

ICRISAT–Indian NARS partnership sorghum improvement research: Strategies and impacts

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More than three decades of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Indian National Agricultural Research System (NARS) partnership sorghum improvement efforts through integrated genetic and natural resources management and socio-economic research led to the development and release/marketing of several improved varieties and hybrids and crop production packages by exploiting complementary expertise. Adoption of these improved technologies directly translated into food security for millions of poor in the Indian semi-arid tropics (SAT). This article traces how the ICRISAT–Indian NARS partnership sorghum improvement research methods together with innovative technology-sharing and dissemination methods have improved the livelihoods of millions of resource-limited farmers in the Indian SAT.

Keywords: Breeding, germplasm, improvement, research, sorghum.

SORGHUM [*Sorghum bicolor* (L.) Moench] is a major cereal of the world after rice, wheat, maize and barley. It is the third important staple foodgrain after rice and wheat for millions of poor and most food-insecure people in the semi-arid tropics (SAT) in India. While the rainy-season sorghum grain is used mostly for animal/poultry feed, post-rainy season produce is used for human consumption. In SAT India, sorghum is truly a dual-purpose crop; both grain and stover are highly valued outputs. In large parts of SAT India, sorghum stover represents up to 50% of the total value of the crop, especially in drought years¹. Sorghum also offers great potential to supplement fodder requirement of the growing dairy industry in India because of its wide adaptation, rapid growth and high green-fodder yields as well as good quality.

Production constraints

The yield and quality of sorghum produce is affected by a wide array of biotic (pests and diseases) and abiotic stresses (drought, low temperature and problematic soils). The major biotic constraints include shoot fly, stem borer and head bug among insect pests; grain mould and anthracnose (northern India) among the diseases, while terminal drought and low temperature (post-rainy season) and problematic soils – salinity (some parts of India) are the

major abiotic constraints. Due to these production constraints and the use of traditional cultivars (low-yielding) coupled with traditional production practices, sorghum grain productivity was low (0.7 t ha⁻¹ in the rainy and 0.5 t ha⁻¹ in post-rainy season) in the early 1970s.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, in collaboration with the Indian National Agricultural Research System (NARS) partners, which include National Research Centre for Sorghum (NRCS), Hyderabad; Indian Council of Agricultural Research (ICAR), New Delhi; State Agricultural Universities (SAUs) and other universities, research institutions and organizations, private sector seed companies and non-governmental organizations (NGOs), aimed to enhance sorghum productivity through integrated genetic and natural resources management and socio-economic research that directly translated into food security and income gains through improved competitiveness for sorghum in the sorghum-based industrial markets of India. In this article, we have outlined the research strategy of ICRISAT and made an attempt to trace how its partnership sorghum improvement research with the Indian NARS has improved the incomes of millions of resource-limited farmers in the Indian SAT through significant improvements in realized incomes not only from the higher and sustained productivity and cultivar diversity (thus assuring food security), but also from hybrid seed-production activities and broadened utilization of sorghum.

Research strategy and breeding processes

The research strategy of ICRISAT is founded on four global research themes (Crop improvement, Biotechnology, Agro-

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ecosystems and markets, and policies and impacts) addressed through problem-based and impact-driven regional and local projects. The strategy recognizes greater integration and diversification of partnerships as a core research methodology for development and impact. The breeding approaches followed at ICRISAT influenced the Indian programme and vice versa. Over the years, the External Programme Reviews (once in five years), donors' perceptions, Indian NARS capacity and ICRISAT research management structures guided ICRISAT to change its strategy from breeding for wide adaptability to breeding for regional or specific adaptations, and later to trait-based breeding¹. Similarly, Indian NARS also changed its strategy from breeding for wide adaptation approach to regional adaptation. The needs of sorghum research in India have influenced the global sorghum improvement programme at ICRISAT, in setting up its own objectives and to dichotomize them into regional and global goals.

Germplasm evaluation

A strong germplasm resource base and its characterization is a pre-requisite for any systematic crop improvement programme. ICRISAT, in collaboration with ICAR, conducted several multi-locational trials for evaluation of germplasm for important agronomic characters like photo-period sensitivity, forage yield and its related traits, responses to biotic stresses, etc. to identify locally adapted material for use in breeding programmes.

