Sorghum Research Reports

Genetic Enhancement and Breeding

Sorghum Breeding Research at ICRISAT – Goals, Strategies, Methods and Accomplishments

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Introduction

Sorghum (*Sorghum bicolor*) is the fifth most important cereal crop grown in the world. It is grown over 42 million ha as a rainfed crop mostly by subsistence farmers in the semi-arid tropics (SAT) of Africa, Asia and Latin America. Sorghum grain is used mainly for human consumption in Asia and Africa while it is used as animal feed in the Americas, China and Australia. In India, the rainy season sorghum grain is used mostly for animal/poultry feed while the postrainy season sorghum grain is used primarily for human consumption. The crop residue (stover) after grain harvest is a valuable source of fodder and fuel in India and Africa. Sorghum also has great potential to supplement fodder resources in India because of its wide adaptation, rapid growth, high green and dry fodder yields with high ratoonability and drought tolerance.

Sorghum is mostly grown by resource-limited farmers with minimal inputs which is one of the reasons for its low productivity. The yield and quality of sorghum produce is affected by a wide array of biotic (insect pests and diseases) and abiotic (drought and problematic soils) constraints. The important productivity-limiting constraints are: shoot fly (*Atherigona soccata*) (India and Eastern Africa), stem borer (*Chilo partellus*) (India and Africa), midge (*Contarinia sorghicola*) (Eastern Africa and Australia) and head bug (*Calocoris angustatus*) [India and Western and Central Africa (WCA)] among pests; grain mold (complex of fungi predominantly *Fusarium* spp, *Curvularia* spp, *Aspergillus* spp, *Alternaria* spp) (all regions) and anthracnose (*Colletotrichum graminicola*) (WCA and northern India) among diseases; *Striga* (*Striga asiatica*, *S. densiflora, S. hermonthica*) (all regions in Africa); drought (all regions); and problematic soils – saline (some parts of India and Middle East) and acidic (Latin America).

Breeding Goals and Strategies

The breeding goals (involving partners) have undergone significant changes since the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was established in 1972 at Patancheru, India with sorghum as one of its five mandate crops for research aimed to improve its productivity for food use in SAT. External environments, perceptions of donors and national agricultural research systems (NARS), changing crop requirements and opportunities, and NARS capacity are the most important factors that influenced these changes. The identification of geographic functional regions with a set of constraints has resulted in the gradual shift in breeding strategy from initial wide adaptability to specific adaptations, and to trait-based breeding for threshold traits through the 1980s and 1990s. The ICRISAT-Patancheru-based wide adaptability approach was abandoned by early-1980s, and three research centers with regional hubs were established in Africa and one in Central America to take up breeding for region/production system-specific adaptations. Thus, five different phases in sorghum breeding goals could be recognized in ICRISAT's global sorghum breeding program. These are: (1) wide adaptability and high grain yield (1972–75); (2) wide adaptability and breeding for biotic and abiotic constraints(1976–79); (3) regional adaptations and resistance breeding (1980–84); (4) specific adaptations and resistance breeding (1985–89); and (5) trait-based breeding, sustainable productivity and upstream research (1990–present) (Reddy et al. 2004).

Breeding sorghum for high and stable yield with improved drought tolerance has received top priority at ICRISAT. Besides these, traits that are required for adaptation to different sorghum production systems have been considered. For example, improved postrainy season sorghums in India would require in addition to higher grain and fodder yields, tolerance to drought, shoot fly and lodging and grain quality (semi-corneous endosperm grains) suitable for making '*roti*' (unleavened bread). On the other hand, in the northern Guinea zone of WCA, improved sorghum lines should have longer maturity, and hard grains with stable resistance to *S. hermonthica*, anthracnose, grain mold, stem borer and head bug. Also, grain quality-evident traits such as soft endosperm grains preferred in Eastern Africa for food product preparations such as *injera* and *kisra* and hard endosperm grains preferred in Western Africa for *tô* preparation were given due importance (Reddy and Stenhouse 1994).

Initially, major emphasis was given on developing improved varieties in collaboration with NARS for all SAT areas from ICRISAT-Patancheru. Later, hybrids as the target materials were given considerable importance at ICRISAT-Patancheru. Since 1995, emphasis was laid on developing improved hybrid parents at ICRISAT-Patancheru for Asia, and finished products (varieties and hybrids) at other ICRISAT locations in Africa, through partnership research.

