Designing a sorghum genetic improvement program

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Introduction

For ages farmers have exercised selection through saving and carrying forward the grain from healthy plants as seed for sowing the next crop. Plant breeders further augmented/enhanced the crop productivity, thus mediating directed evolution. The art of plant breeding lies in the breeder's skills in observing plants with unique economic, environmental, nutritional and aesthetic characteristics. In this article, we briefly describe various factors that need to be considered in launching a crop improvement program with emphasis on sorghum.

Economic importance

Sorghum is cultivated in over 45 million hectares in 92 countries traditionally and primarily for grain both as food (Africa and India) and as animal feed (developed countries, China, Australia, etc) and stalks as animal fodder. Of late, sweet sorghum juice is emerging as potential feedstock source for bioethanol production for use in blending petrol with dual objectives of reducing air pollution and dependency on fossil fuel. Thus, the main types of sorghums that a breeder should visualize are grain sorghum, dual-purpose sorghum, fodder sorghum and sweet sorghum.

Basic characteristics

Yield potential: Generally, sorghum can be cultivated in fields of varying fertility levels. Sorghum responds well to fertilizers. Selection of cultivars suitable for target environment and the duration that match with the rainfall pattern coupled with the use of recommended production package helps realize maximum productivity potential of the improved cultivars.

Water requirement: Sorghum requires less moisture for growth compared to maize (Table 6). It has a fibrous root system. Low rainfall conditions encourage root development; roots grow deeper even up to 1.5 m under receding soil moisture and able to extract moisture from a greater volume of soil. Traditionally, it is cultivated as a rainfed crop in rainy season in areas receiving 600 to 1000 mm rainfall in many countries in May/June plantings. However, in postrainy season in India, it is cultivated in *vertisols* after cessation of rains when crop matures by utilizing receding soil moisture in September/October plantings.

Table 6. Water use efficiency of sorghum in comparison to maize.

Crop	Water use efficiency (kg water/kg dry matter)
Sorghum (Lima, 1998)	310
Maize (Chapman and Carter 1976)	370

Temperature requirement: It can be cultivated in temperatures ranging from 43°C (maximum) to 15°C (minimum); but growth and germination occur in some varieties even in temperatures as low as 12°C (minimum).

Germplasm base

Archaeological evidence suggests that sorghum domestication dates back to about 3000 BC (Doggett 1965a). Ethiopia/Sudan—Eastern Horn of Africa is considered to be the primary center of origin while India is considered to be the secondary center of origin. These centers of origin provide the greatest variability for breeders to select further. Harlan and de Wet (1972) classified sorghum by recognizing five basic races (*bicolor, guinea, caudatum, kafir* and *durra*) and their 10 hybrid races (eg, *caudatum-durra*, etc) based on the orientation of glumes over the developing grain. These races are known to differ significantly not only for grain quality traits but also for yield potential. It is established that inter-racial hybrids have greater heterosis than those of intra-racial hybrids. The knowledge on characteristics of these races becomes handy for the breeder for systematic genetic improvement of sorghum for traits of interest.

Breeding behavior

A breeder should know the breeding behavior of sorghum before launching a breeding program as breeding methods largely depend on the pollination control mechanisms. The inflorescence in sorghum is called panicle with racemes on tertiary rachis each with one or several spikelets. One spikelet is always sessile and the other pedicillate except the terminal sessile spikelet, which is accompanied by two pedicillate spikelets. The sessile spikelets have both male (androecium) and female (gynaecium) parts, and the pedicillate are usually male or female in sex. Outcrossing occurs to an extent of 5–20% depending on the weather conditions and genotypes. However, it is usually handled as self-pollinated species in breeding.

Outcrossing is mediated by the wind. Anthers mature first before stigmas and comes out of glume (called protandry), but there is variation among landraces. Anthesis (flower opening) begins from florets at the top to those at the base of the panicle usually in the morning hours after 0800 (House 1985). Outcrossing in sorghum can be facilitated by the use of genetic male-sterility. There are nearly eight different recessive genes in homozygous condition that contribute to male sterility. Among these, ms_3 and ms_7 genes are more stable and are being deployed/maintained in various populations. Cytoplasmic-nuclear male sterility (CMS) system also facilitates outcrossing in sorghum. CMS systems have facilitated development of commercial hybrids in sorghum. As many as six CMS systems are being maintained at ICRISAT. These are A_1, A_2, A_3, A_4(g), A_4(vzm) and A_4(M).

Adaptation

Sorghum has considerable potential to adapt itself to varied environmental conditions and hence, can be bred for broad adaptability. Materials bred at ICRISAT-Patancheru have done exceedingly well not only in India but in other countries as well. For example, ICSV 112, a variety bred at ICRISAT, Patancheru has been released in India, Zimbabwe, Zambia and the Central/Latin American countries. Similarly, CSH 9, a hybrid bred in the Indian Sorghum Program and released for cultivation in India, performed well in eastern and southern African countries.

Once the material is selected for broad adaptability, further improvement in yield gains can be obtained through breeding for regional adaptation, and then for specific adaptation within the region and finally for threshold traits within the specifically adapted materials. This strategy helped ICRISAT to maximize the utilization of germplasm in breeding program and enhance the yield potential significantly (Fig. 16).