Screening for forage traits

The National Bureau of Plant Genetic Resources (NBPGR), New Delhi and ICRISAT evaluated 1500 accessions (selected from the world collection of sorghum germplasm maintained in the ICRISAT genebank) for forage yield and their components during 1986–92 at three locations, viz. NBPGR, New Delhi; Indian Grassland and Fodder Research Institute (IGFRI), Jhansi and NBPGR Regional Station, Akola, and identified many promising lines. The results of the evaluation have been published^{2,3}.

Screening for biotic stresses in hot-spot locations

The global programme of ICRISAT for biotic stress resistance breeding took advantage of the hot-spot locations in India for screening the materials for resistance to various pests and diseases. For example, screening for rust and midge at Dharwad, Karnataka; stem borer at Hisar, Haryana and at Warangal, Andhra Pradesh (AP); anthracnose and leaf diseases at Pantnagar, Uttar Pradesh (now in Uttarakhand); drought at Anantapur, AP, and *Striga* at Akola, Maharashtra. Several sources of resistance to these biotic

constraints were identified. Examples are: IS 1034, IS 1071, IS 1096, IS 2205, IS 18551 and IS 2123 for shoot fly; IS 1044, IS 1119, IS 2123, IS 5470, IS 2205 and IS 21969 for stem borer; IS 18700 (DJ 6514) for midge; IS 23599, IS 25017, IS 4006, IS 5959 and IS 13267 for grain mould; IS 18484 for anthracnose, and IS 18331 (N 13) and IS 18475 (555) for *Striga*.

Breeding products

Initially, both ICRISAT and the Indian NARS programmes placed greater emphasis on grain yield and good grain types, and the partnership was on an informal basis. ICRISAT extensively made use of several high-yielding good grain types from the Indian programmes. For example, CS 3541, 555, UChV₂, GPR 148, GPR 165, GPR 168, SPV 105, M 35-1, and CSV 1 (Swarna) in varietal/restorer programmes, and 2077B and 296B in seed parents' development programme were used as parents for developing varieties or hybrid parents at ICRISAT for regional and/or global use. As the programme emphasis changed from breeding for high yielding to improving for resistance to various biotic (grain moulds, shoot fly, stem borer, midge, anthracnose, *Striga*, etc.) and abiotic (drought) stresses, which are also relevant to India, ICRISAT strengthened the sorghum improvement programme by initiating several projects on breeding for the resistance traits. This approach at ICRISAT generated diversified arrays of breeding materials improved for resistance to insect pests, diseases, *Striga* and drought. This enabled the Indian programme to take advantage of the breeding materials and resistant sources improved in the joint Indian NARS–ICRISAT partnership programmes. For example, the improved resistant lines – ICSV 745 (ref. 4; released as DSV 3 by Karnataka State), ICSV 197 (ref. 5) and ICSV 735, ICSV 758 and ICSV 808 (ref. 6; midge-resistant); ICSV 705 and ICSV 708 (shoot fly-resistant); ICSV 700, ICSV 112 and ICSV 702 (stem borer-resistant); Malisor 84-7 (head bug-resistant); ICSR 94015, ICSV 95019 and ICSV 96101 (grain mould-resistant); SP 36257 (downy mildew-resistant); A 2267-2 (multiple leaf diseases-resistant), and ICSR 89014 (ergot-resistant) were utilized in the various resistance breeding programmes in India. The *Striga*-resistant varieties, SAR 1 (released as ICSV 145 for cultivation in AP, Tamil Nadu and Karnataka by the Indian Government)¹ and SAR 19 may be cited as examples of successful partnerships between ICRISAT and ICAR.

The ICRISAT-bred varieties, ICSV 1, ICSV 112, SDS 2650, S 34, S 35, GD 57904, ICSV 126, GD 57903 and GD 11183 were utilized in Indian varietal breeding programmes; and ICRISAT-bred restorers and seed parents, MR 750, MR 830, ICSV 89058, ICSV 194, ICSV LM 865B, ICSR 89058, ICSB 101, ICSB 56, ICSB 73, ICSB 70, SPL 90B, SPMD 8643A (midge-resistant) and SPSFR 94010A, SPSFR 96069A, SPSFR 8643A and SPSFR

86065A (shoot fly-resistant) were utilized in the development of hybrids in the Indian programmes. Also, some of the seed parents such as ICSA 88020 were utilized in forage hybrids development at Hisar. Varieties, ICSV 1 (CSV 11) and ICSV 112 (CSV 13) and the hybrid CSH 11 were released for commercial cultivation by Indian farmers⁷.

