (Kenya, Uganda and Tanzania) progressed into an East African regional sorghum improvement program, which started in 1958 at Serere, Uganda. This regional program, focused on managing the endemic weed, *Striga* in addition to bird damage in the next two decades (1958-1978). This next phase resulted in the development of three varieties, two of which-SEREDO (Serena × CK60) with brown grains, and Lulu-D (SB77 × Seredo) with white grain are still popular in Kenya, Uganda and Tanzania.

Sorghum improvement research in Uganda is based at Serere Agricultural and Animal Production Research Institute (SAAPRI). In collaboration with ICRISAT and International Sorghum and Millet Collaborative Research Support Program (INTSORMIL), and a number of Non-governmental organizations (NGO's) operating in the countries, several improved varieties have been released since 1969 such as Serena, Hijack, Himidi, Hibred, Lulu Tall, Lulu dwarf, Dobbs Bora, Seredo and 2Kx17/B/1 (Esele 1995).

ICRISAT came to the region in 1978 to assist in sorghum improvement; the focus was on the use of selected landraces as parents in hybridization to create variability, and adaptive testing of advanced lines derived from crosses. ICRISAT operated from India and Kenya under a project of the Tanzanian Government. This collaborative research expanded later into two successive regional networks during 1986 –1993- East Africa Regional Cereals and Legumes (EARCAL) network, and the East Africa Regional Sorghum and Millets (EARSAM) network. In 2002, the East and Central Africa Regional Sorghum and Millets (ECARSAM) network was set up. While EARCAL/EARSAM were funded by USAID through the SAFGRAD/ICRISAT collaboration, ECARSAM is funded by the European Union through ASARECA. Between 1993 and 1999, ICRISAT' s involvement in East Africa was strengthened with inputs of improved varieties from the Southern Africa Development Community (SADC)/ICRISAT Sorghum and Millet Improvement Program (SMIP). Collaborative adaptive testing, both on-station and on-farm in Ethiopia during 1995-2000 has resulted in the release of five sorghum varieties for production in the western lowlands (ICSV210, PP290), central mid-highlands (IS29415) and eastern lowland Wadi (89MW5003, 89MW5056). The varieties, Serena and Seredo varieties are popularly used in mixtures with finger millet thin porridge for making, and with cassava flour for ugali, in the Great Lakes Region.

The two countries, Ethiopia and Sudan can be regarded as the strongest in the region for sorghum improvement. In line with the Ethiopian government's policy guidelines, the Institute of Agricultural Research (IAR) organizes sorghum improvement research in a team approach in Ethiopia. The team is composed of scientists from different disciplines such as breeding, agronomy, pathology, entomology, and weed science.

For the purpose of sorghum improvement research in Ethiopia, four adaptation zones of sorghum are recognized. The zones are classified as: highlands (altitude of >1900 m) with about 800 mm rainfall; intermediate (altitude of 1600-1900 m), with more than 1000 mm rainfall; low lands (altitude of <1600 m) with low rain fall less than 600 mm rainfall; and low land (altitude of <1600 m) with high rain fall (Gebrekidan 1981). Each of the four distinct zones of adaptation requires specific type of sorghum to match with agro-ecological conditions and which cater to the needs of the farmers and the end users. However, due to the shortage of trained human resources and the inadequate research infrastructure, only one coordinated national breeding program operating from Nazret/Melkassa Research Center responsible for the identification and development of improved varieties/hybrids resistant to anthracnose, ergot, grain mold stalk borer (*Buseola fusca*), shoot fly in late-planted sorghum, *Striga* and frost before grain filling and improved management practices suitable to all the four adaptation zones in order to increase the productivity levels. To assist The Nazret/Melkassa Research Center, several technology testing centers representing each of the four adaptation zones have been set up. In addition to Research Center at Nazret, Werer Research Center, low land irrigated center, serves as an off-season program site. The primary objective of this center is to seed increase of breeding lines selections and promising varieties and hybrids for the ensuing rainy season. Over the years, the sorghum improvement program has developed from indigenous germplasm lines are from introduced advanced breeding lines and recommended/ released several varieties (Debelo *et al.* 1995). Through EARSAM, Ethiopian national program took the lead in developing large-scale field screening techniques for resistance to the major diseases such as ergot, anthracnose, and grain mold and several resistant genotypes have been identified. These screening techniques and resistance sources have enhanced the pace of developing varieties and hybrids resistance to the major diseases.

The Ethiopian Sorghum improvement program (ESIP) started in full-scale in 1973. The program also served as home for the popular *zera zera* (*caudatum* race) type sorghums, which were extensively used as parents in ICRISAT sorghum improvement programs [illegible] ESIP made good progress with release of the varieties; Awash 1050, the popular ETS series, and Gambella 1107 (E-35-1) that has been widely used in ICRISAT breeding programs. (Reddy *et al.* 2004a).

Sudan in Africa is known for its strong capacity and long experience in sorghum research with strong linkages with regional and international centers. The sorghum research in Sudan dates back to early 1940's. Initially, crop improvement through breeding and crop husbandry research was given greater emphasis but later focus was shifted to more adaptive on-farm research. Sorghum research included genetic improvement for yields and grain quality and resistance to major production constraints such as *Striga*, and post harvesting handling, and utilization. During early 1940's, sorghum research concentrated on collection and evaluation of local and exotic germplasm. The full-fledged sorghum improvement program was initiated in 1952 in the central rainfed research station at Tozi in Sudan (Ibrahim *et al.* 1995). A program for hybrid breeding was started by the Arid lands Agricultural Development (ALAD) Project in collaboration with the Agricultural Research Corporation (ARC) of Sudan in 1970's. In 1977, ICRISAT/Sudan Cooperative Sorghum/Millet Improvement Program was initiated. The most significant outcome of these collaborative research activities is the release of a commercial hybrid, Hageen Durra 1 (Tx623A × karper 1597) by ICRISAT and Sudan Agricultural Research Corporation (ARC) in 1983 (Doggett 1988, Ejeta 1986). Between mid 1970's to early 1990's, ARC has released many improved cultivars with yield advantages of 10% to 70% for commercial production in both irrigated and rainfed systems (Babiker *et al.* 1995). They include pure line varieties (Dabar 1-1, G.El Hamam, SRN 39, M. Buda-2, F.W. Ahmed, Ingaz) and hybrids (HD-1 and Sheikan) resistant to *Striga*, which meet the requirements of farmers' and consumer preferences in different agro-ecological zones. At present, a full-fledged multi-disciplinary sorghum research program [illegible] The research areas include: crop improvement, crop management practices, crop protection, post harvest handling and utilization and socio-economics (Ibrahim *et al.* 1995).

