Sorghum germplasm: diversity and utilization

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Introduction

Plant genetic resources can be defined as the "Genetic material of plants that is of value as a resource for the present and future generations of people" (IPGRI 1993). The importance of genetic resources was recognized at the inter-governmental platform under the umbrella of Food and Agricultural Organization (FAO) of the United Nations as "common heritage of mankind" that should be made available without restriction (FAO 1983). The genetic resources have evolved as a product of domestication, intensification, diversification and improvement through conscious and unconscious selection by countless generations of farmers, man-guided diversity in the form of landraces and improved cultivars that provide basic and strategic raw materials for crop improvement the world over in present and future generations.

The amount of genetic variability available in sorghum (*Sorghum bicolor* L. Moench) is immense. Much of the genetic variability is available in areas of the first domestication of the crop (Africa) and regions of early introduction (Asia). In Africa, the genetic variability is available in both cultivated species and wild progenitors of the crop (Gebrekidan 1982). DeWet and Harlan (1971) reported on the distribution of both wild relatives and the major cultivated races of the crop in Africa. However, this natural genetic diversity is subjected to a range of threats from natural selection and destruction of habitats and often merely expedient agricultural practices of mankind. Landraces and wild relatives of cultivated sorghum from the centers of diversity have been rich sources of resistance to new pathogens, insect pests and other stresses such as high temperature and drought, as well as sources of traits to improve food and fodder quality, animal feed and industrial products. Preventing the vulnerability of landraces and wild relatives of cultivated sorghum from extinction, following the release of varieties and hybrids, collection and conservation of sorghum germplasm was accelerated about four decades ago. Since then, germplasm collection and conservation has become an

integral component of several crop improvement programs at both national and international levels (Rosenow and Dalhberg 2000).

Status of genetic resources

Sorghum germplasm collections vary in number and kind in various parts of the world. However, status of germplasm maintained at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, USA, Africa and China are worth discussing considering the size of the crop improvement programs (Rosenow and Dalhberg 2000) in these centers.

ICRISAT, Patancheru, India: The first major effort to assemble a world collection of sorghum was made in the 1960s by the Rockefeller Foundation in the Indian Agricultural Research Program (House 1985, Murty et al. 1967). A total of 16,138 accessions were assembled from different countries, and International Sorghum (IS) numbers were assigned to them. In 1976, ICRISAT was given the responsibility to add sorghum germplasm to the world collection in accordance with the recommendations made by the Advisory Committee on Sorghum and Millet Germplasm sponsored by the International Board for Plant Genetic Resources (IBPGR) [now the Bioversity International] (IBPGR 1976, Prasada Rao et al. 1989).

At present, ICRISAT is a major repository for the world sorghum germplasm collection with a total of 36,774 accessions from 90 countries. The existing collections of sorghum germplasm conserved at ICRISAT have been estimated to represent about 80% of the variability present in the crop (Eberhart et al. 1997). About 90% of these collections have come from developing countries in the semi-arid tropics. About 60% of these collections have come from six countries: India, Ethiopia, Sudan, Cameroon, Swaziland and Yemen. The largest collection is from India. It is interesting to note that about 84% of the total collections are contributed by landraces in contrast to wild species, which contributed only one percent to the total collection. Based on the geographical origin, the accessions are further classified. About 63% of the total number of accessions are from African countries and about 30% are from Asian countries. In addition to this, the germplasm maintained at ICRISAT, India, are classified into five races: *bicolor, guinea, caudatum, kafir* and *durra* and their derivative (Gopal Reddy et al. 2002). The collection is predominantly represented by three basic races: *durra* (21.8%), *caudatum* (20.9%) and *guinea* (13.4%). Among the intermediate races, *durra-caudatum* (12.1%), *guinea-caudatum* (9.5%) and *durra-bicolor* (6.6%) are common. The country-wise distribution of basic and their intermediate races revealed that three countries, India, Uganda and Zimbabwe have all the five basic and ten intermediate races (Gopal Reddy et al. 2002).

Ethiopia: Ethiopia, one of the rich centers of diversity, began a centralized collection of sorghum at the Jimma Agricultural Technical School between 1958 and 1960 (Rosenow and Dalhberg 2000). In the early 1970s, the Ethiopian Sorghum Improvement Project (ESIP) began the collection, evaluation, documentation and conservation of germplasm. Through the early 1980s ESIP had amassed a collection of approximately 5500 accessions (Doggett 1988). It is estimated that through continued research efforts, the germplasm has grown to roughly 8000 collections (Rosenow and Dalhberg 2000). The distinct types of sorghum from Ethiopia are (1) *zera zeras*, (2) *durras* and (3) *durra-bicolor* derivatives. The *zera zeras* have been extremely useful in providing germplasm for the improvement of food type sorghums.