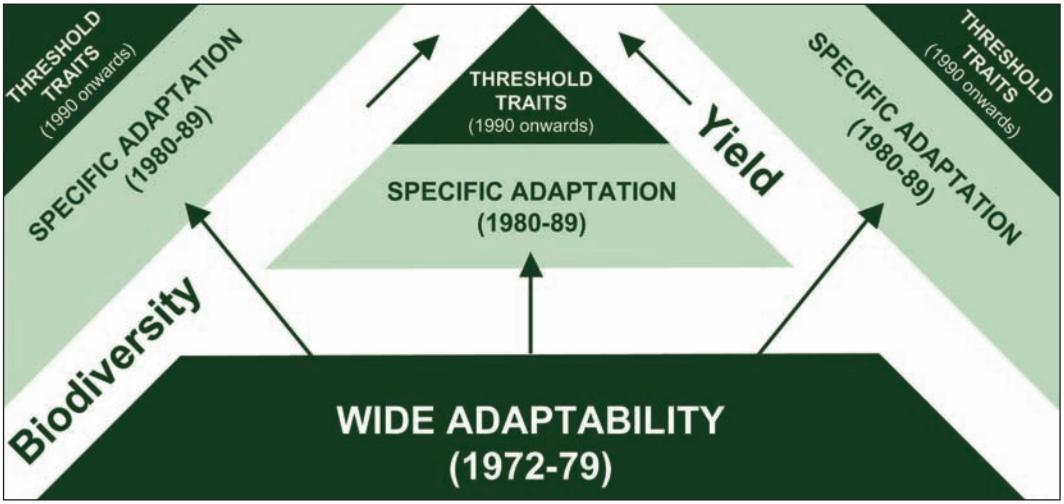

Fig. 16. Adaptation, germplasm utilization and yield levels.

Abiotic and biotic stresses

Information on the factors that limit the productivity needs to be gathered and they should be prioritized based on their importance in the target region and the availability of resources. Tolerance to drought, salinity and acidity among abiotic stresses and shoot fly, stem borer and headbug among the pests and grain mold, anthracnose, rust, leaf blight and downy mildew among diseases are important yield limiting factors and their importance vary depending on the season and location. Therefore, there is a need to develop efficient screening techniques and identify tolerance/resistance to various yield-limiting factors.

Target materials

In sorghum, target materials could be varieties or hybrids. Hybrids are popular with farmers in countries like USA, India, China and Australia. Hybrids have heterosis for grain and biomass yield, better resistance and adaptation to varied environmental conditions. The cytoplasmic-nuclear male sterility system has made it possible to produce hybrids for commercial cultivation. Further, private sector seed companies have taken up the seed production, distribution and sales in these countries helping farmers have easy access to the seed of improved cultivars. Parental lines performance has positive relationship with hybrids performance (Rao and House 1972; Mukherjee 1995); therefore parents need to be improved to improve hybrids. Heterosis in hybrids is proportional to the divergence between the parents involved (Crow and Kimura 1970). Therefore, the genepools for developing A/B-lines (female parents) development and R-lines (male parent) developments need to be handled separately to maintain divergence between them. In many of the countries in Africa (except Nigeria and Ghana), varieties are the target materials. Hybrids did not pick up because of poor seed systems in place.

Grain and fodder quality traits

Grain quality traits such as bold grain with thin pericarp and luster with semi-corneous endosperm are important for making "*roti*", while hard grain (small grain size) contribute to lessening grain mold damage. Grain nutritional traits selection programs, such as, for high protein or lysine are not successful in sorghum. Heritabilities of fodder digestibility, high protein and less fiber content are reasonably high and it is possible to breed for high grain yield and high fodder quality.

Genetics and tools

Information on the genetics of various` traits of interest is important in designing a breeding program. For example, if a trait is under the control of a few genes, one may use backcrosses or pedigree breeding. On the other hand, if traits are under the control of a large number of traits, population improvement with appropriate recurrent selection schemes with ms_3/ms_7 gene may be followed. The latter method is time and resource consuming. The researchers are under pressure to deliver improved cultivars within a short period, say 4 to 6 years. So, commonly, breeders follow the pedigree method of breeding.

The new science tools—marker assisted selection or genetic engineering can also be deployed in sorghum wherever resources and expertise are available. For example, markers for resistance to shoot fly and *Striga* and stay-green traits are identified in sorghum, and applying them in practical breeding is underway both in the Indian Sorghum Program as well as at ICRISAT. Genetic engineering to transfer Bt genes to control stem borer is also underway in these programs.

Resources and team

The scope of a breeding program depends on the resources available and the extent and the expertise of team members. When the resources are limited, for example, one can conveniently use simple mass selection in (ms_3) population for all traits that can be observed before flowering. Examples are mass selection for resistance to shoot fly, high tiller number, midrib color (brown) intensity, etc. On the other hand, if the resources permit, one may go for a full-fledged population improvement program or pedigree method of breeding. Also, new science tools may be followed provided resources and expertise are available.

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