Apart from these, several germplasm accessions/selections have been released as superior varieties through partnership research in India. Notable among these are NTJ 2 and Parbhani Moti with large and pearly white grains for post-rainy season cultivation in AP and Maharashtra, respectively. Thus, the partnership research efforts by a multi-disciplinary team of scientists at ICRISAT and in the Indian NARS programmes have led to the release of 22 improved cultivars using ICRISAT-bred materials in India.

Germplasm exchange and utilization

The success of the ICRISAT–Indian NARS partnership sorghum improvement programme is due to the dynamic sorghum improvement programme involving a multidisciplinary team of scientists utilizing the strong genetic resources base of 36,744 accessions from 91 countries (India alone contributed about 17%) representing all the five basic and their hybrid races maintained at the Rajendra S. Paroda Genebank in ICRISAT⁸. India is by far the largest recipient of sorghum germplasm. Over 25 years, the ICRISAT genebank has supplied 126,729 seed samples to sorghum scientists in India on specific requests. A total of 5701 germplasm seed samples have been supplied to scientists of ICAR institutes and SAUs in response to 116 specific requests during 1999–2003. ICRISAT has duplicated and repatriated 14,615 sorghum germplasm accessions to the high-tech facility at NBPGR⁹.

In pursuit of diversifying its breeding products (160 pairs of high-yielding, male-sterile lines; 567 pairs of trait-specific, male-sterile lines; 873 improved restorer lines, and 1451 varieties), ICRISAT scientists have captured both racial as well as geographical diversity. Nearly 4000 germplasm accessions were utilized to generate variability, of which 557 have contributed to the development of the elite lines mentioned above. The tropical germplasm lines (152) originating from India have contributed immensely (30% of the total germplasm lines originating from other countries/regions) towards the development of these breeding products. The formation of core collection (2247 accessions)¹⁰ has helped enhanced utilization of these genetic resources.

ICRISAT–ICAR partnership projects

The increased need for prioritization and focused research led to the development of formal partnership projects between ICRISAT and ICAR. Currently, there are two formal partnership projects: (i) Diversification of seed parents

and restorers with adaptation to rainy and post-rainy seasons, and (ii) mechanisms and molecular markers for resistance to grain mould, shoot fly and stem borer. In these partnership projects, for example, some of the materials (PKV 801, KR 194, C 43, PMS 7B) developed with the Indian programmes are being used to develop mapping populations to identify molecular markers for resistance to grain mould.

ICRISAT also supplies advanced lines to NRCS towards trait-based nurseries and NRCS organizes and distributes them along with their own materials to the selected All India Coordinated Sorghum Improvement Project (AICSIP) centres for evaluation. For example, NRCS organizes evaluation of Sorghum Grain Mould Variability Nursery (SGMVN) and Sorghum Grain Mould Resistance Stability Nursery (SGMRSN) at the AICSIP centres in Akola, Parbhani, Palem, Surat and Patancheru, to identify major pathogenic fungi and variability among them in different environments and also to identify stable grain mould-resistant (GMR) advanced breeding lines (for use in GMR breeding) developed from GMR breeding at ICRISAT and in the Indian NARS programmes. Similarly, NRCS organizes evaluation of shoot pests and sugarcane aphid resistance nurseries at the AICSIP centres. As a long-term and balanced breeding strategy to develop the much needed broad, genetic-based, improved pure-line varieties as well as hybrid parents for sustained productivity as well as for developing cultivars that cater to the diverse and ever-changing consumer preferences and tastes, population improvement programmes were revived in partnership with NRCS. A total of 19 ICRISAT-developed genetic male sterility-based populations¹¹ are being maintained at ICRISAT in collaboration with NRCS.