Sudan: A large collection of Sudanese landraces was assembled in Sudan in the 1950s. These were maintained at Tozi Research Station and the entire collection was provided to the Rockefeller Foundation Project in India (Rosenow and Dahlberg 2000). The *caudatum* race dominates in Sudan and Sudanese sorghums have been very useful as sources of drought resistance (Rosenow et al. 1999).

United States of America: Around 1905, the United States Department of Agriculture (USDA) undertook collection and distribution of sorghum and Texas was selected as the first research station to work on sorghum in collaboration with USDA and Texas Agricultural Experimental Station (Quinby 1974). A total of 42,221 germplasm accessions have been maintained at National Plant Germplasm System (NPGS) in the United States of America (Dahlberg and Spinks 1995).

China: Through extensive and planned collections of landraces throughout the country, 12,836 accessions have been assembled in China and 10,414 of these have been registered as genetic resources and are currently being preserved in National Genetic Germplasm Resources Bank (Qingshan and Dahlberg 2001). These accessions include 9652 local varieties, improved varieties and strains that originated from 28 provinces, municipal and autonomous regions. These were further classified according to use: 9859 sorghum accessions were classified as food types, 394 accessions were classified as varieties for fodder and 125 varieties were classified for use in sugar production. Only a limited number of local Chinese cultivars are in the sorghum collections at ICRISAT, India or US National Collection (Qingshan and Dahlberg 2001).

At the global level, sorghum germplasm collections consist of approximately 168,500 accessions; one of the largest collections (21% of global total) is held at ICRISAT, Patancheru, India. The total accessions consists of 18% landraces/ old cultivars, 21% advanced cultivars/breeding lines, 60% of mixed categories of unknown material, while very few are wild relatives (Chandel and Paroda 2000).

NRCS, India: A total of 20,812 accessions are conserved at medium-term storage along with 1456 accessions as duplicates. The maximum accessions are a repatriation material (11,113 acc.) followed by other IS lines (3442 acc.). Local germplasm (3560 acc.) and exotic collections (494 acc.) are other important materials. 9984 accessions of sorghum genetic resources are held at AICSIP centers. 2373 accessions of specific sorghum germplasm are held at 7 AICSIP centers.

Maintenance of genetic resources

Genebanks conserve genetic resources. The most fundamental activity in a genebank is to treat a new sample in a way that will prolong its viability as long as possible while ensuring its quality. The samples (or accessions as they are called) are monitored to ensure that they are not losing viability. A cornerstone of genebank operations is the reproduction—called regeneration—of its plant material. Plant samples must periodically be grown out, regenerated, and new seed harvested because, even under the best of conservation conditions, samples will eventually die (Bioversity International 2006).

Sites for preservation and maintenance of the largest sorghum accessions are located at ICRISAT, India; the National Seed Storage Laboratory, Fort Collins, Colorado, USA; and the USDA-ARS Plant Genetic Resources Conservation Unit (PGRCU), Griffin, Georgia, USA. Several countries also maintain their own collections within their national collections. Major grow-outs and regeneration takes place at ICRISAT, India and at the USDA-ARS Tropical Agriculture Research Station, Mayagüez, Puerto Rico (Rosenow and Dahlberg 2000). At ICRISAT, India, all collections are maintained in the postrainy season by selfing about 20 representative panicles from each line. Seeds harvested in equal quantities from these panicles are mixed and a bulk of about 500 g is preserved in aluminum cans in the medium-term storage facility (4ºC and 20% relative humidity). Freshly rejuvenated accessions with 100% viability and 5$\pm$1% seed moisture content are being stored in long-term storage (-20ºC).

