Sorghum, a crop of substance

ICRISAT's submission for the 2004 CGIAR King Baudouin Award

ICRISAT's Vision – The improved well-being of the poor of the semi-arid tropics through agricultural research for impact. With this impact we have the determination to substantially contribute to the attainment of the Millennium Development Goals, specifically those tackling poverty, hunger, gender and health issues.

ICRISAT's Mission – To help the poor of the SAT through science with a human face and partnership-based research for development to increase agricultural productivity and food security, reduce poverty, and protect the environment in SAT production systems.

ICRISAT's Mandate – To improve the livelihoods of the poor in semi-arid crop-livestock-tree production systems through integrated genetic and natural resource management strategies. ICRISAT will make major food crops more productive, reliable, nutritious, and affordable to the poor; diversify utilization options for staple food crops; develop tools and techniques to manage risk and utilize the natural resource base of SAT production systems in a more sustained fashion; develop options to diversify income generation; and strengthen delivery systems to key clients. Partnership-based research for impact, gender sensitivity, capacity building and enhanced knowledge and technology flows are integral to this mandate.

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From subsistence to substance:

Sorghum improvement for the semi-arid tropics

Executive Summary

Sorghum (**Sorghum bicolor** *[L.] Moench) is the fifth most important cereal crop by area after wheat, rice, maize and barley in the world. Traditionally, a staple food crop for millions of poor in the semi-arid tropics (SAT) of Africa and Asia, its importance as a fodder and feed crop for livestock steadily increased over the last decade or two. It is cultivated on marginal, fragile drought-prone environments in SAT. In mid-1970s, the productivity levels of sorghum were <0.7 t ha^{-1} in Africa, <0.8 t ha^{-1} in Asia and <0.5 t ha^{-1} in India when the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was established at Patancheru, Andhra Pradesh, India. Low productivity was the result of dependency on traditional cultivars and management practices and exacerbated by an array of biotic stresses (insect pests—shoot fly, stem borers, midge and headbugs; diseases—grain mold, anthracnose, rust, downy mildew, leaf blight and* **Striga***); and abiotic stresses (drought and problematic soils—acidic and saline). ICRISAT, in close collaboration with the National Agricultural Research Systems (NARS) in SAT, the Advanced Research Institutes (ARIs) and sister organizations of the Consultative Group on International Agricultural Research (CGIAR) over the years has been engaged in improving the productivity of sorghum in various SAT regions through genetic improvement of sorghum coupled with integrated genetic and natural resources management approaches. These research efforts have led to many and diversified impacts; overall effect being the significantly improved livelihoods of resource-poor farmers and low-income people in SAT.*

Significant grain productivity improvements were facilitated due to release and adoption of several partnership cultivars (total 194—Africa: 110, Asia: 50 and other countries: 34) having specific adaptation to local environments. The improved cultivars developed by ICRISAT's partnership research in southern Africa currently occupy 15-50% of the sorghum area in eight southern African Development Committee (SADC) member states. The increased sorghum area in Africa (by 9 million ha) coupled with increased productivity (by 150 kg ha^{-1}) enhanced the total production by 10 million t from 1971–73 to 2000–2002, signifying its contribution to the regional/national food security. With a dramatic increase in productivity between 1971–73 to 2000–2002, India (by 280 kg ha^{-1}) is able to spare nearly 6 million ha and Asia (by 450 kg ha^{-1}) about 7.4 million ha of sorghum area to other competitive crops while still maintaining sorghum production in 2000–2002 comparable to that of 1972, when ICRISAT was established.

Several cultivars such as S 35, ICSV 111, ICSV 400 etc, in western and central Africa, Seredo, M 36121, ICSV 112, SV 2, Macia etc, in eastern and southern Africa and SPV 351, SPV 475, ICSV 745, CSH 11 and many ICRISAT-public/private sector partnership varieties/hybrids in India, China, Myanmar, the Philippines and Pakistan in Asia and in Latin American countries are contributing to on-farm cultivar biodiversity in SAT regions of the world. In India alone, more than 4 million ha are occupied by over 54 hybrids developed from ICRISAT-based parental lines or their derivatives.