Breeding Methods and Techniques

Initially, population improvement program with S_1/S_2 selection schemes involving ms_3/ms_7 male-sterile genes was used extensively in the 1970s to improve several broad-based populations like US/R, US/B, Fast Lane, etc. The lines derived from these populations through head-to-row selection were tested widely across several locations in Asia and Africa in an effort to select for wide adaptability for a range of traits, including red and white grain. Later, pedigree and backcross breeding methods also received some emphasis to transfer relatively small sets of genes into improved white-grained backgrounds. Grain yield was the main selection criterion in population, pedigree and backcross breeding methods. However, from 1980s onwards, major emphasis was placed on breeding for resistance to various biotic and abiotic stresses in each of the regions. In the later part of the 1980s, pedigree and backcross methods were deployed extensively for specific adaptations within each region. A trait-based pedigree breeding approach in which families were used as the selection units for resistance response, and individuals within the resistant families as selection units for grain yield was followed from 1990 onwards. Also, since 1990, simple mass selection is being used to improve the populations to develop trait-based gene pools; eg, ICSP-high tillering population. Simultaneous testcrossing and backcrossing the selected maintainer plants along with the selection for resistance trait and grain yield in the trait-based breeding programs were carried out to improve male-sterile lines for specific resistance traits and high grain yield (Reddy et al. 2004).

More recently, SSR (simple sequence repeat) markers associated with resistance to shoot fly and *Striga*, and stay-green were identified by evaluating the parents and recombinant inbred lines (RILs) derived from resistant × susceptible crosses. The RILs were developed through head-to-row generation advance. Further, genetic transformation for stem borer resistance is being used for deploying Bt-genes and T_1 tansgenics are currently being tested in the greenhouse.

Accomplishments

Breeding Products

ICRISAT's partnership efforts with NARS from SAT countries led to the release of 194 improved cultivars over the years (Table 1); Southern and Eastern Africa (SEA) (60), WCA (50), Asia (50) and Latin America (34).

Apart from these, over 54 hybrids that are being marketed by private seed companies in India were developed from ICRISAT-bred hybrid parents or their derivatives. Besides these, breeding efforts at ICRISAT have led to the development of various types of elite lines and gene pools. The lines include: high-yielding male-sterile lines (160), trait-specific male-sterile lines (567), restorer lines (873) and varieties (1451). The demand and diversity of male-sterile and restorer lines were demonstrated by the number of research seed samples supplied by ICRISAT-Patancheru upon request by different national programs. A total of 194,356 sorghum seed samples have been supplied to 107 countries during 1986–2003: Africa - 34,764; Asia - 14,351; Americas - 15,036; Europe - 1,305 seed samples. The ICRISAT web page (http://www.icrisat.org/text/research/grep/homepage/sorghum/breeding/pedigree.htm) provides complete information on the characteristic features of these materials including their pedigrees. Some of the most important improved cultivars and elite hybrid parents resistant to biotic and abiotic stresses are described below.

***Striga* resistance.** *Striga,* an abnoxious obligate parasitic weed, is one of the most important biotic yield constraint in Africa, although less important in Asia. ICRISAT's African sorghum improvement program has developed a *Striga* resistant variety 'Framida' that has been released in Burkina Faso and Ghana. Similarly, a *Striga* resistant variety SAR 1 has been released for cultivation in *Striga* endemic areas in India. Several *Striga* resistant seed

Table 1. Number of ICRISAT-derived released sorghum varieties over the years in Asia, Africa and Latin America.

Region	1972–80	1981–90	1991–2000	2001–04	Total
Asia	2	15	32	1	50
Western and Central Africa	2	12	27	9	50
Southern and Eastern Africa	7	21	23	9	60
Latin America	4	16	14	0	34
Total	15	64	96	19	194

parents (eg, ICSA 579, ICSA 583, ICSA 584, ICSA 588 and ICSA 592) were also developed for use by national programs in Asia.

Disease and insect tolerance. Grain mold, shoot fly, stem borer and midge are important biotic constraints in Asia and Africa. ICRISAT in partnership with national programs in Asia has developed many grain mold resistant varieties. PVK 801, besides being grain mold resistant, is a dual-purpose variety with good quality stover.