Core collection

Although several subsets of total base collection were developed for utilization by sorghum scientists, they turned out to be location-specific and did not give a fair representation of the base collection (Prasada Rao et al. 1995). Therefore, the concept of “core collection” (Brown 1989) was used to set up a “core collection” at ICRISAT. A core collection consists of a limited set of accessions derived from an existing germplasm collection, chosen to represent the genetic and geographical spectrum of the whole collection. The rationale behind a core collection is the

maintenance of as much genetic diversity as possible within a smaller, more manageable representative "core collection" (Dahlberg and Spinks 1995). Following this concept, a core collection was set up at ICRISAT-Patancheru, India by stratifying the total base collection geographically and taxonomically into subgroups within regions. Accessions in each subgroup were further clustered into closely related groups based on the principal component analysis (PCA) using agronomic data. Representative accessions from each cluster were drawn in proportion to the total number of accessions present in that subgroup. Thus, the core collection of 3475 set up at ICRISAT, India represents approximately 10% of the total world collection (Prasada Rao and Ramanatha Rao 1995). The core collection is an economical, practical and effective method for conservation, maintenance and utilization of the germplasm (Eberhart et al. 1997).

In the USA, a core collection containing over 200 out of 42,221 accessions was developed by a sorghum curator located at USDA in Mayagüez, Puerto Rico, representing genes for plant height, maturity, drought resistance, pericarp color, and greenbug, aphid, downy mildew resistance (Dahlberg and Spinks 1995).

Characterization, evaluation and documentation of genetic resources

Characterization: Characterization of each sample involves a careful description of the special characteristics that are inherited, easy to score, and expressed consistently in all environments. Since most of the traits recorded during characterization are those that can be seen, the person responsible for managing the germplasm material is best placed to carry out the work of documenting these characteristics. Many of the characteristics that are recorded on individual accessions can serve as diagnostic descriptors for the accessions. Such diagnostic characters help genebank curators keep track of an accession and check for the genetic integrity over a number of years of conservation. Again, descriptors lists are a vital tool for ensuring that those who are documenting the characteristics of conserved species are using the same language and standards.

Evaluation: Germplasm is evaluated for growth traits, agronomic performance, yield and responses to biotic and abiotic stresses using visual observations and measurement on standard scales. Molecular markers (such as isozymes and DNA markers), which are neutral to environment variation may also be used for evaluation. Evaluation is primarily carried out by germplasm users, in multidisciplinary teams that include breeders, entomologists, pathologists and agronomists. The potential value of the germplasm depends on the efficiency of the techniques designed to differentiate accessions. Since farmers possess valuable traditional knowledge and are the ultimate users of the finished products of crop improvement programs,

it is advantageous to involve farmers and consider their views and expectations during germplasm evaluation.

Documentation: The proper documentation of plant genetic diversity is an indispensable part of making diversity useful to farmers, breeders and researchers. Before we can use what we've got, we've got to know what we have. In order to increase international exchange of material, a certain amount of uniformity in data collection, recording, storage and retrieval is critical. Developing standards for documentation and protocols for exchanging information is essential for ensuring that bridges can be built between myriad information sources. Coping with the vast amount of data on crop species and varieties and making it available requires adequate database design and information management systems (Bioversity International 2006).

As a prerequisite for efficient utilization of the germplasm, it must be properly evaluated, characterized and documented with a workable retrieval system so that any group of entries carrying any desired characteristics could be easily retrieved and used in breeding programs (Gebrekidan 1982). A total of 29,180 accessions have been characterized for 23 important morpho-agronomic characters based on "list of sorghum descriptors" (IBPGR/ICRISAT 1980) at ICRISAT, Patancheru, India, during rainy and postrainy seasons. The range of variability available in cultivated races and their wild relatives is extensive, and the extreme types are so different as to appear to be separate species (Prasada Rao et al. 1995).

The characterization data with passport information have been documented using ICRISAT Data Management Retrieval System (IDMRS) program and have been converted to the System 1032 (a Relational Database Management Software), for rapid and more efficient management (Prasada Rao et al. 1995). A number of trait-specific promising genetic stocks are maintained at ICRISAT-Patancheru, India. These are: stocks resistant to insect pests such as shoot fly, stem borer, midge and head bug; resistant to diseases like grain mold, anthracnose, rust and downy mildew; resistant to parasitic weed, *Striga,* and stocks with important traits like glossiness, pop, sweet stalk and scented types. Approximately 50% of the total US germplasm accessions have been characterized based on 39 agronomic descriptors (Dahlberg and Spinks 1995) and 21,661 accessions located at USDA-ARS S-9 site in Griffin, Georgia, USA. In addition to these initial descriptors, many accessions have been screened in nurseries for further evaluation and various accessions have been identified as having resistance to aluminum toxicity, shoot fly, stem borer, *Striga*, midge, rust and downy mildew (Dahlberg and Spinks 1995). The details of the passport data and characterization of US sorghum germplasm collection have been documented in the Germplasm Resources Information Network (GRIN) and are also available through the sorghum curator located in Mayagüez, Puerto Rico.