South African development community (SADC)

Sorghum research in the Southern Africa Development Community (SADC) region, mainly in South Africa and Botswana began before the Second World War with emphasis on selections within landraces, bird resistance, and resistance to *Striga* and drought. These activities spilled over into Zimbabwe and Zambia with diversified focus on hybrid development and production. As early as 1940, converted sorghum genotypes, especially combined *Kafirs* and the white grain male-sterile lines were introduced into South Africa. The entry of private seed companies led to the commercialization of sorghum for industrial use such as in 'opaque beer' and malting for foods and drinks. In South Africa, selections from landraces included the then well known Red Swazi, which is still one of the earliest maturing (90-95 days) variety in the region and Framida, selected for *Striga* resistance from an introduced Chadian/Nigerian landrace. The male parent (Red Nyoni) of the most popular hybrid, DC 75 known for its opaque beer brewing quality is a landrace selection, which is popular in Zimbabwe and Zambia. Red Nyoni was selected from the improved landrace, Red Swazi in Zimbabwe (Doggett, 1988). One of the most popular and widely grown sorghum varieties in Botswana and the rest of the Southern Africa region is Segolane was also selected from landraces. Among the other varieties released earlier in Botswana and derived from the introduced *Kafirs* from USA are 8D and 65D (Saunders, 1942).

The cyclic occurrences of severe droughts in the late 70s in the region, led to the heads of States of SADCC (Southern Africa Development Conference community) to deliberate on interventions to minimize the effect of drought. This led to establishment of SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) in 1983/84. Sorghum improvement in SMIP has used a regional, collaborative and multidisciplinary approach since its inception. In the 15-year period from 1983/84 to 1997/98 improved varieties and hybrids were developed, tested on-station and on-farm and released by the National Agricultural Research System (NARS) of the eight countries in SADC region. The major objectives of sorghum improvement research in the region include: development of high yielding and early maturing dual purpose varieties with resistance to drought, downy mildew, leaf blight, sooty stripe, and *Striga.* Apart from these, the grains were also evaluated for food, malting, and feed qualities.

The SMIP program made significant achievements in germplasm movement and utilization; cultivar development, testing, and release; assessment of grain qualities for different end uses; strengthening research capacities in the national programs; and strengthening linkages with non governmental organizations (NGOs), private sector and seed companies in Zimbabwe and South Africa, millers in Botswana and Zimbabwe, breweries and feed companies in Zimbabwe; farmers' organizations, and universities. More than 12000 sorghum germplasm accessions were assembled from all over the world and made accessible to National Agricultural Research System NARS for sorghum improvement. From these 10,075 improved breeding lines, 4634 improved varieties, 379 hybrid parents and 3436 experimental hybrids were developed and supplied to Angola (100), Botswana (2398), Lesotho (681), Malawi (1449), Mozambique (322), Namibia (139), South Africa (147), Swaziland (326), Tanzania (3702), Zambia (5330), and Zimbabwe (3930). A total of 27 varieties and hybrids were released in eight SADC countries. Botswana (three varieties and first white grain hybrid in the region), Malawi (two varieties), Mozambique (three varieties), Namibia (one variety), Swaziland (three varieties), Tanzania (two varieties), Zambia (three varieties and three hybrids), and Zimbabwe (five varieties and one hyrid). However, of these 27 released varieties and hybrids, only 9 (33%) are cultivated on about 20-30% of the sorghum area in six countries. Five sources of resistance to three *Striga* species were identified (Obilana, *et al* 1988; Obilana, *et al* 1991). Twenty-three drought-tolerant male parents (R-lines) and 36 female parents (A-lines) with their maintainer (B-lines) parents were developed and are presently being used by South Africa, Tanzania, Zambia, and Zimbabwe in their hybrid development programs (Obilana, 1998). The variety Macia proved most popular in the region, having been released in five SADC countries (latest was in Tanzania in 1999) and is increasing in hectarage.

The comparative grain quality assessment of improved sorghum genotypes, including 100 indigenous varieties with 27 released varieties revealed that the grain quality of released varieties was better than that of improved genotypes and indigenous varieties. The transfer of this information to farmers dispelled their popular perception that released varieties are inferior to released varieties for grain quality and led the increased adoption of released varieties (Obilana, 1997). Consequent of success to farmer participatory variety selection methods, three countries are now retargeting their breeding approaches. Training in seed production and pollination techniques was provided across the region to country Scientists, and in-country training was organized in Botswana, Tanzania, and Zimbabwe. Areas where progress has been difficult include increasing productivity of the improved cultivars, and seed production and distribution. SMIP has also helped identify future research needs and options for commercialization of sorghum in each country.

