CHAPTER

4

History of Sorghum Improvement

P. Sanjana Reddy[1], Belum V.S. Reddy[2]

[1]ICAR-Indian Institute of Millets Research, Hyderabad, India; [2]International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India

1. INTRODUCTION

Sorghum, *Sorghum bicolor* (L.) (Moench), is a staple food for millions of the poorest and most food insecure people in the semiarid tropics (SAT) of Africa and Asia. Being a C4 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 crops. These are also the areas subjected to frequent droughts. In many of these agroecologies, sorghum is truly a dual-purpose crop; both grain and stover are highly valued products. In Africa, sorghum is predominantly grown for food purposes although its fodder is used for thatching in Western Africa and animal feed in some parts of Eastern Africa. In the United States, Australia, China, etc., it is grown for livestock feed and animal fodder purposes. The fodder is an important cattle feed. Thus, sorghum is the key for the sustenance of human and livestock populations in SAT areas of the world.

The yield and quality of sorghum 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 West and Central Africa [WCA]) among pests; grain mold (all regions) and anthracnose (WCA and Northern India) among diseases and *Striga* (all regions in Africa); 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 loss to the tune of US$ 3032 million (www.agbiotechnet.com/pdfs/0851995640). The world sorghum productivity is dismally low (0.7 t/ha) because of these production constraints and the use of traditional cultivars (low-yielding) and traditional production practices.

Sorghum has not received wide attention in the scientific community especially in Africa and Asia in the past because of the fact that it is considered as a coarse grain and much of its production is at subsistence level. Increased pressures of population growth on food supplies, enhanced utilization of animal products, and depleting fossil fuel reserves have driven attention toward utilizing the full potential of this crop as food, feed, fodder, and fuel. Genetic improvement is the cost-effective means of enhancing sorghum productivity for different end uses. Depending on the production environment, constraints, and end-product utilization, the objectives of sorghum improvement programs have been different in different parts of the world. The purpose of this article is to review briefly the sorghum improvement research and its outcome in different parts of the world.

2. SORGHUM IMPROVEMENT IN INDIA

In India, unlike in other countries, sorghum is cultivated in two seasons—*kharif* (rainy) season (June/July–September/October) as a rain-fed crop and *rabi* (post-rainy) season (October–December/January) under residual soil moisture/limited irrigated conditions. Sorghum or *jowar* (*S. bicolor*) is grown for food (from grain) and straw (animal fodder) in the arid and semiarid regions of India (Maharashtra, Andhra Pradesh, Karnataka, and Tamilnadu) and in areas receiving as little as 400–500 mm rainfall per year (Pray and Nagarajan, 2009). As production

Breeding Sorghum for Diverse End Uses
https://doi.org/10.1016/B978-0-08-101879-8.00004-8

environment and production constraints are different, cultivar options are quite different for two seasons (Rana et al., 1997). In 1965−66, the area shared between *kharif* and *rabi* in the total cropped area was 62.0% and 38.0%, respectively. But these proportions have changed to 37% and 63%, respectively, by 2014−15 (Charyulu et al., 2016). This is mainly because of poor grain quality of *kharif* sorghum due to molded grains and thereby the area has been diverted to other crops (Charyulu et al., 2013). However, the average productivity under *rabi* sorghum was low because of the cultivation under residual moisture conditions, nonavailability of high-yielding cultivars, partial or less use of chemical fertilizers, high seed rate and narrow row spacing, etc. (Sanjana Reddy and Patil, 2015). However, the grain quality is much superior in *rabi* season as compared with *kharif* season. Most of the *kharif* production goes for industrial and poultry uses, whereas majority of the *rabi* production goes for human consumption.

2.1 Rainy Season

Indian public sector agricultural research agencies have been breeding improved sorghum varieties since the early part of the 20th century with the involvement of a number of agriculture research centers. In 1962, Indian Council of Agricultural Research (ICAR) launched Accelerated Sorghum and Millet Improvement Program with an objective to initiate hybrid breeding. Later in 1969, the All India Coordinated Research Project on Sorghum (AICRP-Sorghum) was launched with 18 centers spread over 13 state agricultural universities (SAUs) covering 11 sorghum-growing states. Indian Institute of Millets Research (IIMR), formerly Directorate of Sorghum Research and National Research Center for Sorghum (NRCS), was established in 1987 by ICAR to strengthen the basic and strategic research activities encompassing sorghum productivity, sustainability of production, product utilization, and profitability (source: http://millets.res.in/about-institute.php). IIMR is the nodal agency in the country dealing with all aspects of sorghum research and development including coordination and consultancy. IIMR works closely with many other sister institutions of ICAR, SAUs, and national and international agencies such as International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and other institutions both in the public and private sector. IIMR is also mandated with organizing and coordinating sorghum research at All India Level through AICRP on sorghum. Initially, development of pure-line varieties using specific adaptation approach was given importance. 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 the ICAR, with Rockefeller Foundation assistance, the first sorghum hybrid, Coordinated Sorghum Hybrid (CSH1), bred in India was officially released for commercial cultivation in 1964 (Rao, 1982). With its early maturity, bold grain, and short stature, it was well adapted in light soils and low-rainfall areas. The formation of ICRISAT established in Hyderabad, Telangana, in 1972 further stimulated research on sorghum. A major driver for the spurt in private sector growth was the strong public sector research support program on sorghum. Later, the release of most popular hybrids (CSH5 and CSH6 in the mid-1970s and CSH9 in the early 1980s) augmented the spread of sorghum hybrids and boosted productivity. Overall 31 hybrids have been released, some of them (7) with adaptability to post−rainy season, which caters to the need of grain for human consumption. The program released 25 varieties for rainy season and 10 for post−rainy season. The dual-purpose varieties CSV 15, CSV 20, CSV 23, and CSV 27 could realize good grain and fodder yields in farmer's fields. Apart from this, multicut forage sorghum hybrids CSH 20MF and CSH 24MF and forage sorghum varieties CSV 21F and CSV 30F were released.