A total of 3012 accessions with NRCS have been characterized since 2001. An online database on status of sorghum genetic resources at NRCS, along with passport data and evaluation data, has been prepared for easy retrieval of the information on the required germplasm line. Database on status of sorghum genetic resources at All India Coordinated Sorghum Improvement Project (AICSIP) centers with 9984 accessions of sorghum genetic resources held at AICSIP centers has been prepared. A Geographic Information Systems (GIS) map for the sorghum germplasm collections held at NRCS has been prepared.

Utilization of genetic resources

It is obvious that only a small fraction of the total available collection could be fully utilized by breeders at any given time. Crop improvement programs are often interested in portions of the collection that carry special desirable characters that are highly important at any particular point of time (Gebrekidan 1982). Early work on utilization of sorghum germplasm was confined to pure line selection within cultivated landrace populations in Africa and India that resulted in improved cultivars, some of which continue to be widely grown. Selection within dwarf populations was taken up, followed by exploitation of cytoplasmic male-sterility, which permitted the production of commercial hybrids (Dahlberg et al. 1997). Crossing and/or backcrossing between adapted introductions and local germplasm has been used to derive improved pure-line varieties and parental lines (Prasada Rao et al. 1989). Useful traits, such as increased seed number, larger panicles, greater total plant biomass, drought tolerance, disease resistance, greater plant height, longer maturity, greater leaf area indices, increased green leaf retention and greater partitioning of dry matter have contributed to increased yield (Miller and Kebede 1984).

Utilization has been primarily limited to agronomically important and in some cases, wild sources of germplasm. For example, use of *zera zera* sorghum has become widespread in the development of new, superior hybrids because of superior yield potential and grain quality (Duncan et al. 1991). The classic example of germplasm utilization in sorghum has been the Texas A&M-USDA Sorghum Conversion Program. Till date 633 converted lines have been released globally; 50 are listed in Rosenow et al. (1995); and 40 new lines have been released (TAES and USDA-ARS 1996).

The successful introgression of resistance to midge and downy mildew has greatly stabilized sorghum production in Australia and Argentina. Considerable opportunities remain for exploiting the collections to improve sorghum production globally. For example, over 340 accessions of the genus sorghum belonging to sections *Chaetosorghum, Heterosorghum, Stiposorghum, Parasorghum* and *Eu-*

Sorghum have been evaluated for resistance to shoot fly at ICRISAT, Patancheru, India. Seven accessions with high levels of resistance and in some cases close to immunity were found (Nwanze et al. 1995). Transfer of this high level of resistance to cultivated sorghum could greatly improve productivity of late sown crops in Africa and Asia, where shoot fly is a major production constraint (Dahlberg et al. 1997).

Since its establishment in 1972, ICRISAT has made efforts to (1) diversify the germplasm base to enhance yield levels and (2) to identify resistance sources and use them to develop varieties and seed parents. The major germplasm sources utilized so far in varietal improvement include temperate lines from US, *zera zera* lines from Ethiopia and Sudan, and some lines of Indian origin. The male-sterile gene sources used were mainly CK 60, 172, 2219, 3675, 3667 and 2947. These were further diversified by using parents such as CS 3541, BTx 623, population derivatives (Bulk Y, Indian Synthetic, FLR, RS/B, US/B, Serere, Diallel and WAE), IS 6248, IS 2225, IS 3443, IS 12611, IS 10927, IS 12645, IS 517, IS 1037, IS 19614, E 12-5, ET 2039, E 35-1, Lulu 5, M 35-1 and Safra. In the development of restorer parents and varieties, the basic germplasm sources used were: IS 84, IS 3691, IS 3687, IS 3922, IS 3924, IS 3541, IS 6928, ET 2039, Safra, E 12-5, E 35-1, E 36-1, IS 1054, IS 1055, IS 1122, IS 1082, IS 517, IS 19652, Karper 1593, IS 10927, IS 12645, IS 12622, IS 19652, IS 18961, GPR 168 and IS 1151.