Varieties such as ICSV 112 and ICSV 745 which are high yielding are also foliar disease resistant (ICSV 745 is also midge resistant). By using a trait-based breeding approach, ICRISAT has developed several grain mold resistant (eg, ICSA 300, ICSA 369, ICSA 400, ICSA 403 and ICSA 404) and shoot fly tolerant (eg, ICSA 419 and ICSA 435 for rainy season and ICSA 445 and ICSA 452 for postrainy season) cytoplasmic-nuclear male sterility-based seed parents. These seed parents have good potential for developing hybrids resistant to these biotic constraints and thus stabilizing yield gains obtainable from these hybrids.

Resistance to soil mineral toxicities. Of all the soil mineral stresses or chemical toxicities, acidity and associated Al^{3+} toxicity and salinity are probably the most important constraints to sorghum productivity in tropical environments. Although sorghum is known to be relatively more tolerant to soil salinity and acidity than other comparable crops such as maize (*Zea mays*), further enhancement of its genetic potential through plant breeding would be an eco-friendly and a more sustainable approach than just management options for increased productivity in such soils. Of more than 6000 sorghum genotypes from the world collection screened at Quilichao, Colombia, approximately 8% was found to tolerate 65% Al^{3+} saturation. Besides these, several high-yielding male-sterile lines, restorer lines and forage sorghum lines were found to be tolerant to Al^{3+} toxicity and have been supplied to NARS scientists. These are: grain sorghum A/B-lines: ICSB 93, ICSB 89002, SPMD 94004, SPB2 94013 and SPB2 94029; grain sorghum R-lines: ICSR 110, ICSR 91008, ICSR 91012, ICSR 93033 and GD 27669; and forage sorghum lines: ICSR 93024-2 and IS 31496.

Similarly, some of the elite sorghum varieties, hybrids and improved lines with better tolerance to salinity (at 250 µM NaCl solution; EC 23.4 dS cm^{-1}) are: grain sorghum A/B-lines: ICSB 766, ICSB 676 and ICSB 300; grain sorghum R-lines: ICSR 196, ICSR 91005, ICSR 89010 and ICSR 93034; and grain sorghum varieties: ICSV 112, CSV 15, S 35, NTJ 2 and ICSV 145.

Sweet-stalked sorghum. In recognition of the increasing demand created for ethanol due to the Indian government's policy to mix 5% ethanol in petrol and likely and gradual increase of this proportion up to 10%, ICRISAT renewed its sweet sorghum research (which was initiated in 1980 and discontinued in early 1990s) for the identification and development of sweet-stalked and high biomass sorghum lines starting in 2002. Sweet sorghums have a great potential for ethanol production by virtue of their high stem sugar concentrations, with a brix value up to 24%.

Several promising lines such as ICSB 38, ICSB 631 and ICSB 264 among the B-lines, SSV 84, Seredo, ICSR 93034, S 35, ICSV 700, ICSV 93046, E 36-1, CSV 15, NTJ 2 and Entry# 64 DTN among the varieties/R-lines with over 19% stalk sugar content were identified. Recently, a sweet stalk sorghum hybrid, NSSH 104, has been developed by crossing ICSA 38, an ICRISAT-bred female parent with an improved and released sweet stalk variety SSV 84 and it is being recommended for release by the National Research Centre for Sorghum (NRCS), Hyderabad as special purpose sorghum for cultivation in India.

Forage sorghum. Forage sorghum cultivars are commonly grown in northern India and West Africa. It is fed to animals as a green chop, silage or hay. Improvement of forage sorghum in India focuses on breeding varieties and hybrids with high forage yield, better quality [high sugar, high crude protein, low hydrocyanic acid (HCN), other nutritional and digestibility parameters], good seed yields, ratoonability and resistance to pests and diseases.

At ICRISAT, a strong program on forage sorghum improvement has developed a diversified set of hybrid parents, and grain and dual-purpose varieties. Evaluation of a large number of sorghum lines developed earlier under the Genetic Resources and Enhancement Program at ICRISAT and the lines selected from high tillering population resulted in the identification of tillering lines useful for developing forage varieties and hybrids. Some of them with high fresh fodder yield are: ICSR 93024-1, IS 33941, ICSR 93022, ICSR 93025-1-1, HT Pop-F_3-18-2, HT Pop-F_3-28-1, HT Pop-F_3-42, HT Pop-F_3-47, HT Pop-F_3-51-1, HT Pop-F_3-51-2 and HT Pop-F_3-53-3. Besides these, IS 1059, IS 2944, IS 324, IS 4776 and IS 6090 for low HCN and IS 3247 and PJ 7R for low tannin content have been identified at ICRISAT.