West and Central Africa (WCA)

The West and Central Africa (WCA) region is the largest and most important sorghum production area in Africa. The sorghum crop in WCA is essentially rain-fed, and its cultivation extends from latitude 8°N to 14°N typified by varied agro-climatic zones of humid (Southern Guinea Savanna) and sub-humid (Northern Guinea Savanna) to semi-arid (Sudan Savanna) and arid (Sudano-Sahelian) conditions, from south to north. The These agro-climatic zones are characterized by sharply varying rainfall, temperatures and soil conditions, ranging from high rainfall (600-1200 mm) in the Guinea Savannas to low rainfall (250-600 mm) and very high temperatures in the Sudan and Sudano-Sahelian zones. A combination of these with varying day length periods demands sorghum varieties different maturity photoperiod sensitivities. Also, the production constraints and adaptations requirements vary with agro-climatic zone.

Before 1940, there was no account of sorghum breeding research work in WCA. However, by the early 50s, local landraces were collected and selections were made in Burkina Faso, Cameroon, Mali, Niger and Nigeria. In Nigeria, the landraces were initially grouped into four main types-namely *Guinera*, Kaura (mostly yellow endosperm types of *Durra-caudatum* hybrid race), Farafara (white grain type of the race *Durra*), and *Caudatum* types (Curtis, 1967). Several selections were made, most popular of which were the Warsha type sorghums, short Kaura and Janjare from Niger and Nigeria, and Muskwaris/Masakwa (transplanted sorghums in vertisols and hydromorphic soils) sorghum from Lake Chad and the inland delta of the river Niger in Mali. By 1966, exotic materials were introduced and tested, and pedigree-breeding programs began from the derivatives of local × local, local × exotic and exotic × exotic crosses. Extensive breeding programs became established across the region (Andrews 1970, 1975a and 1975b; Barrault *et al* 1972; Ogunlela and Obilana, 1982). Chantereau and Nicou (1994) reviewed such activities in French West Africa, which were initiated by IRAT in 1964. In the next 10-15 years, i.e. by 1971 – 1984, several improved pure line varieties and hybrids were developed, tested and released during 1971-89 (Obilana 1979, 1981, 1981a, 1981b; Chantereau and Nicou 1994, Andrews 1975a, 1975b; Carson 1977, El Rouby 1977).

Following selections among landraces, introductions and lines derived from crossing and backcrossing programs, both hybrid development and population improvement with recurrent selection programs started across the region. In Nigeria, before 1970's, the hybrids directly introduced from USA and India failed to make a dent to boost sorghum productivity due to their poor adaptation. Therefore, the exotic seed parents were crossed with local breeding lines to develop male-sterile lines from 1970 onwards. The most useful materials derived from this process are: CK60A (semi-dwarf and early); ISNIA, Kurgi A and RCFA (pedigree: (CK60B×FF60) × (CK60A) which are semi-tall and late maturing, (Obilana 1982a). From 1977, testing of large number of hybrids involving three (RCFA, ISNIA and Kurgi A) of the four locally developed male sterile lines and improved and released varieties was intensified (Obilana 1982b). Of these, five hybrids (SSH 1, SSH 2, SSH 3, SSH 4, SSH5) were identified as promising (Obilana, 1982a). Similar efforts in Niger resulted in the development and production of the hybrid, NAD-1 by 1989. The experiences of breeding and potential of hybrid sorghum in other African countries are presented by House *et al* (1997).

ICRISAT' s involvement in sorghum breeding in West and Central Africa began in 1979 with the establishment of centers at Kamboinse and Ougadougou in Burkina Faso; later shifted to Niamey in Niger, and now operating from Samanko in Mali since 1985. The ICRISAT' s genetic enhancement work in West Africa was preceded by Institut de Recherche Agronomiques Tropicales (IRAT's) involvement in francophone territories from 1964. Selection from segregating materials (derived from exotic × local crosses) and exotic germplasm introduction were the focus of both programs. ICRISAT was also involved in population improvement for grain food quality among *guinea* sorghums in Sotuba and Samanko, Mali. Breeding for *Striga* resistance was also initiated in 1979 in Burkina Faso by ICRISAT. One of the achievements from the joint presence of ICRISAT and IRAT in West Africa is the development of the variety, IRAT 204, derived from a IRAT 11 × IS

12610 cross. IRAT 11 is a derivative from Senegal local (Hadien-kori) × Niger local (Mourmoure) cross. IS 12610 is an Ethiopian germplasm accession from ICRISAT gene bank.

To stabilize and to improve foreign exchange earnings in Nigeria, during 1980s, breeding programs were focused on the development of varieties suitable for malt preparations and brewing of clear lager beer. As a result, improved varieties with good malt and brewing clear lager beer qualities were developed and released (Obilana, 1985). Collaborative grain quality testing including malting quality and proximate analysis, between Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Samaru, Zaria, and the Federal Institute for Industrial Research (FIIRO), Oshodi, Lagos (Obilana and Olaniyi 1983, FIIRO, 1986) led to the identification of SK 5912, the best malting sorghum. These were followed by series of pilot brewing and test marketing of lager beer made of sorghum malt (barley malt was replaced in ratios of 25%, 50%, 75% and 100% by sorghum malt) in 1984 in collaboration with three breweries. Following positive outcomes from acceptability, quality testing and successful marketing of the 100% sorghum malt, the government of Nigeria banned import of barley malt in 1988, thus saving more than US$100 million foreign exchange. The federal Nigerian government installed a brewing industry with a production capacity of 18 million hectolitres of beer in 1988 (Bogunjoko, 1992). A spillover effect of this impact is the establishment of intermediate malt industries. This led to quantum increase of sorghum malt and sorghum malt syrup production by beverage industries producing malt drinks (maltina, malta and Amstel) by major breweries and beverage companies in Nigeria (e.g. Cadburry Ltd., Lagos). Another spillover impact of breeding and selection of varieties suitable for brewing malt is the use of sorghum malt in composite flour with wheat and maize, as weaning foods (Murty *et al* 1997).

The large-scale demand for the variety SK 5912 encouraged sorghum researchers to intensify the efforts on the identification/development of varieties suitable for brewing malt and lager beer. An effort in this direction led to selection of another white-grain sorghum variety ICSV 400 by Nigerian and ICRISAT scientists (Murty *et al*, 1997).