Considering the potential of sweet sorghum juice as a feedstock for bioethanol production following the Indian Government's initiatives for the production and use of biofuels, considerable progress has been made in the development of sweet sorghum cultivars. The sweet sorghum varieties, CSV 19SS, CSV 24SS, and a hybrid CSH 22SS, have been released for commercial cultivation.

2.2 Post−rainy Season

Rapid progress has not been achieved in post−rainy sorghum improvement program unlike rainy sorghum improvement program. More than 80% of the post−rainy sorghum area is still dominated by two important cultivars: *Maldandi*, a local landrace, and M 35-1, a selection from *Maldandi* released in 1937 (Patil et al., 2014). The age old association and the consequent local preferences for the taste of the respective local varieties are the dominant reasons for their continued cultivation in spite of their erratic behavior and low yields (Rao and Murthy, 1972). Focussed breeding on *rabi* sorghum was initiated in the early seventies which over the years led to the release of several state and central release varieties. At the national level, the variety CSV 7R was released in 1974, CSV 8R in 1979, Swati in 1984, CSV 14R in 1992, Sel 3 in 1995, Phule Yashoda in 2000, CSV 18 in 2005, CSV 22 in 2007 and CSV 26 in 2012 and CSV 29 in 2013. The released post−rainy sorghum varieties, CSV 8R, CSV 14R, CSV 18 and Swati, were better received by the farmers. Several varieties were released at the state level (Patil et al., 2014).

Most of the post—rainy sorghum varieties are only of *Durra* type whereas rainy sorghum cultivars belonged to *Caudatum* and *Kafir* races (Reddy et al., 2003). The varieties such as CSV 7R, CSV 8R and CSV 14R were developed using selections from segregating populations derived from the crosses among Indian locals, M 35-1 and IS 2644 with American germplasm lines. Marginal improvement was achieved for grain yield over the most popular landrace variety M 35-1 until 2000. Most of these varieties could not become popular as they did not match shoot fly resistance level and grain quality of M 35-1. Although efforts were made to introgress farmer preferred traits such as bold, lustrous and semicorneous grain type and juicy stalks into the hybrids targeted for post—rainy season cultivation by crossing improved Indian landraces as pollinators with the established exotic and elite female parent, CK 60A (*milo* or A_1 cytoplasm), the resulting hybrids lacked "marked" heterosis, had threshing difficulties, and were too tall, a habit not amenable for increasing plant population per unit area. The hybrids, CSH 7R and CSH 8R developed from the improved parents and released in 1977, though had high heterosis, were not acceptable to farmers, for they lacked grain luster, resistance to shoot fly and lodging. Later CSH 12R released in 1986 also could not progress well as compared to the varieties and failed to make any impact in farmer's fields. However, study by Rana et al. (1997) have indicated appreciable levels of heterosis for grain yield and other agronomic traits. Greater yield heterosis was observed in derivative × tropical (African) varietal crosses due to diversity of genes (Rana et al., 1985). Rana and Murty (1978) have also reported that increase in number of seeds per panicle branch in short compact headed varieties (tropical) and increase in the panicle branches in the long panicle type (temperate) by introgression of genes from African germplasm result in yield heterosis. Large heterotic response for grain yield and harvest index were accompanied by stalk rot and shoot fly susceptibility (Rao, 1982). For increasing the grain yield within the limits of the available water supply, the choice of female parent for hybrid production should be made for both leaf area and photosynthetic rate and the selection of pollinators should be made for maximum seed number per panicle (Krieg, 1988).

The second phase of *rabi* sorghum breeding with emphasis on hybrid cultivars was initiated in the late eighties. During this period two hybrids, SPH 504 and SPH 677 were identified for central release as CSH-13R and CSH-15R. CSH-13R has significant yield superiority over M 35-1, but is highly vulnerable to shoot fly and low temperature and had inferior grain quality. CSH 15R based on a *rabi* MS line (104A) developed at Mohol Center had a marginal yield advantage over M 35-1. It was felt that *rabi* hybrids will have a tangible impact only when the parental lines have *rabi* adaptability and desired combining ability (Rao et al., 1986).

A mission mode project on development of hybrid crops under National Agricultural Technology Project funded by World Bank was in operation specifically to develop *rabi* sorghum hybrids at IIMR (then NRCS) and 7 AICSIP centers working on *rabi* sorghum at National level from 1999 to 2005 (Rana and Kaul, 2005). As a part of the project, more than 4900 new hybrids were developed and tested during 1998 to 2005 across seven centers. SPH 1010 bred at Akola center was released as CSH-19R in 2000. While CSH-15R was suitable for general cultivation, CSH-19R was ideal for favorable locations.

3. INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS EFFORTS IN SORGHUM IMPROVEMENT

ICRISAT was established in 1972 at Patancheru, Telangana, India, with sorghum as one of its five mandate crops. Improvement for yield potential and resistance to drought, *Striga*, grain mold, downy mildew, charcoal rot, shoot fly, stem borer, midge and head bug, and wide adaptability received major attention up to 1980. Genetic male sterility—facilitated populations and pure-line varieties were the target cultivars during the initial years. In resistance breeding programs, emphasis was given for developing and 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 the 1970s. During the 1980s, major emphasis was given to regional adaptation and breeding for resistance to biotic stresses (grain molds and insect pests) in white grain background. Breeding for resistance to drought, downy mildew, charcoal rot, and *Striga* was discontinued, whereas development and improvement of male-sterile lines for grain yield and food quality traits was initiated (Reddy et al., 2008).

Initially, several open-pollinated populations were introduced from the United States, West Africa, and East African programs and were reconstituted with selection. A total of 19 improvised trait-specific open-pollinated populations are being maintained at ICRISAT and IIMR, Hyderabad, India. Several of the hybrid seed parents derived from some of these populations are being extensively used for the development of high-yielding hybrids in China (Reddy et al., 2008).

Later on, several high-yielding good grain inbred lines and *zerazera* landraces (*caudatum*) were extensively involved in breeding at ICRISAT Asia Center (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 1980s many National Agricultural Research Systems (NARS) had enhanced crop improvement programs aimed at specific adaptation. Thus, the global sorghum improvement program reoriented itself to develop material suited for 12 productive systems in Asia, six in Western Africa, six in Eastern and Southern Africa, and five in Latin America. As a result of this reorientation, at IAC, strategic research on the development of screening techniques, breeding concepts and methods, and intermediate products for utilization in partnership with NARS programs was given emphasis during 1990–94. In addition, an extensive program of 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 were 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" as pollinators were examined for their fertility restoration ability under cool nights and for productivity in post–rainy season. Variability for restoration within the rabi landraces was quite significant indicating the possibility of selection for improved restoration and other traits for hybrid making (Reddy and Stenhouse, 1994). To address the issue of malnutrition prevalent in the poor section of the societies in Africa and Asia whose diets are sorghum-based, ICRISAT, and Patancheru-initiated work on biofortification with a set of 86 diverse sorghum lines involving parental lines of popular hybrids, varieties, yellow endosperm lines, germplasm lines, highdigestible protein lines, high lysine lines, and waxy lines were evaluated for grain Fe and Zn content (Reddy et al., 2008).

Significant genetic differences for grain Fe and Zn content and antinutritional factors (tannin and phytate content) and agronomic and grain traits were observed. While the grain Fe content ranged from 20.1 ppm (ICSR 93031) to 37.0 ppm (ICSB 472 and 296B) with an average of 28 ppm, grain Zn content ranged from 13.4 ppm (JJ 1041) to 30.5 ppm (IS 1199) with an average of 19 ppm. Nevertheless, it was evident that substantial genetic variability exists for grain Fe and Zn content and this variation did not appear to be significantly influenced by the environment as reflected from narrow differences between phenotypic co-efficient of variation (PCV) and genotypic co-efficient of variation (GCV) and high heritabilities (Reddy et al., 2005). The substantial variability coupled with higher heritability suggests that selection for high Fe and Zn and low tannin and phytate content is effective and hence offers better prospects of breeding Fe- and Zn-dense sorghum cultivars in an antinutritional factor background.

Sweet sorghum research has been given major emphasis at ICRISAT in the last 15 years, considering the importance of ethanol in reducing the pollution. New seed parents and restorer lines were developed for use in hybrid development. Significant heterosis was observed for juice yield and total sugars. Hence major emphasis was given for improving the seed parents with high stem sugars. Selection among the landraces resulted in restorers with high Brix and total stem sugars. The sweet sorghum–based ethanol technology has been successfully demonstrated by Rusni Distilleries, established near Hyderabad, India, in collaboration with ICRISAT's agribusiness incubator.

In collaboration with International Center for Biosaline Agriculture, Dubai, and Agriculture Research Station, Gangavathi, Karnataka, India, ICRISAT has identified 18 lines that are promising under saline conditions. Similarly, improved lines have been developed for fodder quality and quantity and aluminum (Al^{3+}) tolerance (Reddy et al., 2000). Efforts are underway to tag the QTLs associated with drought tolerance, grain mold resistance, and shoot fly resistance.

From 1995 onward, a partnership mode of conducting research to develop improved intermediate products 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. 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. At Patancheru center, ICRISAT is giving major emphasis to the development of hybrid parents for sweet stalk traits, micronutrient density, salinity tolerance, bold grain types, and multicut types (Reddy et al., 2012).

4. SORGHUM IMPROVEMENT IN CHINA

Sorghum has been cultivated in China for at least 40–50 centuries in the arid, semiarid, and water-logged regions. Although distribution is very wide, sorghum growing areas are concentrated in the northern and north-eastern parts of the country. Chinese sorghum belongs to a unique kaoliang group characterized by adaptation to the Chinese environments (Gao et al., 2010). Modern sorghum breeding in China began in the 1920s and has progressed through three stages: (1) collection, classification, and pedigree selection within the best local varieties; (2) cross breeding using crosses between local varieties or local × exotic for variety production; and (3) exploitation of heterosis through the development of single-cross hybrids from inbred parents (Yang, 1997). Heterosis breeding has been the main method of breeding since 1965 in China. 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.