Adoption and Impact

The adoption of improved cultivars along with natural resources management technologies resulted in an increase in sorghum grain productivity by 150 kg ha^{-1} (0.9% annually) in Africa, by 450 kg ha^{-1} (3.1% annually) in whole Asia and by 280 kg ha^{-1} (2.9% annually) in India during 1972 to 2002. The increased sorghum area in Africa (by 9 million ha) coupled with improved productivity resulted in enhanced production by 10 million t during 1972 to 2002, signifying its contribution to regional/ national food security. The higher increase in sorghum productivity in whole Asia and India compared to Africa could be attributed to the adoption of hybrids. Because of increases in sorghum productivity during 1972 to 2002, nearly 6 million ha (35% of the 1972 sorghum area) in India and 7.4 million ha (31% of the 1972 sorghum area) in Asia has been made available to farmers to diversify into high-income cash crops. Figures 1 and 2 show the patterns in area, production and productivity of sorghum over the years as well as the timing of ICRISAT-derived releases in Asia and Africa. Besides increasing grain productivity, the improved cultivars with enhanced resistance to yield constraints have not only stabilized the yield levels but also led to cultivar diversity, and thus contributed to sustainable production systems.

Amongst the varieties released in various countries, ICSV 112 is very popular among farmers in Africa and has been released in five countries (Zimbabwe, Kenya, Swaziland, Malawi and Mozambique). Another variety ICSV 111, released in Cameroon, Chad and Nigeria, has shown high impact on reducing the cost of production and improving productivity. The improved cultivars developed by ICRISAT in Southern Africa currently occupy 15–50% of the area in eight Southern African Development Community (SADC) member states. Macia, is an open-pollinated, early-maturing and high-yielding variety developed at ICRISAT-Bulawayo, Zimbabwe in 1989. It was released in Mozambique (as Macia in 1987), Botswana (as Phofu in 1994), Namibia (as Macia in 1998), Zimbabwe (as Macia in 1998 by SEED Co Ltd, a private seed company) and Tanzania (as Macia in 1999). Farmers are benefiting from rapid and extensive adoption of this variety in Botswana and Mozambique. It is being cultivated in an area of 0.1 million ha in Botswana, Namibia, Zimbabwe, Mozambique and Tanzania, which represent the SADC region of Southern Africa (Table 2).

There has been a yield advantage of 10–20% (up to 200 kg ha^{-1}) and the total benefits accrued from this has been US$7.3 million at US$0.1 kg^{-1}. In Kenya, the variety *Gadam el Hamam* was adopted for early maturity and good taste. The sorghum variety Pato is adopted in approximately 36% of the area under improved varieties in Tanzania.

In Sub-Saharan Africa, the variety, S 35 (ICSV 111) gave 25% more grain yield and its adoption rate was 10–15% in Nigeria and Ghana. Likewise, the sales of the variety ICSV 400 increased substantially to a value of 4.5 million