Intsormil

The International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program (CRSP, pronounced "crisp") located at the University of Nebraska, began in 1979 and includes the participation of seven U.S. universities (University of Illinois, Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University) and the USDA/ARS, as well as research institutions in the U.S. and collaborating countries. The INTSORMIL CRSP, or simply INTSORMIL, is a research organization focused on education, mentoring, and collaboration with host country scientists in developing new technologies to improve sorghum and pearl millet production and utilization worldwide. The results of the research are of benefit to both the United States and collaborating countries.

INTSORMIL research is based on long-term, scientist-to-scientist collaboration to remove constraints to the production and utilization of sorghum and pearl millet. This research involves the development and exchange of data, techniques, germplasm, and information between the United States and collaborating countries, to the benefit of producers, processors and consumers of sorghum and pearl millet worldwide. INTSORMIL plant breeders work with agronomists, plant pathologists and entomologists to select varieties of sorghum and pearl millet which are resistant to pests such as parasitic weeds, fungi, bacteria, and insects. INTSORMIL food scientists work with plant breeders and agricultural economists to identify and develop lines of sorghum and pearl millet with improved characteristics for milling, food products, and livestock feed. INTSORMIL agricultural economists do research on the economic aspects, including economic impact, of agricultural research on the production and utilization of sorghum and pearl millet

The plant breeders of the INTSORMIL have been instrumental in introducing germplasm (genetic material) from many foreign countries into U.S. sorghum and pearl millet lines, improving the resistance of these U.S. crops to many plant diseases. Drought tolerance and disease tolerance bred into U.S. lines of sorghum developed by INTSORMIL researchers have been incorporated into lines of these crops in Africa and Latin America, improving crop production and fighting hunger in those areas.

Researchers of the Sorghum/Millet (INTSORMIL) collaborative Research Support Program (CRSP) have developed a rapid non-destructive bioassay for assessing *Striga* resistance, and new genes found to have stable *Striga* resistance are being bred into improved sorghum varieties. More than nine *Striga*-resistant varieties of sorghum have been tested on farms throughout the African continent, and multiplication of well-adapted varieties is in progress. Using plant breeding and genetic research, INTSORMIL researchers are helping increase sorghum production in arid, *Striga*-affected areas, resulting in alleviation of hunger in Africa. Part of the INTSORMIL utilization research has centered on the relatively low protein digestibility of sorghum grain. Sorghum protein makes up about 12% of grain weight and about 70% of the protein is encapsulated in hard-to-digest spherical assemblies called protein bodies.

A new discovery from INTSORMIL funded research at Purdue University is a sorghum grain type with high protein digestibility. In the accompanying figure, high magnification pictures taken with a transmission electron microscope are shown of normal protein bodies on the left (A) and highly digestible protein bodies on the right (B). The dramatic difference in structure accounts for the improvement in rate of digestion in the highly digestible types of sorghum. Researchers are exploring ways to use this sorghum for human food and animal feed. More easily digestible sorghum is expected to improve human nutrition, particularly in Africa and India, and has the potential to improve the nutrition of livestock, both in the U.S. and elsewhere.

Digestibility affects the value of sorghum as forage for livestock. The brown midrib (BMR) trait in some lines of sorghum developed by INTSORMIL researchers provides greater digestibility than normal forage sorghums. The pictures above and on the left show BMR sorghum × sudangrass hybrid forage to be preferred by grazing cattle in a free-choice test. Six rows of a conventional type sorghum × sudangrass hybrid (the number one pedigree sold all over the world) were alternated with six rows of BMR sorghum × sudangrass hybrid, and the cattle were allowed free choice grazing throughout the field.

BMR Sorghum-Sudan grass forage. The first commercial production of Nutri+Plus BMR sorghum × sudangrass forage hybrid, based on BMR sorghum mutants resulting from research by INTSORMIL scientists, was in 1996, and 1 million pounds were sold during 1997. This BMR hybrid has shown an 18.9% average increase in feed value, compared to normal sorghum x sudangrass hybrids and offers an additional $42.84/acre, based on feed value of $60.00/ton A total of 2.1 million pounds of seed of a highly digestible sorghum × sudangrass hybrid was produced and sold in 1999, and 4.1 million pounds of seed was being produced for sale in the year 2000. Improved nutritional quality of sorghum for livestock forage is another benefit of INTSORMIL research, which through commercialization is providing value to the farmer. Sales of only one company's BMR sorghum × sudangrass seed in the year 2000 are expected to provide additional value to farmers of $17,136,000.00. This value-added product is being well received by the U.S. dairy industry and is also being exported to Pakistan, Mexico and Canada, improving the U.S. balance of trade.

BMR Sorghum forage. In Nebraska, research has shown that BMR forage sorghum outperformed standard sorghum hybrids and may be equal to some corn hybrids when used to feed dairy cows. BMR sorghum silage was shown to be 10 percent more digestible than regular sorghum silage, resulting in more than 10 pounds of milk per day and a value, which could be as high as US$ 200, an acre more than regular sorghum. Palatability and feed intake of cows fed BMR silage were comparable to corn silage diets. Both regular and BMR sorghum average 25 to 30 tons per acre of silage.

Latin America

In Latin America, sorghum is produced on intermediate to large farms except in some inland valleys and eroded mountain slopes of Central America utilizing hybrids imported from USA and cultivars developed in the regions. In Guatemala, El Salvador, Honduras, Nicaragua, and Haiti, a large part of the production is on small subsistence holdings often less than one ha size where farmers use photoperiod-sensitive landraces intercropped with maize and beans using traditional production practices.

The damages due to downy mildew, anthracnose, grain mold, stem borer and midge among the biotic stresses and soil acidity and alkalinity, drought and cold temperature among the abiotic stresses are the major yield constraints apart from the lack of early-maturing, tropically adapted cultivars with high yield potential and tolerance to major stresses in the region.