Through a program of selecting the best introduced seed parents and then evaluating Chinese bred pollinators, hybrid breeding started in 1956 when cms line Tx 3197A and its maintainer Tx 3197B were introduced in China. Based on this source, Chinese academy of sciences and Chinese academy of agricultural sciences released Yiza and Yuanza series of hybrids in 1958. Although these hybrids had a yield advantage of 20%–60%, they were not planted in large areas because of excessive height and weak straw. Breeding short hybrid cultivars started in 1970s and the resultant hybrid Jinza 5 yielded 6 t/ha and widely accepted by farmers. By 1975, 50% of the total sorghum area was occupied with hybrids. In 1979, new male-sterile lines (Tx 622A, Tx 623A, and Tx 624A) were introduced from the United States. Thousands of lines were introduced from India (ICRISAT), United States, and Australia, and germplasm base was diversified (Gao et al., 2010). The increase in yield because of utilization of hybrids is estimated at 30%–40% with the remaining improvement being due to better cultivation conditions (Yang, 1997). Hybrids based on alternate cytoplasm were released anticipating cytoplasm related disease outbreak as in maize. In 1990s, hybrids based on A_2 cytoplasm—Jinza 12, Liaoza 10, Jiza 80, Jiza 83, and Siza 25—were released. The A_3 cytoplasm was used in the development of forage hybrids and the hybrid Jincao No. 1 was the first hybrid to be released in the world based on A3 cytoplasm (Gao et al., 2010).

Sorghums cultivated in China should be resistant to smut (*Sphacelotheca reiliana*), blotch (*Exserohilum turcicum*), anthracnose (*Colletotrichum* spp.), and purple blotch (*Cercospora* spp.) among diseases and European corn borer (*Ostrinia furnacalis*), aphid (*Melanaphis sacchari*), and army worm (*Mythimna seperata*) among pests.

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 (Yang, 1997). Chinese sorghums outperform the US adapted lines and hybrids under cold conditions at germination stage and early season sowing (Franks et al., 2006). Selection for rapid seedling emergence rates in water-limited areas was followed to develop cultivars resistant to drought at seedling stage. New male-sterile lines and restorers with resistance to drought are being developed using this method of selection (Yang, 1997).

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, Liaoning Academy of Agricultural Sciences (LAAS) (Yang, 1997). The most common haplotype was that found in Canada, United States, and United Kingdom (Li et al., 2014).

Sorghum head smut caused by the fungus *Sphacelotheca reiliana* is 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 two or three pairs and some minor genes (Zhen and Xiaoguang, 1993). Among 10,083 germplasm accessions screened, 39 showed immunity to race 2, while 3 accessions have shown resistance to race 3 (Yue and Yuxue, 1993). The race 4 has been identified using a set of differential sorghum lines. The new race is highly virulent on sorghum line A_2V4 and its hybrid, Jinza 12, which are known as resistant to all existing Chinese races of *S. reilianum*, including races 1, 2, and 3 (Zhang et al., 2011).

Breeding for quality: Chinese Kaoliangs 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. Nutritive composition of hybrid sorghum grain is poor and the traditional fragrance of original local varieties needs to be recovered in high-yielding background (Yang, 1997). The grain quality traits that were identified to be improved include increased protein content and digestibility, reduced tannins, maximizing carbohydrates for brewing, and higher amylopectin for Moutai and Luzhon flavors (Gao et al., 2010).

Because sorghum is the main raw material of compound feeds for livestock and poultry, breeding for feed quality has been one of the major objectives of sorghum breeding in China (Yuxue et al., 1992). Two types of forage cultivars are developed for silage and hay. Sweet sorghum and high biomass grain sorghum hybrids are used for silage and sorghum–sudangrass hybrids are used for hay making. Although several varieties were released, the research is still in its infancy. Incorporation of brown midrib trait is ongoing (Gao et al., 2010). The focus is on breeding for high biomass coupled with good nutritional value and low hydrocyanic acid content (Yang, 1997).

In China, sweet sorghum is primarily used for silage preparation. With the introduction of improved sweet sorghum varieties such as Rio, Roma, Ramada, and Wray from several countries, a systematic sweet sorghum breeding program was initiated in LAAS 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. More than 10 research institutions and industries are engaged in sweet sorghum research. According to government regulations, sweet sorghum for energy should be cultivated in arid regions and saline/alkaline soils. Several promising sweet sorghum cultivars currently grown are M-81E, Lvneng No. 1, 2, 3, Nengsi No. 1, among varieties, Chuntian No. 2, Liaotian No. 1, 2, and Nengsiza No. 1, among hybrids. The A_3 cytoplasm is proposed to produce sweet sorghum without grains. A_3 cytoplasm−based male-sterile lines with high sugar content are identified as an immediate research need (Zhao et al., 2007). The famous Chinese liquors have sorghum as the main feedstock (Lu et al., 2009). The sorghum grain that is being produced just balances the requirement of liquor industry. Although varieties specifically suited to the industry have been developed (Wang et al., 2006; Zhao et al., 2007; Ding and Zhao, 2008), adoption was very low because of lack of association between breeders and liquor manufacturers.