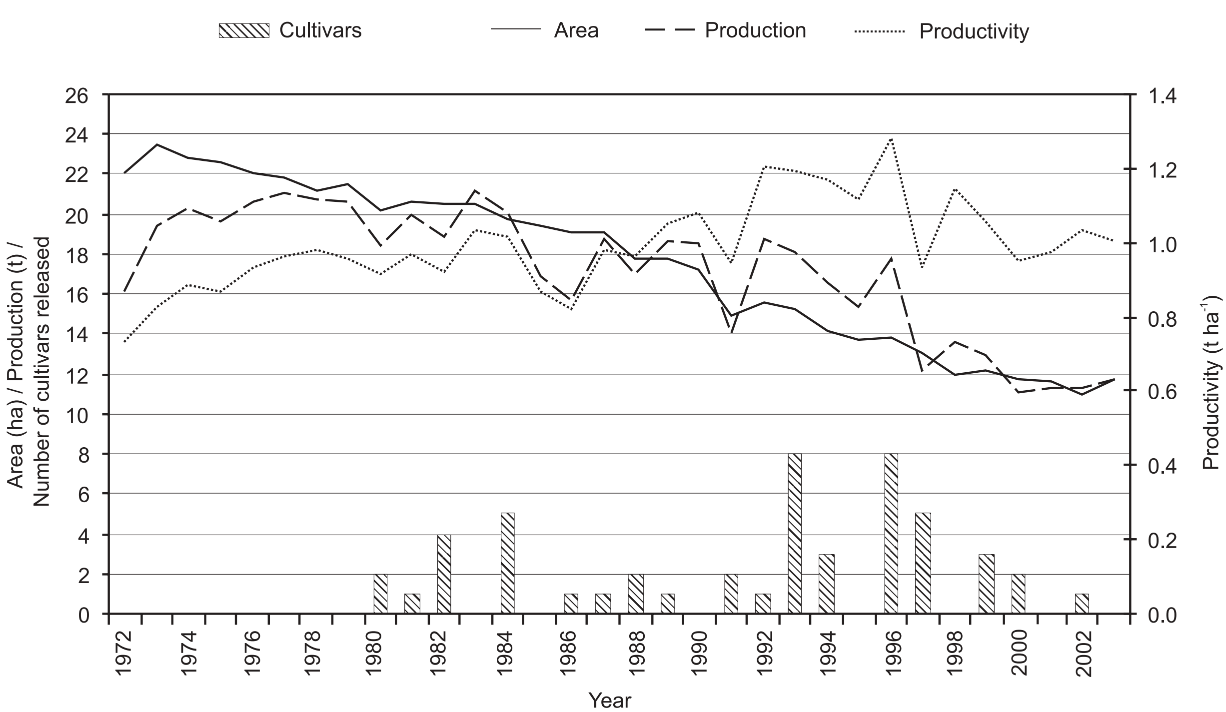

Figure 1. Sorghum area, production and productivity and number of cultivars released in Asia during 1972 to 2002.

Naira (US$40,000) in 2001 because the variety was used by the agro-industry. The extra-early maturing variety CSM 63 E or "Diacumbe" is highly accepted by farmers in WCA and the area of CSM 63 E cultivation has been continuously increasing in past many years. Seven new varieties have been released in Mali mostly belonging to the *guinea* race – Tieble (CSM 335), Kossa (CSM 485), Ngolofing (CSM 660), Marakanio (CGM 9-9-1-1), Padi (ICSV 901), Nazomble (Nazangola anthocyané) and Nazondje (Nazangola tan). Tieble and Ngolofing are spreading rapidly among farmers in the 800–1000 mm zone of Mali due to their good yield, relative earliness and excellent grain qualities. A hybrid (NAD 1) has been released in Niger for which seed production and adoption

Table 2. Estimated adoption and spread of SDS 3220 (Macia) in the SADC region of Southern Africa.

Country	Released name	Year of release	Approximate adoption area (ha)	Percentage of total area under sorghum
Botswana	Phofu	1994	37500	25
Namibia	Macia	1998	3000	10
Zimbabwe	Macia	1998	26300	15
Mozambique	Macia	1987	22000	7
Tanzania	Macia	1999	20000	3

Source: Shiferaw et al. (2004).