Although the majority of the countries in the region have well-developed agricultural research institutions, the sorghum component is weak in many of them because of poor operational budgets and trained human resources. ICRISAT initiated the Latin America and Caribbean Program in 1976 by stationing its staff at International Wheat and Maize Improvement Center (CIMMYT), Mexico. The program was aimed to develop early, dwarf and bold grain varieties for fertile soils in both the highlands and lowlands of Central America. The program was later transformed as Latin American Sorghum Improvement Program (LASIP) in 1990 and led by Varthan Guiragosian and Cropmton Paul, a cereal breeder. LASIP had a comparative advantage in the development of tropically adapted improved germplasm resistant/tolerant to major production constraints food-grade cultivars in Latin America. Several varieties were released and adopted based on ICRISAT-bred improved grermplasm. Due to funding Constraints, LASIP was discontinued in 1993. However, considering the interest shown by Latin American NARS, a program for improving sorghum for acid soil tolerance was initiated in 1996 with funding support from Inter American Development Bank (IADB).

The acid and infertile Oxisol areas in Tropical America are dominated by Savanna system in the *Llanos* of Colombia and Venezuela, and the Cerrados of Brazil (Gourley 1991), which traditionally used for livestock grazing. Sorghum is considered to have potential to contribute to sustainable agro-pastoral systems. The INTSORMIL program identified 20 acid soil tolerant lines 1980s (Gourley 1991), but they were susceptible to leaf diseases. At its centers in India and Africa, ICRISAT has developed diverse sets of high-yielding sorghum breeding lines useful as base materials for testing in acid soils of Latin America. Since 1996, ICRISAT, International Center for Tropical Agricultural (CIAT) and the national programs of Brazil, Colombia, Honduras and Venezuela have jointly implemented an IADB-funded project on " A research and network strategy for sustainable sorghum production systems for Latin America". The major objective of this project include; (1) to assemble, multiply and evaluate grain and forage sorghum breeding lines for tolerance to acid soils and resistance to foliar diseases, (2) to develop a research network of scientists working on this crop in the region and train them in sorghum research, and (3) to test the most promising genotypes in the target production systems.

A diverse set of 378 pairs of grain sorghum A-/B-lines, 784 grain sorghum R-lines/varieties and 94 forage sorghum lines were introduced into Colombia from ICRISAT-Patancheru. In addition to these, male sterility inducing gene (ms_3)-based two-grain sorghum populations (ICSP LG-Large grain and ICSP B-maintainer) and one forage sorghum population (ICSP HT-high tillering) developed at ICRISAT were introduced. These introductions were tested empirically for grain and forage under acid soil conditions and selected fifteen grain sorghum A-/B-lines for high yield, and resistant to leaf diseases and tolerant to acid soils and twenty-one R-lines (on A_1 cytoplasm) for high yield under acid soils (Reddy *et al* 2004a). Besides these, four forage lines (IS 31496, IS 13868, ICSR 93024-1 and ICSR 93024-2) were selected for tolerance to acid soils.

In back-up breeding program, ICSP LG-large grain and ICSP B-maintainer populations were merged and selected alternatively at CIAT farm under neutral Ph, and at Matazul under acid soil conditions. Some of the selections (male fertiles) were advanced through pedigree breeding. Several promising progenies were also selected from the segregating materials of the specific crosses made among the lines selected for acid-soil tolerance and less susceptible to foliar diseases.

Nearly 200 hybrids involving selected A- and R-lines and INTSORMIL R-lines were evaluated at Matazul (60% Al^{3+} and 4.6% organic matter). These hybrids produced more than 5 t ha^{-1} grain yield while the Al^{3+} tolerant check Real 60 yielded 4 t ha^{-1}. Some of the outstanding hybrids include; ICSA 38 x REAL 60, ICSA 73 x ICSR 110, ICSA 89002 x REAL 60 and SPMD-A 94045 x A 2267-2. These are less susceptible to leaf diseases, greener at maturity, and also taller than the check Real 60 (Reddy *et al.* 2004c).

Impacts on Indian sorghum research and productivity

A major portion of the world collection consists of tall, photosensitive tropical landraces. These, as such, are of limited value in crop improvement programs. To augment the use of tropical germplasm and to broaden the genetic base, the US scientists began a tropical conversion program using the long-day rainy season and the short-day post-rainy season germplasm at Puerto Rica Centre. At ICRISAT, several tall, late flowering *zera zera* (from Ethiopia-Sudan border) *Kaura* and *Guineense* (from Nigeria) landraces has been converted into short and early flowering lines.

Germplasm introduction

A total of 22,701 exotic germplasm accessions have been introduced into India from different countries. The major contribution is from the USA, Cameroon, Ethiopia, Zimbabwe, Sudan, Uganda and Nigeria. The core collection constituted at ICRISAT consisting of 3,475 accessions (approximately 10% of total collection), which represents the genetic spectrum of total collection at ICRISAT (Prasada Rao *et al.* 1995). The core collection is expected to enhance the utilization of genetic resources by the Indian national sorghum scientists.

Germplasm evaluation

Indian sorghum germplasm has been evaluated at International Crop Research Institute for Semi Arid Tropics (ICRISAT), Patancheru for various agronomic, resistance (biotic and abiotic) and grain quality-evident traits. Among the insect-pests, the most intensive screening was carried out for resistance to shoot fly and stem borer. The resistant sources identified are predominantly of India origin, and a few are from Ethiopia, Nigeria, Sudan and the USA. The sources that showed stable resistance to stem borer and shoot fly are IS 1044, IS 1054 (M35-1), IS 1151, IS 1055 (BP53), IS 1119, IS 2195, IS 4664, IS 5469, IS 5613, IS 8315, IS1082, IS 2205, IS 12308, IS 13100 and IS 18554, and IS 1594, IS 4261, IS 4825, IS 4881, and IS 4923, respectively).