The stable resistant sources for shoot fly and stem borer, such as IS 1082, IS 2205, IS 5604, IS 5470, IS 5480, M 35-1 (IS 1054), BP 53 (IS 18432), Karad Local (IS 18417), Aispuri (IS 18425) in India, IS 18577, IS 18554 in Nigeria, IS 2312 in Sudan, IS 18551 in Ethiopia, IS 2122, IS 2134 and IS 2146 in US have been used both in Indian and ICRISAT programs to impart resistance.

The midge resistant lines DJ 6514 and IS 3443 were used at ICRISAT to develop an improved midge-resistant variety, ICSV 197 (SPV 694).

The multiple disease resistant sources like ICSV 1, ICSV 120, ICSV 138, IS 2058, IS 18758 and SPV 387 (anthracnose and rust); IS 3547 (grain mold, downy mildew, anthracnose and rust); IS 14332 (grain mold, downy mildew and rust); IS 17141 (grain mold and anthracnose); IS 2333 and IS 14387 (grain mold and downy mildew); and IS 3413, IS 14390 and IS 21454 (grain mold and rust) are currently being used in breeding programs.

Some of the *Striga* resistant germplasm lines used in *Striga* resistance breeding are IS 18331 (N 13), IS 87441 (Framida), IS 2221, IS 4202, IS 5106, IS 7471, IS 9830 and IS 9951. Some of the breeding lines like 555, 168, SPV 221 and SPV 103 proved to be useful resistance sources. The *Striga*-resistant variety SAR 1 developed at ICRISAT from the cross 555×168 was released for cultivation in *Striga*-endemic areas.

Nearly 1300 germplasm lines and 332 breeding lines were screened for early- and mid-season drought stresses. The most promising of these are: early season and terminal drought tolerant: E 36-1, DJ 1195, DKV 17, DKV 3, DKV 4, IS 12611, IS 69628 and DKV 18; mid-season drought tolerant: DKV 1, DKV 3, DKV 7, DJ 1195, ICSV 378, ICSV 572, ICSV 272, ICSV 273 and ICSV 295.

The high-lysine sorghum lines, IS 11167 and IS 11758 from Ethiopia were used in the breeding program for transferring the gene to a desirable agronomic background. Some promising high-lysine derivatives with shriveled and plump grain have been obtained.

Several sweet-stalked sorghum lines like IS 20963, IS 15428, IS 3572, IS 2266, IS 9890, IS 9639, IS 14970, IS 21100, IS 8157 and IS 15448 have been promising and the sweet stalked trait is being incorporated into elite agronomic background.

Many lines with desirable forage attributes have been identified: IS 1044, IS 12308, IS 13200, IS 18577, IS 18578 and IS 18580. Regarding quality parameters, IS 1059, IS 2944, IS 3247, IS 4776 and IS 6090 were selected for low HCN, and IS 3247 and PJ 7R for low tannin content (Vidyabhushanam et al. 1989).

A total of 86 trait-based hybrid parents (B- and R-lines), advanced breeding lines and germplasm accessions evaluated in the initial stage at ICRISAT, Patancheru to find out the grain Fe and Zn content indicated low levels of micronutrient density. 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 and the grain Zn content ranged from 13.4 ppm (JJ 1041) to 30.5 ppm (IS 1199) with an average of 19 ppm.

Studies on 2262 sorghum core germplasm accessions at ICRISAT, Patancheru indicated that a large variability for grain Fe (7.7 ppm to 192.3 ppm) and Zn (13.7 ppm to 91.3 ppm) content exists among and is much higher than that exists among hybrid parents of released/marketed hybrids and popular varieties. As many as 17 accessions recorded grain Fe content over 90 ppm (range 96–192 ppm) and 11 accessions recorded grain Zn content over 58 ppm (range 58–91 ppm). Accessions from USA recorded the highest Fe content that belonged to *bicolor* race.

Over the years, the sorghum improvement program at ICRISAT developed 758 A-/B-lines and 922 R-lines for various traits. Evaluation of 222 designated B-lines indicated that the grain Fe content ranged from 22.4 ppm to 51.3 ppm and the grain Zn content ranged from 15.1 ppm to 39.6 ppm. As many as 20 B-lines recorded Fe content over 45 ppm and 13 B-lines recorded Zn content over 32 ppm. Two most promising B-lines, ICSB 406 with high grain Fe (51 ppm) and Zn (40 ppm) and ICSB 311 with high grain Fe (47 ppm) and Zn (36 ppm) were identified, which can be used in development of new hybrids with high Fe and Zn content.

