

## Sorghum Hybrid Parents Research at ICRISAT: Retrospect and Prospects

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### Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the first ever self-pollinated cereal staple crop in which heterosis has been commercially exploited using a cytoplasmic-nuclear male-sterility (CMS) mechanism to improve productivity. This system was first described in sorghum by Stephens and Holland (1954). This CMS system has been designated as A<sub>1</sub> (*milo*). Since then a large number of hybrids have been developed and released and/or marketed for commercial cultivation in all sorghum-growing countries with a strong national agricultural research system (NARS). These hybrids have contributed significantly to increasing grain and forage yields in several countries.

Encouraged by this success, continued research investments have been made in the development of hybrid parents [male-sterile (A-) lines (seed parents) and restorer (R-) lines] and hybrids by the sorghum improvement programs of several NARS and by ICRISAT. Research on hybrid parents at ICRISAT was initiated in 1978 at its headquarters at Patancheru, Andhra Pradesh, India; in 1985 at Bulawayo, Zimbabwe in Eastern and Southern Africa; and in 1982 at Sotuba, Mali in Western and Central Africa. In this article, we review the progress made in hybrid parents research in the light of strategies followed, and sketch the outline of future research at ICRISAT.

### Seed Parents Research at ICRISAT-Patancheru, India

Sorghum seed parents research at ICRISAT-Patancheru can be seen as three phases: Phase I (1978–1988), Phase II (1989–1998) and Phase III (1999 onward).

**Phase I (1978–1988).** During this phase, grain yield and food-quality characteristics, along with major adaptation traits such as maturity time received emphasis in an effort to match crop-season and region-specific requirements. The breeding strategy involved conversion of F<sub>6</sub> homozygous lines with male-sterility maintainer reaction (B-lines) derived from pedigree selection into A-lines. Lines with good general combining ability (*gca*) for grain yield, grain quality, desired maturity and plant height (dwarf) were converted into A-lines using 5–6 backcrosses to a known A-line with A<sub>1</sub> cytoplasm. A total of 92 high-

yielding A-/B-lines, including 17 early-maturity lines (<66 days to 50% flowering), and 75 medium-maturity lines (66–75 days to 50% flowering) were developed during this period.

**Phase II (1989–1998).** A trait-based breeding approach was followed to develop hybrid parents resistant to biotic and abiotic constraints during this phase. It involved simultaneous selection for resistance to specific biotic stresses [such as shoot fly [*Atherigona soccata* (Rond.)], stem borer [*Chilo partellus* (Sw.)], midge [*Stenodiplosis sorghicola* (Coq.)], head bug (*Calocoris angustatus* Leth.), grain mold (fungal complex consisting of *Curvularia lunata*; *Fusarium* spp.; *Alternaria alternata*; *Cladosporium oxysporum*; *Colletotrichum*, etc.), downy mildew (*Peronosclerospora sorghi*), leaf blight (*Exserohilum turcicum*), anthracnose (*Collectotrichum graminicola*), rust (*Puccinia purpurea*) and *Striga*] and abiotic stresses (such as terminal drought) based on families, and for grain yield based on individual plants within the selected resistant families from the F<sub>4</sub> generation onward. The selected lines with maintainer reaction were converted into A-lines. The trait-based method ensured retaining greater genetic diversity in the A-lines. Thus, 567 trait-based A-/B-lines (Reddy et al. 2005) and 30 high-yielding A-/B-lines were developed at ICRISAT-Patancheru in Phase II, resulting in a total of 597 A-/B-lines.

**Phase III (1999 onward).** This phase marked the beginning of race-specific and alternative (non-*milo*) CMS systems (A<sub>2</sub>, A<sub>3</sub> and A<sub>4</sub> in that order) with the goal of diversifying A-lines. Further, diversification of A-lines for farmer-preferred evident grain quality traits such as white, large and lustrous grains for postrainy season adaptation (typical of India) has been emphasized. Diversification of A-lines was scaled down to only two major biotic constraints, shoot fly (for rainy and postrainy seasons) and grain mold (for the rainy season), while maintaining high yield potential. These efforts led to the development of 732 A-/B-lines, which include A<sub>1</sub> CMS system-based 165 (160 old + 5 new) high-yielding lines, 487 biotic and abiotic stress-resistant-lines, and 51 A<sub>2</sub>, 17 A<sub>3</sub> and 12 A<sub>4</sub> CMS system-based lines at ICRISAT-Patancheru. All these A-/B-lines have been designated as ICSA 1, 2, 3, ... etc., nos., where 'ICSA' refers to ICRISAT sorghum A-/B-lines (the characteristics of these lines are available and

placed in the public domain). Since 2000, 85 (other than the 732 cited earlier) new race-specific A-/B-lines (39 A<sub>1</sub> and 46 A<sub>2</sub> CMS system-based lines) have been developed. The grain yield potential of some of the best *durra* large-grain B-lines (A<sub>1</sub>) is significantly higher than the control 296B which has a comparable grain size.