Impacts on livelihoods of resource-poor farmers and people

Adoption of improved cultivars and on-farm cultivar diversity

The worth of the improved cultivars is indicated by their successful adoption by farmers, and is the precondition for creating impacts. India has the highest level of adoption of improved cultivars (65% of total sorghum area) in Asia (excluding China). Of this, more than 50% of the area is covered under cultivars with ICRISAT content. In India, more than 4 m ha is occupied by over 54 hybrids developed by private sector seed companies based on ICRISAT-bred parental lines or their derivatives. For instance, ICRISAT–private sector partnership hybrids, JKSH 22 and VJH 540, known for their high grain-yield potential, large grain and earliness, showed remarkable adoption covering 210,000 ha in 2002 (ref. 1) and 142,000 ha in 2003 (ref. 12), respectively, in the rainy season areas in major sorghum-growing States in India. Apart from these, several other

private sector hybrids with ICRISAT content such as MLSH 296, GK 4009 and GK 4013 are widely adopted in India. A dual-purpose, GMR rainy-season adapted sorghum variety PVK 801 (being cultivated in over one lakh hectares in Maharashtra) developed by ICRISAT in partnership with Marathwada Agricultural University (MAU), Parbhani, and SPV 1411 (Parbhani Moti), a post-rainy season variety with pearly white large grains (being cultivated in over two lakh hectares in Maharashtra and Karnataka) are highly popular among farmers because of their higher grain- and fodder-yielding ability coupled with good grain and stover quality. Another hybrid SPH 840 developed by ICRISAT in partnership with Panjabrao Deshmukh Krishi Vidyapeeth, Akola, is also popular as its grain- and fodder-yield potential is better than the highly popular hybrid CSH 16. These are only illustrative examples of ICRISAT-bred hybrid parents and the power of partnership to exploit the complementary expertise between ICRISAT and Indian NARS and the private sector to develop and deliver desired products. Adoption of these improved cultivars along with improved crop production technologies developed through natural resources management research¹³ resulted in an increase of sorghum grain productivity by 280 kg ha⁻¹ during the period from 1971–73 to 2000–03.

Costs of production and cost-benefit ratio

A study of cost-benefit in India showed that the cost of unit production (cost per ton) using improved varieties decreased in different States in the 1980s and 1990s compared to that in the early 1970s, despite the increase in total cost of production because of the use of additional inputs¹³. The productivity gains from improved cultivars have more than compensated the cost of additional inputs used for their cultivation. The reduction in per ton cost of production in the 1990s was 40 and 37% in Maharashtra and Rajasthan, respectively, compared to that in the early 1970s. The cost-benefit ratio of production of improved cultivars in India¹³ is 1 : 1.4. The popularity of hybrids triggered hybrid seed production in India and several seed villages in AP and Karnataka became prosperous by taking up large-scale hybrid seed production. Seed production of ICRISAT-private sector partnership hybrid, JKSH 22 alone earned farmers on an average over Rs 137 crore per year in AP and Karnataka, and Rs 1200 crore from commercial cultivation of JKSH 22 in Maharashtra and other sorghum-growing areas in India¹².

Impacts on sustainable production systems

Improved genetic resistance to biotic and abiotic stresses

Cultivars with improved genetic resistance to biotic stresses formed an integral component in integrated insect pest

and disease management, which together with the cultivar diversity resulting from partnership-trait-based breeding approach, has led to sustainable production systems and environment protection in SAT India. Further, the improved short-duration cultivars not only helped escape terminal drought (commonly experienced in SAT), but also could fit into different cropping systems and crop rotations leading to sorghum-based crop diversification and hence sustainable agro-ecosystems. In India, varieties bred for specific adaptation such as ICSV 112 and ICSV 745, which are relatively early and resistant to foliar diseases (and ICSV 745 resistant to midge) introduced in Warangal district, AP showed grain-yield advantages to the tune of 56% in intercropping and 30% in sole cropping systems, and enabled farmers to earn 13% higher income in ICSV 112 and 58% in ICSV 745. These varieties gave 20% higher grain yield and 35% higher fodder yield than the locally adopted cultivars in the drought-prone Melghat region of Maharashtra⁹.