5. SORGHUM IMPROVEMENT IN AFRICA

The crop is grown as a rain-fed crop in diverse environments across tropical and subtropical agroecologies in Africa; from extreme lowland arid and semiarid zones (of Libya, Sahel of West Africa, and Botswana) to the subhumid and humid lowlands (of southern Guinea Savanna of West Africa) and the mid-highlands (of Great Lakes Zone of East Africa). The semiarid and subhumid highlands are typified by highlands of Ethiopia, Eastern and Central Africa, and Lesotho (where sorghums are cultivated around Mokhotbug at an altitude of 2400 m). Sorghum breeding began in the late 1930s replacing traditional farmer selection activities. This involved the identification, selection, and release of better landraces as "improved local selections." At the same time, exotic germplasm lines were introduced, adapted, and tested. Between 1930 and 1950, a multilateral collaboration in Eastern Africa involving Kenya, Uganda, and Tanzania began (Doggett, 1988). Between 1948 and 1960, useful cultivars, local varieties, and exotic germplasm lines were used in hybridization program and pedigree and bulk breeding programs were initiated. Population development and its improvement through recurrent selection were possible with the availability of genetic male sterility (ms_3 has been extensively used). Greater prominence was given to wide adaptation and increased productivity. In the late 1970s, a regional approach to sorghum breeding was initiated as a result of such collaborations. The first of such regional approaches to sorghum breeding was the Organization of African Unity/Scientific Technical and Research Commission Joint Project 31 on Semi-Arid Food Grain Research and Development in Africa (SAFGRAD), which was initiated in 1976. Subsequently, regional sorghum breeding approach extended at different periods in three regions—East and Southern Africa, South African Development Community (SADC), and WCA. Specific regional breeding programs were set up with the objective of tackling different production constraints specific to different regions.

5.1 Eastern and Southern 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 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 2 decades (1958−78). This phase resulted in the development of three varieties, two of which—SEREDO (Serena × CK60) with brown grains and Lulu-D (SB77 × Seredo) with white grains—are still popular in Kenya, Uganda, and Tanzania.

Sorghum improvement research in Uganda is based at Serere Agricultural and Animal Production Research Institute. In collaboration with ICRISAT and International Sorghum and Millet (INTSORMIL) Collaborative Research Support (CRSP) Program and a number of nongovernmental organizations 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.

The collaborative research with ICRISAT, which came to the region in 1978, expanded into two successive regional networks during 1986−93—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 was funded by USAID through the SAFGRAD/

ICRISAT collaboration, ECARSAM is funded by the European Union through Association for Strengthening Agricultural Research in Eastern and Central Africa. Between 1993 and 1999, ICRISAT's involvement in East Africa was strengthened with inputs of improved varieties from the Southern African Development Community (SADC)/ICRISAT 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 (ICSV 210, PP 290), central mid-highlands (IS 29415), and eastern lowland Wadi (89MW 5003, 89MW 5056). The varieties, Serena and Seredo, are popularly used in mixtures with finger millet for making thin porridge and with cassava flour for ugali in the Great Lakes Region. The two countries, Ethiopia and Sudan, can be regarded as the strongest in this 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. 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; lowlands (altitude of <1600 m) with low rainfall, less than 600 mm; and lowland (altitude of <1600 m) with high rainfall (Gebrekidan, 1981). Each of the four distinct zones of adaptation requires specific type of sorghum to match with agroecological conditions and which cater to the needs of the farmers and the end users. However, because of the shortage of trained human resources and the inadequate research infrastructure, only one coordinated national breeding program operating from Nazret/Melkassa Research Center is 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 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 the Research Center at Nazret, Werer Research Center, lowland irrigated center, serves as an off-season program site. The primary objective of this center is to increase seed of breeding lines, selections and promising varieties, and hybrids for the ensuing rainy season. Over the years, this center developed sorghum lines from indigenous germplasm lines and from introduced advanced breeding lines and recommended/released several cultivars (Debelo et al., 1995). EARSAM, the 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 resistant to major diseases.

The Ethiopian Sorghum Improvement Program (ESIP) was started on full scale in 1973. The program also served as home for the popular *zerazera* (*caudatum* race) type sorghums, which were extensively used in sorghum improvement programs across the world. Nationally, the ESIP made good progress with release of the varieties, Awash 1050, the popular ETS series, and Gambella 1107 (E 35-1), which has been widely used in ICRISAT breeding programs (Reddy et al., 2004a). The sorghum research in Sudan dates back to early 1940s. 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 postharvest handling and utilization. During early 1940s, 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 rain-fed research station at Tozi in Sudan (Ibrahim et al., 1995). A program for hybrid breeding was started by the Arid Lands Agricultural Development Project in collaboration with the Agricultural Research Corporation (ARC) of Sudan in the 1970s. In 1977, the 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 ARC in 1983 (Doggett, 1988; Ejeta, 1986). Between mid-1970s and early 1990s, ARC has released many improved cultivars with yield advantages of 10%–70% for commercial production in both irrigated and rain-fed systems (Babiker et al., 1995).

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) varieties 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, Segolane, was also selected from landraces. Among the other varieties released earlier in Botswana and derived from the introduced *kafirs* from the United States are 8D and 65D (Saunders, 1942).

The cyclic occurrences of severe droughts in the late 70s in the region led the heads of States of Southern Africa Development Conference Community to deliberate on interventions to minimize the effect of drought. This led to the 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 NARS of the eight countries in the 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.