For salinity tolerance IS 164, IS 237, IS 707, IS 1045, IS 1049, IS 1052, IS 1069, IS 1087, IS 1178, IS 1232, IS 1243, IS 1261, IS 1263, IS 1328, IS 1366, IS 1568, IS 19604 and IS 297891 were found to be good based on two years of testing at three salinity levels (5, 10 and 15 dS/m).

In India, the varietal improvement program was initiated in the 1930s. The locals were tall, late maturing, flowering after the rainfall ceased, generally photosensitive and characterized by localized adoption and low harvest index. Their response to improved management in terms of the increased yield was very poor. Most of the improved varieties were the result of pure line selection practiced in principal local varieties. Local × local hybridization followed by selection resulted in varieties with marginal increase in grain yield. Notable among these varieties developed during the early period and still under cultivation are the Co-series in Tamil Nadu; the PJ *kharif* and *rabi* selections, Saoner, Ramkel, Aispuri, the Maldandi, Guntur and Anakapalle series of Andhra Pradesh; the bilichigan, fulgar white, fulgar yellow, kauvi, Nandyal, hagari, yanigar varieties of the erstwhile Mysore state (Rao 1972).

With the discovery of workable cytoplasmic-nuclear male-sterility and initiation of the accelerated sorghum project (which later became the All India Coordinated Sorghum Improvement Project) in 1962, hybrid breeding was given due emphasis. Initially, the germplasm from the USA *(kafir milo* cytoplasm and other germplasm) and hybrid combinations by making temperate×temperate crosses were tested. During 1962–1969, out of temperate×temperate and temperate × tropical crosses, three hybrids, ie, CSH 1, CSH 2 and CSH 3 were released.

Introduction of CSH 1 in farmers' fields during 1960s resulted in a quantum jump in productivity and production as the hybrid responded well to improved management practices as compared to old varieties. It became popular with farmers as it had high yield potential, was suited to light soils and low rainfall areas. The second hybrid CSH 2, was based on the same male sterile, CK 60A as that of CSH 2 and a new R-line IS 3691, which was a yellow endosperm selection of *Hegari* from USA. Later on, a new male-sterile line, 2219B was identified from germplasm line *kafir shallu* and a hybrid CSH 3, was developed by using 2219 A and IS 3691 (R-line of CSH 2). CSH 2 and CSH 3 did not become popular due to inherent seed production problems.

During the next decade (1970–1979), three hybrids, CSH 4, CSH 5 and CSH 6 were released. Hybrid CSH 4, based on ms 1036A had better fodder yield. The female line, ms 1036A was developed from a cross of CK 60B and PJ 8K (a local variety from Maharashtra) and the R-line being a selection from IS 3924. Though this hybrid was good for grain yield, the hybrid was not popular among the farmers as its grain quality was not better than CSH 1.

In general, grain yield of improved cultivars was tripled by utilization of exotic breeding material in hybrid program, however, these cultivars especially hybrids were not well received by the farmers because of their increased susceptibility to major pests and diseases and inferior grain quality compared to locals.

Keeping the above factors in mind, new male-sterile lines were developed with different genetic backgrounds. The ms lines and R-lines were developed from derivatives of crosses between temperate × tropical crosses. The ms line of CSH 5, (2077B) was developed from IS 2046, a germplasm line from Senegal. The hybrid CSH 5, based on converted lines ms 2077A and CS 3541, contributed not only to substantial yield improvement but revolutionized sorghum seed industry. The hybrids were tolerant to mites and aphids also. This improvement was achieved by introduction of genes from tropical material IS 3541. An early maturing hybrid CSH 6 developed from early MS line 2219A and CS 3541 became very popular as hybrid suited for inter-cultivation with pigeonpea.

Further increase in grain yield was achieved by development of hybrids like CSH 9, CSH 10 and CSH 11 based on new MS line 296A during 1980-1989. Indian germplasm line *karad local* was crossed with American material IS 3922 to develop the MS line 296A, which was the best combiner. This ms line has a very compact panicle with more number of primary branches. CSH 9, a medium duration hybrid is widely adapted and extensively grown. The hybrids CSH 10 and CSH 11 developed from the same ms line, 296B, showed marginal superiority for grain yield.