The studies showed that cost-benefit ratios of production from the cultivation of improved cultivars were improved in several regions in Africa and Asia. It was 1:1.25 in West and Central Africa (WCA) and 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 together contribute an additional US$19 million per year in income streams. In Zambia and Zimbabwe, IRR from the adoption of the cultivar, ICSV 88060 is estimated at 11–15% and 22%, respectively.

The partnership research carried out in one region/ country produced significant spillover impacts in other regions/countries. Several ICRISAT-Patancheru-bred varieties were further selected, tested and released in many African countries. These are, amongst others, ICSV 112 (SV 1 in Zimbabwe), A 6460 (SV 2 in Zimbabwe), ICSV 2 and IS 23520 (Zambia), M 90393 (Ingazi in Sudan), M 36121 (in Ethiopia), M 90038 (SEPON 82 in Niger), M 91019 (S 35 in Cameroon and Chad) etc. Within Asia, several ICRISAT-Patancheru-bred varieties were released. Similarly, within Africa, cultivars developed in one country showed significant superior performance in other countries. This is best exemplified by Macia, a variety developed at ICRISAT-Bulawayo, Zimbabwe, in 1989, was released in Mozambique (in 1989 as Macia), Botswana (in 1994 as Phofu), Namibia (in 1998 as Macia) and Tanzania (in 1999 as Macia). The gains in productivity in midge-endemic areas in Australia through the adoption and use of midge-resistant cultivars (ICSV 197, ICSV 745 and PM 13654) in breeding programs, introduced from ICRISAT-Patancheru is estimated at 2.5% annually that translates into a cost reduction of US$4.0 t^{1}, or a cost saving of US$4.7 million at current average production levels. These benefits are well in excess of Australia's financial contribution to ICRISAT. This is an example of international agricultural research outputs aimed at improving productivity in developing countries also having spillover benefits in developed countries. Several such spillover impacts including in Latin America amply illustrate the synergism of stupendous magnitude, never seen before, from partnership research led by ICRISAT. These studies also demonstrate parallel adaptation of improved cultivars in more than one region.

The targeted large-scale adoption of improved cultivars resistant to biotic and abiotic stresses provided options leading to sorghum-based crop diversification and crop rotations. This together with natural resources management improved practices such as dry seeding, broad bed-furrow system, intercropping systems and integrated pest management implemented in small watersheds has ensured sustainable and productive cropping systems. The potential gain by adoption of cultivars with improved resistance to abiotic and biotic stresses is estimated to be around US$736 million in world. The adoption of dry seeding has resulted in a yield increase of 38.4%, income by 98.5%, employment by 13.6% and cost saving by 17.1% in India. The released cultivars, though improved for grain productivity are rich in crop residue nutritive value, which helped farmers to get additional income through mixed crop-livestock system. The increased grain productivity of the tall dual-purpose cultivars together with nutrient-rich crop residue ensured higher food availability at household level as well as income from livestock that helped women, the main force in livestock-related activities, to have more income at their disposal.