Utilization of germplasm

Usable sources of cytoplasmic-nuclear male sterility (CMS) were developed in the USA in 1950s by incorporating gene from race *kafir* into *milo* cytoplasm (Stephens and Holland 1954). Initially, the CMS lines and other germplasm lines were introduced from the USA and later from Africa, and temperate × temperate and temperate × tropical crosses, particularly the former, were developed and tested. Pedigree selection from segregating lines derived from these crosses resulted in the development and release of, three hybrids, namely, CSH 1, CSH 2 and CSH 3 during 1962-69. Of these, CSH 1 involved CMS CK 60 (introduced from USA) as female parent, which had high yield potential and responsive to improved management practices as compared to old cultivars with adaptation to light soils and low rainfall areas. The introduction of CSH 1 during 1960s resulted in quantum jump in productivity and production.

During next decade (1970-1979), three hybrids, CSH 4, CSH 5 and CSH 6 were developed and released. Of these, CSH 4 was dual-purpose hybrid with high grain fodder yield potential. The seed parent of this hybrid, 1036A, was developed from a cross of CK 60B and PJ 8K (a local variety from Maharashtra). While the hybrid CSH 5 (MS 2077A and CS 3541) had substantial yield improvement and resistance to grain moulds and leafy diseases as compared to CSH 1, CSH 6 derived from the cross between 2219A (early CMS line), and CS 3541 R (converted version of photoperiod-sensitive Ethiopian line IS 3541), became very popular for inter-intercropping in pigeon pea due to its plant type and earliness. CMS 2077, female parent of CSH 5 (MS 2077A and CS 3541) was developed from IS 2046, a germplasm introduced from Senegal.

In general, grain yield was markedly enhanced by utilization of exotic breeding material in hybrid program. However, the increased susceptibility of hybrids to major diseases and insect-pests and inferior grain quality compared to that of local cultivars resulted in poor acceptance of hybrids by the farmers. To overcome these constraints, CMS and restorer (R-) lines were developed from derivatives of temperate × tropical crosses. Further increase in grain yield was achieved during 1980-1989 by the development of CSH 9, CSH 10 and CSH 11, all based on new seed parent, CMS 296. CMS 296 was a very good combiner and was the derivative of cross between Karad local (Indian germplasm) and IS 3922 (American line). While CMS 296 was widely used seed parent, CSH 9 became a widely adapted hybrid.

During 1990s, a few other CMS 296-based hybrids were developed and tested. However, none of these were significantly superior to CSH 9 for grain yield. Nevertheless, release of the hybrids, CSH 13 and CSH 14 provided useful diversification for early maturity and fodder yield. CSH 13 had very high fodder yield potential. The male parent of this hybrid (CSH 13), RS 29 was developed from the cross between SC 108 (an American elite line) and SPV 126 (a tall mutant of CS 3541). CSH 14 was early with grain yield potential at par with CSH 9. However, a need for diversification of CMS parent was felt in view of stagnating yield potential and seed production problems. A high yielding hybrid CSH 16 was developed using new parental lines (CMS 27 and C43 R). This hybrid also showed improvement in grain mould tolerance as a result of incorporation of the Ethiopian germplasm IS 23549 content in its R parent. The CMS parent was developed from multiple crosses involving IS 3687, IS 3922 and 2219B.

Simultaneously with hybrid breeding, improvement of open-pollinated varieties was undertaken. First variety, CSV 1 is a direct introduction (IS 3924) from the USA. CSV 2 and CSV 3 were developed from temperate × tropical crosses. CS 3541, the restorer parent of three popular hybrids (CSH 5, CSH 6, CSH 9), also became popular as a variety CSV 4. It is a converted line of an African germplasm line IS 3541. CSV 5 was developed from Indian local Aispuri and US line IS 3687 and have shown *Striga* resistance. CSV 11which became popular for high fodder yield, was developed from a cross of American elite variety (SC108-3) with Indian elite variety (CS 3541).

SPV 462 which became very popular, was developed from multiple cross involving IS 2947 and IS 3687 introduced from the USA and IS 1151 and BP 53, locals from Maharashtra and Gujarat in India, respectively. SPV 462 has high grain and fodder yield and good grain quality. CSV 13 is another variety developed from multiple cross of exotic and local germplasm. Variety CSV 5, developed from SPV 462 and CSV 13, is dual-purpose variety having as high grain yield as that of CSH 5 and fodder yield as that of CSH 10. The present day varieties and the restorer parents have moderate level of resistance to diseases and insect-pests, but the CMS lines are highly susceptible.

Impacts from ICRISAT – Indian NARS partnership programs

Screening germplasm for forage traits. Mathur *et al.,* (1991, 1992) have published two catalogues on evaluation of forage sorghum germplasm maintained at ICRISAT gene bank based on the studies made under NBPGR-ICRISAT collaboration program. Information on nearly 1500 collections from 37 countries for 26 traits was reported in one catalogue. The other catalogue contains information on 3,943 collections from different states of India evaluated for 19 characters. In both cases, the evaluation was done during rainy season at three locations (Delhi, Jhansi and Akola). The details of books/catalogues/web sites/published on Indian germplasm are available from the ICRISAT *websites-http://www.icrisat.org; http://www.singer.cgiar.org;* and *http://www.nrcsorghum.res.in.*

Screening for production constraints. Based on laboratory and field evaluation, several germplasm sources for *Striga* resistance were identified at ICRISAT and some of them that have been used in breeding program are: IS 18331 (N 13), IS 8744 (Framida), IS 2221, IS 4202, IS 5106, IS 7471, IS 9830, IS 9951, 555, 168, SPV 221 and SPV 103. Tall, stay green, high tillering and stem borer resistant CMS lines (ICSA-/B- 671 to ICSA-/B- 674) have proved useful for developing forage sorghum hybrids in combination with Sudan grass and sweet sorghum pollinators. The germplasm lines used for forage sorghum improvement were: IS 1044 IS 12308, IS 13200, IS1 18577, IS 18578 and IS 18580. Further, IS 3247 has been utilized for developing low-HCN forage sorghums.