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 hybrid). 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, 1991). 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.

5.2 West and Central Africa

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 agroclimatic zones of humid (Southern Guinea Savanna) and subhumid (Northern Guinea Savanna) to semi-arid (Sudan Savanna) and arid (Sudano-Sahelian) conditions, from south to north. These agroclimatic 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 with different maturity photoperiod sensitivities. Also, the production constraints and adaptation requirements vary with agroclimatic zone. Before 1940, there was no account of sorghum breeding research work in WCA. However, by the early 1950s, 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 *Guinea*, 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. In the next 10−15 years, i.e., by 1971−84, several improved pure-line varieties and hybrids were developed, tested, and released. In Nigeria, before 1970s, the hybrids directly introduced from the United States and India failed to make a dent to boost sorghum productivity because of their poor adaptation. Therefore, the exotic seed parents were crossed with local breeding lines to develop male-sterile lines from 1970 onward. 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, SSH 5) were identified as promising (Obilana, 1982a). Similar efforts in Niger resulted in the development and production of the hybrid, NAD-1, by 1989. In the past 1−2 decades, international research organizations such as ICRISAT, INTSORMIL-CRSP, and Reseau Ouest et Centre Africain de Recherche sur le Mil, West- and Central African Millet Research Network have made many contributions toward research support to NARS. The first Regional Sorghum Research Network was created in 1984 and was operational for 5 years from 1986. In 1992, as a joint initiative by INSAH and SPAAR, a regional sorghum "pole" was created by member countries of the Inter-State Committee for Drought Control in the Sahel.

Improved material was developed by crossing the caudatum-based material from ICRISAT with local material. Selection was toward zerazera (caudatum) traits. The caudatum-based varieties were found lacking in local food quality attributes. Therefore, focus was more for the development of guinea-based hybrid parents to develop guinea hybrids. As guineas have good food quality attributes and adaptation to local drought conditions, the guinea-based hybrids are expected to have good acceptability and good adaptation to moisture stress environments prevalent in the region (Camara et al., 2006). ICRISAT was also involved in population improvement for grain food quality among *guinea* sorghums in Sotuba and Samanko, Mali. High frequency of maintainer reaction in landrace varieties from the Sudanian zone of West Africa (33% of accessions from Burkina Faso, Mali, and Senegal) was observed in contrast to landrace varieties from the more humid Guinean zone, which showed complete restorer reaction (sample size of 14). With these results, concerted efforts have been made to develop guinea-race A-lines based on A_1 CMS system by ICRISAT in collaboration with the Institut d'Economie Rurale (IER), Mali and Institut d' Etudes et de Recherches Agronomiques, Burkina Faso.

Breeding for *Striga* resistance was also initiated in 1979 in Burkina Faso, and considerable progress was made in confirming the resistance of cultivars identified earlier at ICRISAT Center in Patancheru, India, and two most stable resistant cultivars were identified that include N-13 (from India) and SRN-4841, a brown sorghum of Nigerian origin (Ramaiah, 1981). One of the achievements from the joint efforts 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. Improved varieties with good malt and brewing clear lager beer qualities were developed and released in Nigeria during 1980s (Obilana, 1985). Collaborative grain quality testing including malting quality and proximate analysis between IAR, Ahmadu Bello University, Samaru, Zaria, and the Federal Institute for Industrial Research, Oshodi, Lagos (Obilana and Olaniyi, 1983; FIIRO, 1986), led to the identification of SK 5912, the best malting sorghum. These were followed by a 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 the 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 hectoliters 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., Cadbury 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). A white grain sorghum variety ICSV 400 with good brewing qualities was identified by Nigerian and ICRISAT scientists (Murty et al., 1997). A total of 112 varieties have been released in different countries in Africa during the course of time.

New A-lines (on A_1 CMS system) were developed involving guinea core collection accessions from Burkina Faso, Senegal, Gambia, Sudan, Uganda, and Malawi by the ICRISAT program and interracial lines by IER (Institut d'Economie Rural, Mali). Besides agronomic traits, these B-lines represent a wide range of maturity that is intended to address the needs of the Northern Sudanian zone (600−800 mm rainfall), the Southern Sudanian zone (800−1000 mm rainfall), and the Northern Guinean zone (1000−1200 mm rainfall). The lines, which flower before 15 September (along with earlier developed CSM 219A and interracial A-lines), are most promising for the Northern Sudanian zone, whereas those flowering between 15 and 25 September and thereafter are most promising for the Southern Sudanian and the Northern Guinean zones, respectively (Reddy et al., 2006). At ICRISAT-Bamako, Mali, several diverse lines with restorer reaction have been identified from a subsample of guinea core collections. A range of interracial R-lines have been identified by the IER Mali program. The characterization of these lines for attributes important for R-lines, such as plant height, pollen abundance, panicle architecture, etc., was initiated in 2004 (Olembo et al., 2010). As a result of collaborative research of INTSORMIL, INRAN, and Purdue University, the hybrid NAD-1 was released in Niger in 1992. The demand for the hybrid encouraged farmers in Niger to get into the hybrid seed production business (INTSORMIL, 1999).