Innovations in science and their sharing

Innovations in research, and sharing of technologies developed out of such innovations are few of ICRISAT's major objectives, among others. Innovative, strategic and upstream research outputs developed by the ICRISAT-Indian NARS partnership research – ideas, concepts, methods, techniques and intermediate products – that were inputs for further research have contributed immensely to increased efficiency of the breeding processes of ICRISAT and those of NARS partners.

Strategic research

Leads in strategic research areas such as reliable and cost-effective screening techniques and identification of resistance sources for various abiotic yield constraints such as drought and soil salinity¹⁴, and biotic yield constraints such as shoot fly¹⁵, stem borer¹⁶, midge¹⁷, grain mould¹⁸, downy mildew¹⁹ and anthracnose²⁰, genetics of several traits of economic importance and use in adaptation such as resistance to shoot fly, stem borer, midge, grain mould and stay-green (a known trait conferring terminal drought resistance), the moving average concept to improve selection efficiency for yield constraints¹ and diversification of cytoplasm and nuclear genetic base of cytoplasmic-nuclear male sterility (CMS)-based sorghum hybrids helped hasten the delivery of outputs both within ICRISAT and NARS programmes in Asia and Africa. The development and dissemination of a method of producing heterotic landrace pollinator-based hybrids for post-rainy season adaptation provided the impetus for the private sector to develop and market post-rainy season-adapted sorghum hybrids for the first time in India.

Technology sharing

Exchange of breeding material: Based on specific requests, seed samples of hybrid parents, varieties and populations were supplied to NARS partners in India. A large number of seed samples representing various categories of breeding materials (A-/B-lines, restorers, varieties/others) have been supplied to several public (A-/B-lines-8294; restorers-2609; varieties/others-55131 samples) and private sector (A-/B-lines-17637; restorers-8036; varieties/others-28186 samples) scientists in India during 1986–2005 on specific requests. It is important to note that multi-national private sector companies share their ICRISAT-procured breeding materials among their various branches and hence there is much wider dissemination of the materials. The use of these improved breeding materials had a multiplier effect, with public and private research organizations further developing 54 finished products (hybrids), specifically for targetted production areas testifying the utility and impact of ICRISAT-bred hybrid parents. Further, the international testing programme of ICRISAT helped in testing some of the cultivars developed by Indian programme scientists, and some of these cultivars have performed well in several parts of Asia (e.g. Thailand) and Africa (e.g. Ethiopia). For example, the hybrid CSH 9 performed well both in Asia and Africa, and the variety GPR 148 is preferred by farmers in Ethiopia for its earliness and bold seed.

Participation in AICSIP trials: The AICSIP has been conducting replicated yield trials at various locations representing different agro-climatic zones with a view to identify and release improved sorghum varieties and hybrids for commercial cultivation in more than one State. ICRISAT-bred varieties/hybrids and those derived from ICRISAT breeding materials by national breeders have been tested in AICSIP trials since 1979–80. So far, 68 varieties and 74 hybrids were entered into advanced trials directly by ICRISAT (up to 1992/93 and thereafter, direct contribution was stopped) and 167 varieties and 74 hybrids developed from ICRISAT materials were entered into advanced trials by national programme breeders²¹. Recently, four ICRISAT-bred sweet sorghum varieties (S 35, ICSV 700, ICSV 25263 and ICSR 93034) were tested in AICSIP during the 2004 rainy season, among which, ICSV 700 and ICSR 93034 have been promoted for advanced testing during the 2005 rainy season. ICSV 700 has been promoted for testing during the 2006 rainy season for the second time. Apart from these, five other varieties [ICSV 574 (SPV 422), SPV 1411, ICSV 93046, Seredo and NTJ 2] and 15 hybrids were tested during 2005 rainy season²² and among these, two varieties (ICSV 93046 and NTJ 2) and one hybrid (ICSA 293 × SSV 74) have been promoted for advanced testing during the 2006 rainy season. Besides, one variety (SP 4481-2) and four hybrids (ICSA 702 × SPV 422, ICSA 324 × NTJ 2, ICSA 324 × ICSV 25263

and ICSA 324 × SSV 74) have been contributed for testing during the 2006 rainy season.