The applied research that led to release and large-scale adoption of diverse cultivars was the result of path-breaking innovative research in strategic areas, adoption of new science tools, networking of public partners and forging public-private sector partnerships. The innovations in strategic research areas such as epidemiology and biology of diseases' and pests' causal organisms, development of cost-effective and reliable screening techniques to identify sources resistant to various stresses, genetics of several traits of economic importance and useful in adaptation, selection procedures, alternative targeted products, trait-based breeding approach to diversify and develop targeted hybrid parents, capturing of both racial and geographical diversity in breeding materials as evidenced by the utilization of nearly 4000 germplasm accessions to generate useful variability, formation of core collection of germplasm accessions to facilitate enhanced utilization of germplasm, stratification of test sites in Africa to help reduce resources utilization in multilocation testing of advanced breeding lines, development of databases and Geographical Information System (GIS) maps etc, helped accelerate the gains from breeding programs both in NARS and ICRISAT. The concept and demonstration of the use of landrace pollinator-based hybrids approach—a path-breaking strategic research—gave impetus to private sector to develop and market hybrids for postrainy season for the first-time in India. Further, the advances made in identifying quantitative trait loci (QTLs) for resistance to shoot fly, Striga and drought (stay-green) and transferring these QTLs to susceptible, but elite sorghum breeding lines using marker-assisted breeding techniques are helping ICRISAT and partners to position themselves to bring about rapid advances in breeding for these traits of yield stability and adaptation. Also, ICRISAT has the distinction of being the first institute in the world to develop stem borer resistant transgenic plants with the cry1AC gene that soon go for greenhouse testing. Besides, these farmer participatory varietal selection, being practiced in India for postrainy season adaptation, and in WCA for adaptation to drier areas helped reduce the time lag in transferring the improved products to farmers.

The publication of research findings (a total of 886 during 1977 to 2004) together with workshops, conferences, field days and capacity building through on-job training and focused short-term courses in various disciplines related to sorghum improvement enabled the researchers world over to improve the efficiency of their sorghum improvement programs.

ICRISAT's role as a catalyst in leveraging the partnerships in research on alternative uses such as use of sorghum in poultry feed, confectionary/syrup and ethanol production industries is paving the way to utilize the marketable surplus resulted from adoption of high-yielding cultivars for commercial purposes. For this endeavor, various public/private sector networks are established suitable for different regions. Farmer—poultry feed and products industry—user coalition has been established by ICRISAT to broaden the demand for sorghum for utilization in poultry feed rations in Andhra Pradesh state in India. A tie-up has been worked out with Rusni Distilleries Private Limited, Hyderabad, a private sector company based in India to incubate ethanol production technology from several sweet sorghum cultivars developed at ICRISAT. Most significantly, ICRISAT, again is the first premier institute in CGIAR system to tap private sector seed companies resources for public research on hybrid parents development through an innovative consortium model. The consortium netted about US$0.2 million during 2000–2003 and an amount of US$1 million is expected during 2004–2008.

In addition, the popularity of private sector hybrids, most of which are based on ICRISAT-developed parental lines or their derivatives has triggered seed production activity in several villages in Andhra Pradesh and Karnataka states in India. It is estimated that on an average, hybrid seed production fetches US$630 ha^{-1}, about three times the income from commercial crop. In the last three years, a total of 29,800 t of certified hybrid seed of ICRISAT-private sector hybrids was produced which gave a total income of US$18.8 million to farmers in these states. Between 1994 and 2002, seed production of JKSH 22, an ICRISAT-private sector partnership hybrid earned farmers an average of over US$0.3 million per year in Andhra Pradesh and Karnataka states in India and US$2.7 million per year from cultivation of JKSH 22 in Maharashtra and other sorghum growing areas in India.

Thus, the applied research aided by strategic research, new tools and innovative technology sharing through networks, private sector consortium and coalitions has brought about a significant transformation of sorghum from subsistence food crop to a crop of substance resulting in enhanced livelihoods for resource poor farmers and poor people living in SAT regions of Asia, Africa and Latin America.

Sorghum "Team ICRISAT" will continue to carry out research, "Science with a Human Face" by generating International Public Goods (IPGs) to benefit resource-poor farmers, consumers and sorghum-based entrepreneurs.