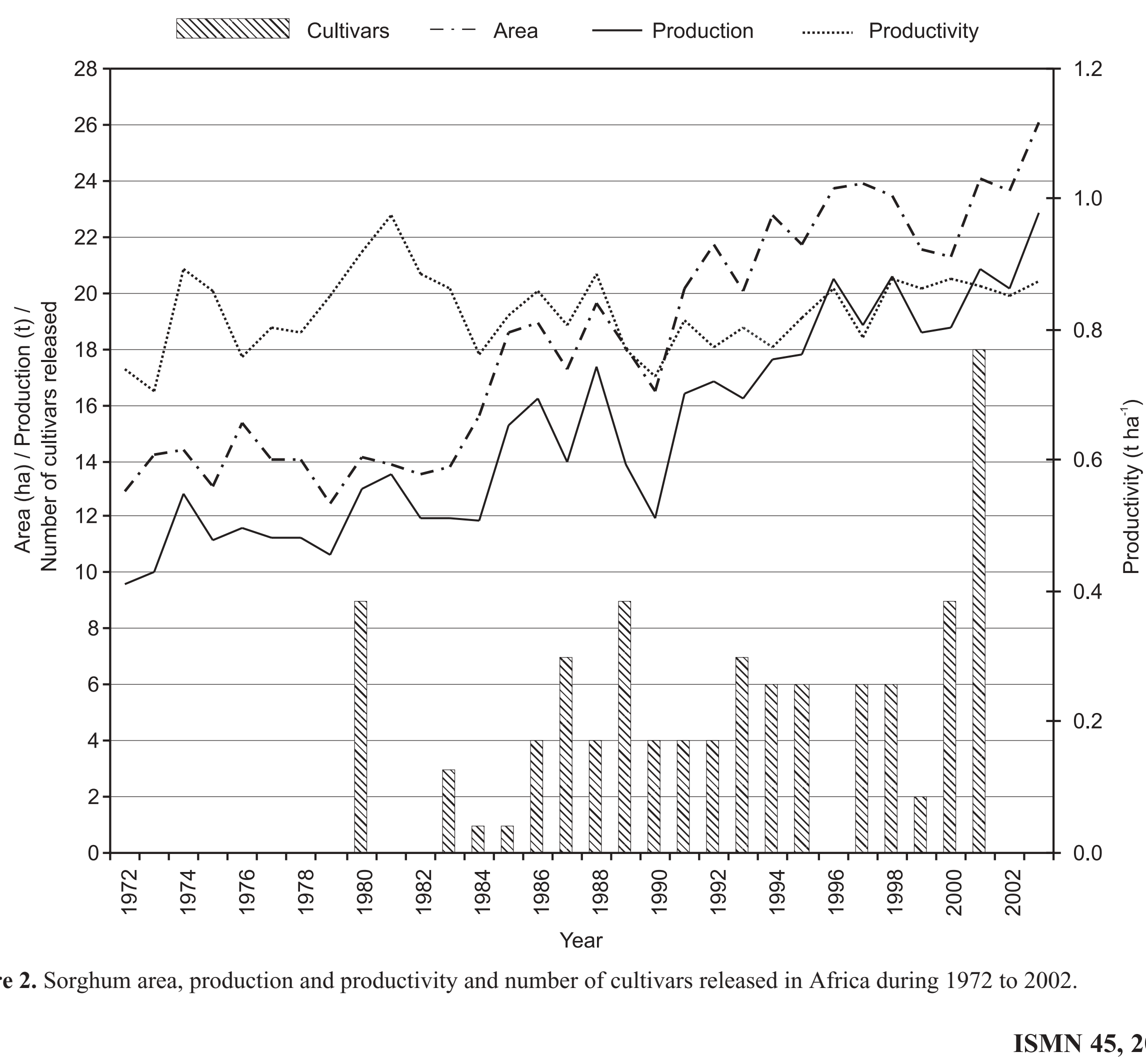

Figure 2. Sorghum area, production and productivity and number of cultivars released in Africa during 1972 to 2002.

are increasing in Niger and Nigeria. The hybrid ICSH 88902 has been released in Nigeria.

Similarly, several varieties released in Asian countries such as India, Myanmar, Pakistan, Philippines and Thailand have become very popular. A variety NTJ 2 is highly popular for its *roti*-making quality with terminal drought tolerance in the postrainy season sorghum growing areas in Andhra Pradesh, India. The varieties bred for specific adaptation, eg, ICSV 112 and ICSV 745, which are relatively early, dual-purpose (grain and stover) and foliar disease resistant (ICSV 745 is also resistant to midge) and introduced in Warangal district of Andhra Pradesh showed yield advantages ranging from 29% in monoculture and 56% in intercropping systems and enabled farmers to earn 13% higher income with ICSV 112 and 58% with ICSV 745. These varieties gave 20% higher grain yield and 35% higher fodder yield than locally adopted cultivars in Melghat region of Maharashtra state in India.

Nine sorghum varieties (including germplasm accessions) were released in Myanmar from 1980 to 1996. Two sorghum varieties, ICSV 107 (PARC-SS1) and IRAT 408 (PARC-SS2), introduced from ICRISAT-Patancheru were released in Pakistan in 1991. Two sorghum varieties, IES Sor 1 and IES Sor 4, developed using ICRISAT germplasm were released in the Philippines in 1993 and 1994, respectively. Suphanburi 1 derived from ICRISAT germplasm was released in Thailand in 1996 (Deb et al. 2004).

Several ICRISAT-bred improved hybrid parents have been extensively used by both public and private sector research organizations to develop and market hybrids in Asia. In India alone, around 4 million ha is occupied by more than 54 hybrids developed from ICRISAT-bred parental lines or their derivatives. Notable among them is JKSH 22, a hybrid developed from ICRISAT-bred seed parent by a private sector based in India. It is known for its higher grain yield potential, bold grain and earliness (5–10 days compared to the most popular hybrid CSH 9) and showed remarkable adoption from 1500 ha in 1994 to 210,000 ha in 2002 (Fig. 3).