In Mali, sorghum research initially focused on resolving production constraints through the development of new varieties. From 1960 to 1974, local varieties had been identified and recommended for wide distribution. From 1978 to 1986, sorghum surveys were carried out by IER, IBPGR, and ORSTOM (Clément and Leblanc, 1986) to create the Malian Sorghum Collection (CSM varieties). More than 1300 accessions were evaluated by different stations and substations for Agricultural Research (Touré, 1979, 1980). Malisor 84-7 was used by breeders as the stable source of resistance to bugs. Noteworthy improved varieties mentioned in Diakité (2009) include several of the CSM series, such as CSM 63E (Jakumbe), Tieble, Jigiseme, Tiemarifing, Gadiaba, and Seguétana CZ. For the entire 1970−2010 period, Mali contributed 60 of the 135 varieties released by the five countries (Burkina Faso, Mali, Niger, Nigeria, Senegal). Hybrids have dominated releases since 2008 when the first Guinea-race sorghum hybrids bred for this region were released (Kelly et al., 2015).

As a result of collaborative effort of Nigerian national system and ICRISAT, two biofortified and drought-resistant varieties (12KNICSV-188 and Improved Deko) with iron content three times higher than typically grown sorghum at 129 ppm were developed in 2016 (source: http://www.icrisat.org/new-sorghum-varieties-will-fight-malnutrition-and-climate-change-in-sudan-and-sahel-region-of-nigeria).

6. SORGHUM IMPROVEMENT IN 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 the United States 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 1 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. 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 at developing 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. LASIP had a comparative advantage in the development of tropically adapted improved germplasm resistant/tolerant to major production constraints for food grade cultivars in Latin America. 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 INTSORMIL program identified 20 acid soil tolerant lines in the 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 objectives 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 hybrid parental lines, varieties, forage sorghum lines, and (ms3)-based two-grain sorghum populations (ICSP LG-large grain and ICSP B maintainer) and one forage sorghum population (ICSP HT-high tillering) were introduced into Colombia in October 1995 from ICRISAT-Patancheru. These introductions were tested empirically for grain and forage under acid soil conditions and 15 grain sorghum A−B lines were selected for high yield, resistance to leaf diseases, and tolerance to acid soils and 21 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 the 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 with acid soil tolerance and less susceptible to foliar diseases were also selected from the segregating material derived from specific crosses. 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 grain yield while the Al^3+ tolerant check Real 60 yielded 4 t/ha. These are less susceptible to leaf diseases, greener at maturity and also taller than the check Real 60 (Reddy et al., 2004b).

7. SORGHUM IMPROVEMENT IN AUSTRALIA

Grain sorghum is a critical component of the cropping systems in north-eastern Australia because of its wide planting window, adaptation to drought, and its capacity to make use of summer rainfall. Australian sorghum cultivars are hybrids and produced exclusively by commercial seed companies. There are four private sector organizations that produce the commercial hybrids. The Queensland Government initiated the sorghum-breeding program back in 1958 at the Hermitage Research Station near Warwick, and the program began delivering to Australian grain growers through the private seed industry in the mid-1960s. With a focus on improved yield and climate resilience, commercial licensing of new sorghum lines started in 1989. The grains research and development corporation began funding the program in 1993 and in 2010 Queensland Alliance for Agriculture and Food Innovation took over the program leadership. Resistance to sorghum midge (*Contarinia sorghicola*) and lodging (drought) and high grain yield are the main objectives of this program. Over this period it has evolved to become the most successful public sorghum-breeding program in the world in terms of lines licensed to industry, uptake in commercial varieties, and benefits delivered to grain growers. All Australian hybrid sorghum varieties have genes for several important traits such as midge resistance and stay-green traits. Progress in breeding for midge resistance in locally adapted material has been achieved through resistant female lines QL38 and QL39, although no resistant hybrids have yet been produced for commercial use. The use of the nonsenescence trait from the North American cultivar B35 has led to the development of QL40 and QL41 and their highly nonsenescent, stalk rot, and lodging resistant hybrids. No major advances in grain yield have been made, although grain yield stability has been improved by the incorporation of resistance characters (Henzell, 1992). The emphasis on midge, stay-green, and grain yield is of current focus in breeding programs in Australia (Henzell and Jordan, 2009; Borrell et al., 2014).