Exchange of breeding material. Based on specific requests, seed samples of hybrid parents, varieties, and populations were supplied to NARS partners in India. A large number of seed samples representing various categories of breeding materials (A- and B-lines, restorers, varieties and others) have been supplied to several public (62,161 samples) and private sector (51,428 samples) scientists, in India during 1986 to 2003. It is important to note that multi-national private seed companies share their ICRISAT-procured breeding materials among their various branches and hence there is much wider dissemination of the material across the globe. The use of these improved breeding materials had multiplier effect, with public and private research organizations further developing 54 finished products (hybrids), specifically for targeted production areas testifying the utility and impact of ICRISAT-bred hybrid parents. Further, ICRISAT's international testing program helped in testing some of the cultivars developed by Indian program scientists, and some of these cultivars have performed well in several parts of Asia (e.g. Thailand) and Africa (e.g. Ethiopia). For example, the hybrid, CSH 9 performed well both in Africa and Asia, and the variety, GPR 148 is preferred by farmers in Ethiopia for its earliness and bold seed.

Participation in AICSIP trials. All India Coordinated Sorghum Improvement Project (AICSIP) has been conducting replicated yield trials at various locations representing different agro-climatic zones with a view to identify and release improved sorghum varieties and hybrids for commercial cultivation in more than one state. ICRISAT-bred varieties/hybrids and those derived from ICRISAT breeding material by national breeders have been tested in AICSIP trials since 1979-80. So far, 68 varieties and 74 hybrids were entered into advanced trials directly by ICRISAT (up to 1992/93 and thereafter, direct contribution was stopped) and 167 varieties and 74 hybrids developed from ICRISAT materials were entered into advanced trials by national program breeders (Reddy *et al.* 2004 b).

ICRISAT-ICAR partnership Projects. The increased need for prioritization and focused research led to the development of formal partnerships projects between ICRISAT and ICAR. Currently, there are two formal partnership projects- (i). Diversification of seed parents and restorers with adaptation to rainy and postrainy seasons, and (ii). Mechanisms and molecular markers for resistance to grain mold, shoot fly and stem borer. In these partnership projects, for example, some of the materials (PKV 801, KR 194, C 43, PMS 7B) developed by Indian programs are being used to develop mapping populations to identify molecular markers for resistance to grain mold.

ICRISAT also supplies advanced lines to NRCS towards trait-based nurseries and NRCS organizes and distribute them along with their own materials to the selected AICSIP centers. For example, NRCS organizes the evaluation of Sorghum Grain Mold Variability Nursery (SGMVN) and Sorghum Grain Mold Resistance Stability Nursery (SGMRSN) at AICSIP centers at Akola, Parbhani, Palem, Surat and Patancheru to identify major pathogenic fungi and variability among them in different environments. The purpose is to evaluate the performance of the lines developed from grain mold resistance (GMR) breeding at ICRISAT and in Indian national programs at diverse grain mold pressure locations in different sorghum growing zones in India and to identify advanced lines with GMR across locations for their utilization in GMR breeding. Similarly, NRCS organizes the evaluation of shoot pests and sugarcane aphid resistance nurseries at AICSIP locations. As a long-term and balanced breeding strategy to develop the much needed broad genetic-based improved pure-line varieties as well as hybrid parents for sustained productivity as well as for developing cultivars that cater to the diverse and ever-changing consumer preferences and tastes, population improvement programs were revived in partnership with NRCS. A total of 24 ICRISAT-developed genetic male sterility-based populations that include ICSP LG (*kharif*), ICSP LG (*rabi*), ICSP B (*kharif*), ICSP B (*rabi*), Good grain, West African early, Indian Diallel, Indian Synthetic, Grain mold, ICST HT, Fast Lane R, Fast Lane B, US/R, US/B, Serene elite, Tropical conversion, RS/R, RS/B, ICSP1B/R MFR, ICSP2B/R MFR, ICSP early dual purpose, head pest, shoot pest and photo-insensitive populations are being maintained at ICRISAT in collaboration with NRCS.

Breeding Products. Initially, both ICRISAT and Indian NARS programs placed greater emphasis on grain yield and good grain types, and the partnership was on informal basis. ICRISAT extensively made use of several high yielding good grain types from the Indian programs. For example, CS 3541, 555, UchV$_2$, GPR 148, GPR 165, GPR 168, SPV 105, M 35-1, and CSV 1(Swarna) in varietal/restorer programs, and 2077B and 296B in seed parents' development program were used as parents for developing varieties or hybrid parents at ICRISAT for regional and/or global use. As the program emphasis changed from breeding for high yielding to improving for resistance to various biotic (grain molds, shoot fly, stem borer, midge, anthracnose, *Striga*, etc.) and aboitic (drought) stresses, which are also relevant to India, ICRISAT strengthened the sorghum improvement program by initiating several projects on breeding for the resistance traits. This approach at ICRISAT generated diversified arrays of breeding materials improved for resistance to insect pests, diseases, *Striga* and drought. This enabled the Indian program to take advantage of the breeding materials and resistant sources improved in joint Indian NARS-ICRISAT partnership programs. For example, the improved resistant lines - ICSV 745 (released as DSV 3 by Karnataka State), ICSV 735 and ICSV 197 (midge resistant); ICSV 705 and ICSV 708 (shoot fly resistant); ICSV 700 and ICSV 112 and ICSV 702 (stem borer resistant), Malisor 84-7 (head bug resistant); and ICSR 94015, ICSV 95019, ICSV 96101 (grain mold resistant); SP 36257 (downy mildew resistant); A 2267-2 (multiple leaf diseases resistant); and ICSR 89014 (ergot resistant) were utilized by various programs in India in their resistance breeding programs. The *Striga* resistant varieties, SAR 1 (released as ICSV 145 for cultivation in Andhra Pradesh, Tamil Nadu, Karnataka by Indian Government) and SAR 19 may be cited as the shining examples of successful partnerships between ICRISAT and ICAR programs.