During 1994 to 2002, seed production of JKSH 22 earned farmers, on an average, over US$0.31 million per year in Andhra Pradesh and Karnataka states and US$2.7 million per year from commercial cultivation in Maharashtra and other sorghum growing states in India. In the last three years (2001/02 to 2003/04), a total of 29,800 t of certified hybrid seed of ICRISAT-private sector hybrids (Table 3) was produced which gave a total income of US$18.8 million to farmers in Andhra Pradesh and Karnataka.

Similarly, several sorghum hybrids using ICRISAT hybrid parental material have been released in China during 1982–96. For example, hybrids such as Lio Za 4, Longsi 1, Jin Za No. 12 and Gilaza 80 have been developed from ICRISAT-bred parental lines and released in China.

Cost-benefit Ratio and Returns from Research

The productivity gain from improved cultivars has more than compensated the cost of additional inputs used for their cultivation. The cost-benefit ratio of production of improved cultivars ranged from 1:1.25 (in WCA) to 1:1.4 (in India). The net present value (NPV) of benefits from the cultivar S 35 was estimated at US$15 million in Chad and US$4.6 million in Cameroon, with an internal rate of return (IRR) of 95% in Chad and 75% in Cameroon. Improved sorghum cultivars in Mali are estimated to generate an NPV of US$16 million with an IRR of 69%. The adoption of improved cultivars in eight SADC member states contributed an additional US$19 million

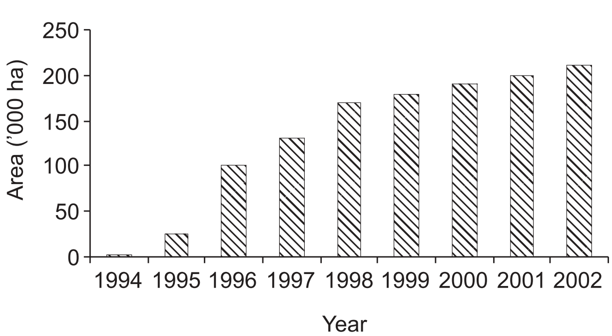

Figure 3. The area covered under JKSH 22, an ICRISAT-private sector partnership hybrid in India.

Table 3. Share of ICRISAT-private sector (PS) partnership sorghum certified hybrid seed production in total sorghum seed production in India.

Year	PS hybrid seed[1] (t)	Total certified seed (t)
2001/02	11600 (71)	16410
2002/03	7200 (63)	11390
2003/04	11000 (61)	18000
Total	29800 (65)	45800

1. Percentage values are given in parentheses.

Source: Yogeshwara Rao, Vikkis Agrotech Ltd., Hyderabad, India (personal communication).

per annum in income streams. In Zambia and Zimbabwe, IRR from the adoption of cultivar ICSV 88060 is estimated at 11–15% and 22%, respectively. The adoption of the improved cultivar SV 2 has yielded 27% in Zimbabwe and adoption of improved cultivars has fetched IRR of 10% to the investments in sorghum breeding (ICRISAT 1998). The adoption and the use of ICRISAT-bred midge resistant cultivars ICSV 745 and PM 13654 in Australia is expected to enhance grain productivity by 2.5% annually in midge-endemic areas that translates into a cost saving of US$4.7 million at the current average production levels (Deb and Bantilan 2003). Australia made net gains at an average of A$1.14 million per year from the impact of ICRISAT's sorghum research. These benefits are well in excess of Australia's financial contribution to ICRISAT (Brennan et al. 2004). This is an example of international research outputs aimed at improving productivity in developing countries and also having spillover benefits in developed countries.

Innovations in Science and Technology Sharing

Innovations in research and sharing of technologies so developed out of such innovations are the key factors for increased impact in farmers' fields. Innovative strategic and upstream research information developed at ICRISAT – ideas, concepts, methods and techniques that were inputs for further research – has contributed immensely to increased efficiency of breeding processes of ICRISAT and those of NARS partners. This research had a multiplier effect, with several public and private research organizations further developing finished products simultaneously for targeted production areas. Some of the important strategic research findings and application of new science tools and their impacts are described below.