8. SORGHUM IMPROVEMENT IN THE UNITED STATES

In the United States, sorghum is grown in 14 states. This country is the worlds' largest exporter of grain sorghum, and its share in world trade is about 70%. Important sorghum-producing states in the United States include Kansas, Texas, Oklahoma, Nebraska, New Mexico, and Missouri. Kansas is the largest producer of grain sorghum in the United States contributing to 40% of its total production. Grain-type sorghum has become a popular rotation crop in the Great Plains. Most US sorghum is used to feed livestock. Plant breeding in the United States started in the 19th century with 30 primary introductions plus sudangrass mostly from Africa. These included 20 sweet sorghum varieties (sorgos) and 10 grain sorghum founder cultivars, which included milo (race durra), kafir (race kafir), hegari, and feterita (race caudatum). They were late maturing and tall. Farmers selected the dwarf and early maturing mutants from them. The Dwarf Yellow Milo and Dwarf Hegari were the result of selections from these introductions. Later on several combine grain sorghum cultivars were released from *kafir* × *milo* crosses. R.E. Karper and A.B. Conner in 1921 reported steriles in the segregating generation of *milo* × *kafir* crosses, which was verified as CMS by J.C. Stephens and R.F. Holland in 1952. The genetic male sterility in the variety Day Milo was utilized in crosses with Blackhull Kafir (Quinby, 1974) to produce the first generation of hybrids in late 1940s, with yield advantage of 40% (Klein et al., 2008). In 1952, both cytoplasmic-male sterility (CMS) and fertility restorers possessing Rf genes were discovered in different milo varieties (Stephens and Holland, 1954), and the CMS system quickly replaced the use of the Day Milo genetic male-sterile system (Klein et al., 2008). R.F. Holland quickly transformed the first commercial hybrids to the male sterility system, and by 1960, 95% of the grain sorghum crop was grown with hybrids. Similarly, sorghum–sudangrass hybrids such as Sudax SX 11 were developed and widely grown. Later O.J. Webster and R.E. Karper introduced Kaura and Korgi germplasms. These were *caudatum* and *durra* yellow endosperm lines. This allowed for new yield plateau and extra drought tolerance. Due to challenges such as maize dwarf mosaic virus, small seed malady, downy mildew and sorghum greenbug, and reduction in public breeding programs, a second yield plateau during 1978–84 period occurred and maintained. The resistant sources for the downy mildew, smut, anthracnose, and ergot were obtained from tropical germplasm and utilized in breeding programs. The SC35 from IS12555 provided a source for stay-green. The resistant lines for greenbug biotypes C, D, E, and I were developed. The midge-resistant cultivars developed were successful in Australia and Argentina as compared with the United States (Smith and Frederiksen, 2000). Apart from the US Department of Agriculture funding for sorghum research, sorghum checkoff collects funds from sorghum producers and uses these funds to promote research. The sorghum checkoff programs officially began in March 2009 and are currently managed by the National Sorghum Producers.

9. INTERNATIONAL SORGHUM AND MILLET'S ROLE IN SORGHUM IMPROVEMENT

The International Sorghum and Millet (INTSORMIL) CRSP, (pronounced "crisp") located at the University of Nebraska, began in 1979. The INSORMIL CRSP is a research organization focused on education, mentoring, and collaboration with host country scientists in developing new technologies to improve sorghum, pearl millet and other grains (teff, fonio, finger millet) production and utilization worldwide. INTSORMIL has projects in 20 developing countries of Africa, Central America, and the Caribbean and in the United States. INTSORMIL agronomists, animal nutritionists, biotechnologists, plant breeders, cereal chemists, economists, entomologists, food scientists, plant pathologists, and weed scientists, from the Land Grant universities of Kansas State University, University of Nebraska, Ohio State University, Purdue University, Texas A&M University, and West Texas A&M University collaborate with national research programs in East Africa, West Africa, Southern Africa, and Central America. INTSORMIL works in 13 countries in Africa, 6 countries in Central America, and in Haiti. The focus is on increasing food security and promoting market development of sorghum and millet through targeted basic and applied research, education, short-term training, and technology transfer to promote adoption and economic impact.

Under the program, more than 2200 sorghum breeding lines were released for use as donors in breeding programs. More than 80 sorghum varieties released for commercial production in 20 countries. It is estimated that 50% sorghum grown in the United States contains germplasm from INTSORMIL-affiliated university research programs. Since the operation of INTSORMIL in 1979, sorghum yields have increased by 10.2% annually. Several varieties have been released in Sudan, Mali, and Nigeria through collaboration with INTSORMIL. Breeding for greenbug and midge resistance has paid rich dividends. Drought tolerance and disease tolerance bred into US 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) CRSP have developed a rapid nondestructive bioassay for assessing *Striga* resistance, and new genes with 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. Sorghum grain type with high protein digestibility was discovered from INTSORMIL-funded research at Purdue University (Reddy et al., 2008). 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 United States and elsewhere. Digestibility affects the value of sorghum as forage for livestock. The *brown midrib* trait in some lines of sorghum developed by INTSORMIL researchers provides greater digestibility than normal forage sorghums.

10. SORGHUM IMPROVEMENT IN EUROPE

Cultivated sorghum is produced in Europe on a very limited scale and the area remained stagnant for the past 4 decades. France, Italy, Russia, and Ukraine account for approximately 90% of both grain sorghum area and production in Europe. Sorghum has potential for fodder and bioenergy use in Europe. The grain sorghum, sweet sorghum, and sudangrass in Europe is used for cattle feed. Broomcorn has industrial use in paper making and other natural products. Chilling sensitivity of sorghum is a major constraint for the successful cultivation outside areas with warm summers, such as the Mediterranean and Southeastern parts of Europe. Anthracnose (*Colletotrichum graminicola*), Fusarium (*Fusarium* spp.), and maize dwarf mosaic virus have been observed in Europe but without significant economic losses. Very limited breeding efforts have been undertaken to improve the crop for European conditions. Favorable hybrid vigor has been demonstrated for broomcorn. Yields have increased by over 30% within the last 30 years (Berenji and Dahlberg, 2004).

11. CONCLUSIONS

Sorghum is grown in the semiarid regions across the world for food in developing and underdeveloped countries and as feed in developed nations. Hybrids and varieties are available to farmers for cultivation that raised the productivity of the crop. Apart from yield enhancement, improving its tolerance to biotic and abiotic stresses is one of the main research theme that led to the development of diverse trait-specific genotypes. Of late, the crop improvement programs have taken into account the various end uses and are focusing on development of end use−specific cultivars. Despite the progress made, challenges specific to region of cultivation exists, along with the germplasm and modern tools for addressing these challenges.

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