### Seed Parents Research: ICRISAT-Bulawayo, Zimbabwe

Hybrid seed parents research in southern Africa has been carried out under the Sorghum and Millets Improvement Program (SMIP) and was initially based on selections from A-/B-lines received from the USA and ICRISAT-Patancheru to exploit the residual variability wherever present in the introductions. Considering the poor adaptation of these introduced materials, SMIP initiated its own programs for developing high-yielding hybrid parents with local adaptation. As a result of concerted efforts, 36 A-/B-lines, designated as SDSA-/B 1 to SDSA-/B 36, were developed through four backcrosses and selections for maturity duration (early to medium), grain yield and grain quality traits, and stay-green. These A-/B-lines are slightly taller than the controls, a little earlier (by 2 days), superior in grain yield (by 8%) and 5–110% superior in milling quality. These new A-lines have been grouped into three categories: (i) dwarf (<1.0 m) with broad drooping leaves, tan plants and resistant to leaf blight and sooty stripe; (ii) semidwarf (1.0–1.6 m) with thin upright leaves, and nontan (purple) plants but susceptible to leaf blight and sooty stripe; and (iii) semi-tall (1.7–1.9 m) with broad leaves, and tan plants but susceptible to leaf blight and sooty stripe.

### Seed Parents Research: ICRISAT-Sotuba, Mali

Research on seed parents adapted to Western and Central Africa (WCA) by the ICRISAT-Mali program was initiated in 1982. A set of 227 Malian landraces (consisting of 74% *guinea* landrace accessions) was assessed for fertility reaction on an A<sub>1</sub> CMS system. A high proportion (36%) of the *guinea*-based landraces showed maintainer reaction, but attempts were not made to convert these lines into A-lines at that time. Concerted efforts have been made since 2002 to develop *guinea* race A-lines based on the A<sub>1</sub> CMS system by ICRISAT in collaboration with the Institut d'Economie Rurale (IER), Mali and Institut d'Etudes et de Recherches Agronomiques (INERA), Burkina Faso leading to the identification of maintainers in *guinea*-race accessions from WCA as well as Eastern and Southern Africa and Asia. The objective was to develop seed parents with acceptable grain quality and *guinea* glume and panicle characteristics, and the required

photoperiod sensitivity for producing hybrids with adaptation to West Africa.

The first *guinea* landrace A-lines were based on Malian varieties Fambe, IPS 001 and CSM 219 (developed by ICRISAT), and seven interracial derivatives of a cross [*guinea* landrace (Bimbiri Soumale) × *caudatum* varieties] developed by IER. While *guinea* landrace-based A-lines are tall, photoperiod sensitive, and possess typical *guinea* grain and panicle architecture, the A-lines derived from interracial derivatives are dwarf, basically photoperiod-insensitive and possess relatively small grain typical of *guinea* races.

The development of new A-lines (based on the A<sub>1</sub> CMS system) continues with sterilization of *guinea*-core collection accessions from Burkina Faso, Gambia, Malawi, Senegal, Sudan and Uganda by the ICRISAT program and interracial lines by IER. These are currently in advanced stages of conversion (in BC<sub>4</sub> generation). In addition, the first set of progenies derived from the dwarf *guinea* random-mating population is being converted into A-lines. These A-lines under development will provide diversity for most agronomic traits, spanning the range of grain size (100-grain weight of 1.0–3.0 g), grain/glume form (*Margaritifera* to *Conspicuum* in the Snowden classification), panicle length (30–60 cm) and plant height (3–4 m) typical of the *guinea* race. Tall A-lines are expected to be useful in developing tall hybrids adapted to the drought-prone areas of West Africa. Besides agronomic traits, the B-lines under conversion represent a wide range of maturity which is intended to address the needs of the Northern Sudanian zone (600–800 mm), the Southern Sudanian zone (800–1000 mm) and the Northern Guinean zone (1000–1200 mm). These lines, which flower before 15 Sep (along with earlier developed CSM 219A and interracial A-lines) are most promising for the Northern Sudanian zone, whereas those which flower between 15 Sep and 25 Sep and thereafter are most promising for the Southern Sudanian and Northern Guinean zones, respectively.

### Restorer Parents Research: ICRISAT-Patancheru, India

There have been no planned efforts to develop restorers at ICRISAT-Patancheru. Several of the improved varieties bred in various projects at the center were found to be restorers on the A<sub>1</sub> CMS system and were added to the restorer gene pool. Besides these, selections found to have a restorer reaction in the A-line development programs were added to the restorer gene pool, though their contribution to it is limited. R-line breeding therefore rested mainly on the varietal development program, in which grain quality traits and yield potential were given major emphasis during the period 1972–1978, and resistance

to biotic and abiotic stresses during 1979–1988. The program of varietal/restorer improvement has been renewed though on a small scale in the last three years. The varietal/R-line improvement programs at ICRISAT-Patancheru led to the identification/development of 883 R-lines (873 old and 10 new) based on  $A_1$ , 146 on  $A_2$ , and three dual R-lines ( $A_1$  and  $A_2$ ). All these R-lines have been designated. Apart from these, 36 dual R-lines based on  $A_1$  and  $A_2$ , two on  $A_1$ ,  $A_2$  and  $A_3$ , and two on  $A_1$ ,  $A_2$ ,  $A_3$  and  $A_4$  (Maldandi),  $A_4$  (VZM) and  $A_4$  (Guntur) CMS systems have been identified.