Strategic research. ICRISAT has standardized large-scale, reliable, cost-effective and repeatable resistance-screening techniques such as interlard-fish meal technique for resistance to shoot fly, artificial infestation technique for resistance to stem borer and infestor-rows technique for resistance to midge among the insect pests, sprinkler irrigation with artificial inoculation technique for resistance to grain mold and infector-row field-screening techniques for resistance to downy mildew and anthracnose among the diseases, and chequer board method of field screening for resistance to *Striga*; and screening techniques for coleoptile and mesocotyl lengths for germination and emergence under deep-sowing areas in Africa, for seedling emergence under high surface soil temperature, for recovery from seedling drought and mid-season drought, for terminal drought stress tolerance and for resistance/tolerance to soil acidic and salinity toxicities. Sources of resistance to these biotic and abiotic stresses have been identified and these have been successfully transferred to NARS in India and Africa. The conceptualization and demonstration of landrace pollinators-based hybrids approach for terminal drought situations, particularly for postrainy situation in India led the private sector to develop and market hybrids for postrainy season for the first time in India. Development and transfer of methods of developing hybrid parents (Asia) and varieties (Africa) resistant to grain mold for rainy season and shoot fly for postrainy season in Asia and varieties resistant to drought, *Striga* and other biotic stresses in Africa and moving average concepts to increase the efficiency of selection for resistance to these stresses resulted in significant improvements in NARS resistance breeding programs (Reddy et al. 2004).

New science tools. Molecular markers and transgenic technologies, ingenuity of farmers and information technologies have been increasingly used. Major quantitative trait loci (QTLs) conferring resistance to several yield constraints have been identified. Molecular marker-assisted selection (MAS) is underway to introgress the QTLs governing *Striga* and shoot fly resistance, and stay-green, a proven trait conferring terminal drought resistance into farmer-accepted cultivars. ICRISAT is the first to develop sorghum transgenics for resistance to stem borer, which are currently under greenhouse testing. Farmer participatory varietal selection (FPVS)/plant breeding has started showing significant benefits for drought-prone areas both in Africa and Asia. FPVS facilitated the release of the variety SPV 1359 for postrainy season cultivation in Maharashtra and Karnataka states in India during 1999–2000. A high-yielding variety 'Tieble' was identified through FPVS trial in Gonsolo village in Mali in Africa during 2000. By 2002, nearly all the households in this village and the surrounding five villages had sown seeds of this variety. Farmer-participatory evaluation of ICRISAT-Patancheru-bred varieties (ICSV 111, ICSV 400 and ICSV 247) along with local cultivar in Nigeria in collaboration with the Institute for Agricultural Research (IAR), Zaria, Nigeria facilitated the acceptance and large-scale adoption of these improved varieties in Nigeria (Tabo et al. 1999). Computerization of seed dispatch and developing databases and websites (http://www.icrisat.org/text/research/grep/homepage/sorghum/breeding/main.htm) for all male-sterile lines, restorers, varieties and hybrids with pedigrees and characteristics has enabled NARS scientists to have better access to ICRISAT-bred breeding materials.

Table 4. Number of trainees from Asia, Africa and Latin America who were imparted training in sorghum improvement at ICRISAT[1].

Region	VS	PDF	RS	RF	In-service (six months)	In-service (short-term)	Apprentices
Southern and Eastern Africa	–	4	19	78	323	49	–
Asia (including India)	8	7	59	111	126	57	37
India	8	4	42	51	1	16	35
Western and Central Africa	–	2	23	17	312	9	–
Latin America	–	7	6	13	22	4	9
Total	8	20	107	219	783	119	46

1. VS = Visiting scientist; PDF = Postdoctoral fellow; RS = Research scholar; RF = Research fellow.

Publications and Capacity Building

The publications of research findings (a total of 886 during 1977 to 2004) include 427 refereed journal articles, 291 conference papers, 49 book chapters and 119 other publications. A total of 1320 NARS scientists and research scholars were trained on various aspects of sorghum improvement during 1974 to 2003. Of these, eight were visiting scientists, 20 post-doctoral fellows, 107 research scholars, 219 research fellows, 783 in-service (six months) trainees, 119 in-service short-term trainees and 46 apprentices (Table 4). Besides training programs, workshops, conferences and scientists' field days have enabled researchers around the world to improve the efficiency of their sorghum improvement programs.

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