Upstream research

Tremendous developments in plant molecular marker and transgenic technologies, ingenuity of farmers and information technology have helped to address more intractable and difficult-to-breed traits such as stem borer, shoot fly and terminal drought-resistance (stay-green trait). Quantitative trait loci (QTLs) conferring resistance to these yield constraints such as shoot fly and terminal drought have been identified in collaboration with MAU; University of Agricultural Sciences, Dharwad and NRCS. Molecular marker-assisted selection (MAS) is underway to introgress the QTLs of stay-green trait from B 35 and E 36-1 donors into the genetic background of M 35-1 (a highly popular post-rainy season variety) in collaboration with NRCS. Similarly, QTLs governing shoot fly resistance (SFR) are being transferred from IS 18551 (shoot fly-resistant donor) into the genetic background of 296B and BTx 23 (hybrid seed parents of several popular hybrids such as CSH 1, CSH 9, CSH 10, CSH 11, CSH 13, CSH and 13R)⁷ in collaboration with Osmania University, Hyderabad. The shoot fly-resistant versions of 296B and BTx 23 will be available by late 2006 for field evaluation. Stay-green QTL introgression lines in the genetic background of R 16 (a popular released post-rainy season variety in Rahuri) are being field-evaluated in collaboration with UAS, Dharwad (Bijapur) and MAU. Further, stay-green and SFR QTLs are being introgressed into the genetic background of post-rainy season-adapted hybrid parental lines through MAS in collaboration with MAU and UAS and are in advanced stages (BC₃F₁). ICRISAT is the first to develop sorghum transgenics for resistance to stem borer, which are currently under contained glasshouse testing. Farmer participatory plant breeding has started showing significant benefits in India. Farmer participatory varietal selection facilitated the release of the variety SPV 1359 for post-rainy season cultivation in Maharashtra and Karnataka states in India, during 1999–2000.

Alternative uses and methods of technology sharing

Research on the alternative uses such as sorghum grains in poultry feed for broiler²³ and layer production²⁴ and stalks (sweet) for ethanol production²² has helped broaden the demand for sorghum and innovative mechanisms of technology-sharing has ensured higher income to farmers.

Capacity building

ICRISAT is instrumental in enhancing the research and development capabilities of NARS in Asia and Africa on

various aspects of sorghum improvement. In India, ICRISAT provided training to 157 scientists during 1974–2004. Among these, eight were visiting scientists (VS), four postdoctoral fellows, 42 research scholars, 51 research fellows, one in-service long-term (6 months) and 16 in-service short-term trainees and 35 apprentices. Apart from these, ICRISAT conducts well-designated, short-term training courses regularly in specific areas to impart expertise to scientists of NARS – both private and public sectors – apart from the long-term capacity-building exercises in various disciplines mentioned earlier. Courses on sorghum hybrid parents' development, grain mould assessment, screening for resistance to diseases and pests, etc. are some of the examples. Other means of capacity building are farmers' and scientists' field days, which helped to obtain a feedback from the participants on research/products, which are being factored into the research portfolio and technology delivery mechanisms of ICRISAT.

Conclusion

The sorghum team at ICRISAT in partnership with Indian NARS (both public and private sectors) has tailored its research agenda, breeding methods and targetting of products to the needs of farmers and sorghum-based entrepreneurs such as private sector seed industry, poultry feed manufacturers and even bio-fuel manufacturers. Research collaboration between Indian scientists and ICRISAT is an example of partnership providing a platform for exploiting complementary expertise. Significant impacts in terms of release of partnership cultivars, adoption, increase in grain productivity and sorghum-based food security and decrease in cost of production contributed significantly to improved livelihoods of resource-poor farmers and rural labours in the Indian SAT. The increased demand for hybrid seed production driven by popularity and enhanced adoption of hybrids together with broadened utilization of sorghum in the food/confectionary industry and poultry feed manufacturing, and its potential use in bio-fuel production have transformed sorghum into a commercial crop while still serving as a staple food crop for millions of poor in SAT. Besides these, sharing of basic and strategic research information, developing a database on the biophysical and socio-economic variables, capacity-building of Indian NARS and several joint scientific publications stand testimony to the power of partnership to disseminate and exchange scientific knowledge. However, this is not enough. The partnership research must continue to respond to change while refining research focus and delivery mechanisms and simultaneously striving towards the vision of reducing poverty and improving livelihoods of resource-poor farmers.

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