**Large-grain high-yielding R-lines.** The R-line development program led to the identification of 142 R-lines based on the  $A_1$  CMS system since 2000. Replicated field evaluation of these new R-lines indicated the superiority of two, ICSR 24010 and ICSR 24006, for grain yield (each with yields of 5.6 t ha<sup>-1</sup>) compared to the control, CSV 4 (4.4 t ha<sup>-1</sup>), and grain size (with 2.8 g and 2.7 g 100<sup>-1</sup> grains, respectively) compared to CSV 4 (2.5 g 100<sup>-1</sup> grains) with a comparable maturity period.

### Restorer Parents Research: ICRISAT-Bulawayo, Zimbabwe

In southern Africa, as was done in the case of A-/B-lines, the development of R-lines was mainly based on selections (for local adaptation, male-fertility restoration, and earliness and grain quality traits) from 33 R-lines introduced from INTSORMIL and several varieties/R-lines from ICRISAT-Patancheru in the 1980s. A total of 23 R-lines designated as SDRS 1 to SDRS 23 were selected from the 33 INTSORMIL introductions. The R-lines were tested for four years (1992/93–1995/96) at Matopos and Lucydale in Zimbabwe. When compared with controls, they gave 15% higher grain yield, were 20% shorter, had 58% harder grains and 10% higher milling yield (Obilana 1998).

### Restorer Parents Research: ICRISAT-Sotuba, Mali

At ICRISAT, Mali, several lines with restorer reaction with a range of panicle length (28–40 cm), 100-seed weight (1.0–2.9 g) and heading date (15 Sep–27 Oct) were identified from a subsample of *guinea*-core collections. A range of interracial R-lines were also developed by the IER-Mali program.

### Looking Ahead

**Genetic diversification.** The hybrid parents need to be further diversified by creating separate gene pools for seed parents by crossing *guinea*- and *durra*-based

B-lines, and for restorer parents by crossing *caudatum*- and *bicolor/durra*-based R-lines for various selected traits for both sorghum crop seasons in India. Of the several available non-*milo* CMS systems,  $A_2$  offers an immediate option for diversifying the CMS base of hybrid parents, and hence hybrids. The hybrid parents also need to be further diversified with *guinea*, *feterita* and *bicolor* races for improving grain yield and *dochna* types from Myanmar and other high-biomass types with sweet stalk (also brown midrib) for improving multicut forage yield potential. The identification and validation of molecular markers linked to stalk sugar content, juiciness and yield would enhance the pace and efficiency of sweet sorghum improvement programs.

**Plant defensive traits.** Given that the shoot fly resistance (SFR) level in the primary gene pool (eg, IS 18551; 2n=20) is low to moderate, the use of wild sorghums such as *S. purpureosericeum* and *S. versicolor*, members of the section *Parasorghum* which are known to have high levels of SFR, would not only enhance resistance levels, but also diversify the genetic base of the hybrid parents. Also, considering the higher levels of SFR, the  $A_4$  (Maldandi) CMS system (Dhillon et al. 2005) needs to be tapped for the development of hybrids with postrainy-season adaptation and having good grain quality traits and SFR levels that match the popular cultivar, M 35-1. Gidda Maldandi with  $D_2$  dwarf genes can be exploited to develop A-lines for postrainy-season adaptation. Resistance to stem borer is also important in sweet-stalk and forage sorghum cultivars as stalks are the main economic product. Low levels of resistance in cultivated types and the complexity of inheritance warrants the use of genetic transformation to enhance the levels of resistance to stem borer.

Considering the complexity of inheritance and operation of different mechanisms for grain mold resistance, efforts need to be made to identify suitable molecular markers to enable pyramiding of the genes associated with various mechanisms in high-yielding hybrid parents. Head bug damage, which is a serious yield constraint in West Africa and in India in the rainy season, promotes grain mold severity. Therefore, it would be useful to develop cultivars with dual resistance to grain mold and head bug. However, benefits from cultivars resistant to these biotic stresses can be maximized if these are integrated with appropriate natural resource management technologies in both Asia and Africa.

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## References

- Dhillon MK, Sharma HC, Reddy BVS, Ram Singh, Naresh JS and Zhu Kai.** 2005. Relative susceptibility to different male-sterile cytoplasm in sorghum to shoot fly, *Atherigona soccata*. *Euphytica* 144:275–283.
- Obilana AB.** 1998. Sorghum improvement. *International Sorghum and Millets Newsletter* 30:4–17.
- Reddy BVS, Ramesh S and Ortiz R.** 2005. Genetic and cytoplasmic-nuclear male-sterility in sorghum. *Plant Breeding Reviews* 25:139–172.
- Stephens JC and Holland RF.** 1954. Cytoplasmic male-sterility for hybrid sorghum seed production. *Agronomy Journal* 46:20–23.