The ICRISAT-bred varieties, ICSV 1, ICSV 112, SDS 2650, S 34, S 35, GD 57904, ICSV 126, GD 57903 and GD 11183 were utilized in varietal breeding program; and ICRISAT-bred restorers and seed parents, MR 750, MR 830, ICSV 89058, ICSV 194, ICSV LM 865B, ICSR 89058, ICSB 101, ICSB 56, ICSB 73, ICSB 70, SPL 90B, SPMD 8643A (midge resistant); SPSFR 94010A, SPSFR 96069A, SPSFR 8643A and SPSFR 86065A (shoot fly resistant) were utilized in the development of hybrids in Indian Programs. Also, some of the seed parents such as ICSA 88020 were utilized in forage hybrids development at Hisar. The varieties, ICSV 1(CSV 11) and ICSV 112 (CSV 13) and the hybrid CSH 11 released for commercial cultivation are popular among Indian farmers.

Apart from these, several germplasm accessions/ selections have been released as superior varieties through partnership research in India. The notable among these are NTJ 2 and Parbhani Moti (SPV 1411) for postrainy season cultivation. The Parbhani Moti with its large and attractive grains compared to that of M 35-1 (the popular postrainy season variety) received greater attention by large number of farmers at farmers' day held at Dharwad jointly by University of Agricultural Sciences (UAS), Dharwad and ICRISAT during October 2004. The demand for its seeds was overwhelming and ICRISAT readily responded and supplied the seeds to about 200 representative farmers in Karnataka. Thus, the partnership research efforts by multi-disciplinary team of scientists at ICRISAT and in NARS programs have led to the release of 22 improved cultivars using ICRISAT-bred material in India.

Of late, use of sweet sorghum for ethanol production is gaining increased importance following the Government of India's policy to blend petrol and diesel with 5% ethanol in first phase and 10% in second phase. Already, research on sweet sorghum, is underway at NRCS and a few state agricultural universities. As a result of these efforts, SSV 84, the first sweet sorghum variety was developed and released by national program during 1992/93. Recently a sweet sorghum hybrid NSSH 104 has been developed at NRCS by using SSV 84 as male parent and ICRISAT-bred ICSA 38 as seed parent and being recommended for release foe commercial cultivation as special purpose sorghum.

Future perspectives

In India, to stabilize the productivity, research thrust needs to be placed on managing major production constraints such as shoot fly and grain mold in rainy season and shoot fly and terminal drought in postrainy season. The breeding research on improvement of postrainy sorghum for grain quality-evident traits such as bold and lustrous pearly white grains and semi-corneous endosperm suitable for chapatti/roti making needs priority. Male-fertility restoration in hybrids under cold temperature experienced in postrainy seasons need to be addressed by selecting the male-sterile lines and pollinator under cold temperatures. The landrace pollinator-based hybrids have the required traits for postrainy season adaptation with farmers-preferred grain quality traits, except that they lacked resistance to shoot fly and had intermediate grain luster. It is therefore expected that if improved male sterile lines with resistance to shoot fly and grain luster become available, they can contribute to enhanced acceptability of hybrids by farmers for postrainy season cultivation. Product diversification such as rainy season-produced grains for use in poultry feed and sweet stalks for use in ethanol production needs greater priority, while still focusing on food-quality grain especially for postrainy season adaptation in India. Simultaneous efforts to link sorghum producers with poultry feed and products manufacturers and distilleries in a coalition approach would ensure sustainable and increased demand for these alternative products.

In China, grain yield for livestock feed and sweet sorghum for silage production needs greater focus. In Australia, grain yield and resistance to midge and terminal drought stress should receive continued focus. In Africa, improvement of grain yield and defensive traits such as resistance to stem borer among the insect pests, anthracnose, ergot and leaf blight among the diseases and witch weed *Striga* should be the major breeding objectives. In regions where there is adequate seed production expertise support such as Nigeria, Zimbabwe and South Africa, hybrid breeding needs to be given greater emphasis along with varietal improvement. Because of large areas with soil acidity toxicities in Latin America, breeding programs should be designed for developing cultivars resistant to these problematic soils focusing on grain yield and green fodder yield for livestock feed and fodder needs. Considering vast areas affected by soil salinity in Western Asia and Northern Africa (WANA) countries, the development of varieties tolerant to soil salinity would not only ensure sustainable and eco-friendly management of such problematic soils, but also help enhance sorghum production.

So far *caudatum*, *kafir*, and *durra* types have been extensively exploited in sorghum improvement programs all over the globe and yielded desired results. However, *guinea* type germplasm resources needs to be tapped to capture further diversity into the varieties and hybrids for sustainable production systems. The variability in the cultivated sorghums (*S. bicolor*) particularly *dochna* types that originated in Myanmar and other higher biomass types with sweet stalk (also brown midrib) and foliar disease resistance needs to be exploited for the improvement of forage and sweet sorghums.

Several countries are in the process of enacting (a few countries have already enacted) legislations for protection of plant varieties (PPV), there is an urgent need for characterization and building database of extant and new varieties/hybrids for protection under these PPV acts to prevent undue exploitation by claiming monopoly rights over production and marketing of these hybrids.

The use of biotechnological tools such as DNA markers and transgenic technology for sorghum improvement have not yielded desired results so far. Therefore, the conventional breeding approaches should continue to receive adequate priority for the improvement of targeted traits, while mastering the DNA marker and transgenic technologies for the improvement of traits such as resistance to grain mold and shoot fly/stem borer, which hitherto remained elusive/intractable through conventional approach.

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