During 1990s, most of the hybrids tested in all-India trials were based on 296A with various restorers but could not make any remarkable dent for grain yield over CSH 9. Though there was no significant grain yield improvement, useful diversification for early maturity and higher fodder yield has been achieved with the release of CSH 13 and CSH 14. The fodder yield of CSH 13 is 40% more than that of CSH 9 although its grain yield is marginally improved. The R-line of this hybrid, RS 29 that contributes to heterosis for fodder yield is developed from SC 108, an American elite line and SPV 126 (a tall mutant of CS 3541). Another hybrid, CSH 14, is about 10 days earlier than CSH 9 maintaining the same level of grain yield. The need for diversification of female parent was felt in view of seed production problems and stagnating yield level. Another high yielding hybrid, CSH 16 was developed from new ms line 27A, and R-line C 43. This hybrid showed further improvement in grain mold tolerance as the new genes from Ethiopian germplasm line IS 23549 was introduced into its R-line. The R-line has very compact panicle. In contrast to 296B, ms line 27A of this hybrid is long and has loose panicles with bold and round seed like that of postrainy season genotype that has consumer preference. 27B has been developed from multiple crosses using germplasm lines such as IS 3687, IS 3922 and 2219B. Recently two hybrids CSH 17 and CSH 18 were released.

Though the yield levels are on par with CSH 16, these were diversified for early maturity and high fodder yield, respectively. By utilizing local variety Vidisha 60-1 at Indore center, the ms line of CSH 18 (MS IMS 9A) was developed. The local variety, Vidisha 60-1 not only contributes to high stover yield but also to improved grain quality. The R-line of this hybrid, Indore 12 is developed from multiple crosses of SSV 53 and SPV 475 germplasm lines.

Whenever there was a change in the male sterile line, the yield benefit was obvious. Hence, there is a need for developing new male sterile lines having better combing ability in comparison to that of available ms lines. So far, several germplasm lines of different botanical races have been utilized in development of parental lines. The grain yield levels of rainy season hybrids have reached the plateau and there is a need to exploit unused germplasm and landraces to diversify the genetic base.

Simultaneously, varietal improvement was achieved by introducing temperate and tropical material. The first variety, CSV 1 is a direct introduction of American line IS 3924. By crossing temperate and tropical germplasm, subsequent varieties CSV 2 and CSV 3 were developed. CSV 4, which was used as restorer of three most popular hybrids, CSH 5, CSH 6 and CSH 9, became a very popular variety. The variety is a converted line of an African germplasm line IS 3541, and developed by crossing it with a US germplasm line, IS 3675. CSV 5, another variety developed from Indian local and US line IS 3687 has *Striga* resistance. CSV 10, which became popular for high fodder value was developed from a cross between American elite variety SC 108 and Indian elite variety CS 3541.

Another variety which became very popular, SPV 462 (from Coimbatore), was developed from multiple cross involving IS 2947 and IS 3687 from USA and IS 1151 and BP 53, locals of Maharashtra and Gujarat in India, respectively. The variety is high yielding for grain and fodder with good grain quality. CSV 13, yet another variety developed from multiple cross having exotic and local genetic base is high grain yielding with medium height. The latest variety, CSV 15 developed from SPV 462 and CSV 13, is a dual purpose variety having grain yield equal to that of hybrid CSH 5 and fodder yield equal to CSH 10.

Germplasm has been used for trait based breeding in rainy season sorghums, especially for resistance to major diseases and pests. Though present day varieties and the restorer lines possess moderate level of resistance, the male sterile lines are highly susceptible. Genetic stocks such as IS 14387, IS 14374, and IS 25017 were extensively used for incorporation of grain mold resistance into male sterile lines. Recently, grain mold tolerant ms line 219 was developed by crossing AKMS 14B (ms line of hybrid CSH 14) with grain mold resistant line IS 14387. Similarly, many grain mold tolerant lines, GMRP and SR, were developed at Parbhani and Surat centers. Important resistant lines are GMRP 9, GMRP 13,

SR 839 and SR 384. Similarly, shoot fly resistance material is developed at Rahuri and Akola centers of AICSIP by using germplasm lines. Seed of varieties bred for rainy season is not as remunerative as that of *rabi* varieties because the seed is not bold and lustrous. Now, efforts are being made to breed varieties with bold and lustrous seeds by using *guinea caudatum* and *durra caudatum*. Some of the germplasm lines contributing bold grain size are IS 51, IS 3142, 9742, IS 17600, IS 19305, IS 31690, etc.

The attempt to develop heterotic hybrids for postrainy season with whole grain quality matching that of local variety Maldandi has met with limited success; Maldandi has a unique feature that combines good grain quality with drought and shoot fly resistance as required for *rabi* season cultivation. Hybrids like CSH 7R, CSH 8R, CSH 12R were based on ms lines developed from rainy season lines, and R-lines were developed from local×US lines that did not show much superiority over M 35-1 for yield and quality. Another *rabi* hybrid, CSH 13 is superior to the *rabi* local for grain yield but inferior to M 35-1 for grain quality. Recently released hybrid CSH 15R, is based on *rabi* adapted MS line having good grain quality and shoot fly tolerance. The R-line of this hybrid is developed from *rabi* locals and CS 3541, an elite *kharif* variety.

Postrainy season varieties were developed by crossing Indian locals, M 35-1 and IS 2644 with American germplasm lines. Marginal improvement was achieved for grain yield over the most popular local variety M 35-1. Recently released variety, CSV 216R (CSV 16) is a landrace selection from *rabi* germplasm from Maharashtra.

The need for further critical evaluation of germplasm and its utilization in grain and forage sorghum improvements is keenly felt. Sorghum collection missions may be further arranged on the specific targeted germplasm availability areas based on the usage, such as sweet sorghum, pop sorghum, dual-purpose sorghum and sorghums resistant to pests and diseases, etc. Landraces are known to possess local adaptation and stability and may offer opportunities for direct utilization. On the other hand, improved varieties with diverse genetic base are likely to show wider adaptation and enhanced performance. Judicious combination of both in recombination breeding programs can further lead to upgradation of yield potential. As discussed earlier, so far, *caudatum* and *durra* types have been exploited. Inclusion of *guinea* germplasm may bring further increase in yield potential, tolerance to grain mold and lodging resistance.

Traditionally, sorghum is used as whole meal flour and milled fractions. The whole meal flour has been used for making '*rotis*' (*bhakri*) and gruel. To a limited extent, sorghums are also used for puffing and making some special dishes. Fortified foods, a blended food product containing grain sorghum and quality protein sources such as soybean have been developed in countries like the USA; these have more

relevance to India but are yet to become popular here. Sorghum malt is used as food in many parts of the world. The *kafir* beer of Africa is a traditional drink of *Bantu* people. Modern malting techniques used in the malting of barley have been successfully applied to grain sorghums.

Sorghum is a multipurpose and bioenergy crop; the grain, stem and glumes are the useful parts. The grain is used as human food (bread, baby food, popped, parched, flakes); livestock feed for poultry, farm animals (rabbits, ducks and pigs); alcohol production (potable and industrial), fuel; malt (malt syrup, beer, beverages; glucose liquid/powder), and other industrial productions: starch, dextrin, dextrose, glue, liquid glucose, alcohols, plastics, textiles, paper board, 'U' – foam industries; stem is used in the production of syrup, jaggery, alcohols and sugar; bagasse obtained as byproduct is used as fodder and in the manufacture of fuel, paper, particle and corrugated boards. Natural color is extracted from glumes (Rana 2000). Sorghum is considered as an industrial and high-energy crop with its diverse uses. Sorghum alcohol, syrup, liquor, beer and malt play an important role for small industries. Commercialization of sorghum lies in proper utilization of its diverse economic importance (Elangovan 2005).

Concurrent with continued conservation, evaluation and documentation of germplasm, efforts to fully exploit the greater genetic diversity of the world collection of sorghum must be escalated. In sorghum, as in other crop species, the need to investigate alternate methods for evaluation and enhancement of exotic germplasm has reached a critical stage. Quantitative traits governing adaptability, such as yield and stress tolerance, will be extremely important in future improvement projects. Although height and maturity conversion of exotic germplasm allows for some evaluation and utilization for these traits, other alternatives must be considered. The evaluation of an exotic source could be conducted prior to conversion in the native environment, where the source is better adapted or another location where information from the collection site is utilized. This evaluation phase will be critical to the increased use of either partially converted lines or the germplasm source *per se*. Increased use of sorghum germplasm in future also may depend on the practical application of molecular techniques. DNA marker techniques to identify diverse segments of the chromosomes controlling inheritance of quantitative traits will become necessary in germplasm enhancement programs. Genetic transformation with exotic genes also plays a major role in sorghum improvement since many desirable genes exist in the World Collection. The challenge to sorghum improvement will be to concentrate on utilization of desirable traits that may aid in evolving superior improved lines aiming to surpass the present productivity plateau combined with better drought, disease and pest resistance and improved grain quality.

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