Importance of Sorghum in Global Agriculture

Sorghum (*Sorghum bicolor* [L.] Moench), the world's fourth major cereal in terms of production, and fifth in acreage following wheat, rice, maize and barley, is a staple food crop of millions of poor in semi-arid tropics (SAT) of the world. It is mostly grown as a subsistence dry land crop by resource-limited farmers under traditional management conditions in SAT regions of the Africa, Asia and Latin America, which are frequently drought-prone and characterized by fragile environments. India grows the largest acreage of sorghum in the world followed by Nigeria and Sudan, and produces the second largest tonnage after the US, with Nigeria, the third largest producer. In most of the regions of India, it is cultivated both as a rainy- and postrainy-season crop. The yield and quality of sorghum produce worldwide is affected by a wide array of biotic and abiotic constraints.

The origin and early domestication of sorghum is hypothesized to have taken place around 5000 – 8000 years ago in northeastern Africa or at the Egyptian-Sudanese border (Mann et al. 1983; Wendorf et al. 1992) with the largest diversity of cultivated and wild sorghum also found in this part of Africa (deWet 1977, Doggett 1988 and Kimber 2000). The secondary center of origin of sorghum is the Indian Subcontinent, with evidence for early cereal cultivation discovered at an archaeological site in western parts of Rojdi (Saurashtra) dating back to about 4500 before present (Vavilov 1992; Damania 2002).

Traditional foods made from sorghum include unfermented and fermented breads, porridges, couscous, boiled rice-resembling foods, snacks, as well as alcoholic beverages. Sorghum blended with wheat flour is used in the last two decades to produce baked products including yeast leavened pan, hearth and flat breads, cakes, muffins, cookies, biscuits and flour *tortillas* (Badi et al. 1990). Malt drinks and malt cocoa-based weaning food and baby food industries are popular in Nigeria. Hard endosperm sorghum is used extensively in southeast Asia for noodles and related products (Murty and Kumar 1995). Sorghum grain is one of the major ingredients in swine, poultry and cattle feed in the western hemisphere, China and Australia (Bramel-Cox et al. 1995), however, demand for grain sorghum in poultry feed depends largely on the price of maize. Sorghum is also grown for forage and is commonly grown in northern India and fed to animals as a green chop, silage or hay. Sweet sorghum is used to a limited extent in producing sorghum syrup and jaggery in India and of late it is gaining importance in the ethanol production.

Sorghum grain and stalk productivity improvement resulted from partnership research efforts globally offer a vast scope for industrial utilization apart from food and feed, thereby improving the economy of developing countries and reduces the need for imports. The popularity of hybrids in Asia, especially in India and China has significantly improved income level of seed growers through hybrid seed production activities. Sorghum, therefore assumes greater importance in the economies of several countries in Africa and Asia largely inhabited by resource-limited farmers besides being a subsistence food staple.

Introduction

Sorghum: cultivation, utilization and food security

Sorghum *(Sorghum bicolor* [L.] Moench) – a major cereal of the world after rice, wheat, maize and barley, is a staple food for millions of poorest and most food-insecure people in the semi-arid tropics (SAT) of Africa, Asia and Latin America. The crop is genetically suited to hot and dry agroecologies where it is difficult to grow other food grains. These are also areas subject to frequent drought. In many of these agroecologies, sorghum is truly a dual-purpose crop; both grain and stover are highly valued outputs. In large parts of the developing world, stover represents up to 50 percent of the total value of the crop, especially in drought years (FAO and ICRISAT 1996).

Sorghum production and utilization in the world fall under two broad groups. Group I countries (primarily in Asia and Africa), where production is traditional, subsistence and small-scale, use sorghum for food. Yields are generally lower and can vary considerably from year to year. Group II countries (developed countries and some developing countries), where production is modern, mechanized, high-input and large-scale, use sorghum primarily for animal feed and yields are higher.

A truly global crop

Sorghum cultivation is distributed throughout the world. In Asia, it is grown in China, India, Korea, Pakistan, Thailand and Yemen. Australia and USA grow the crop too. In southern and eastern Africa, the sorghum-growing countries are Botswana, Burundi, Eritrea, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Rwanda, Somalia, South Africa, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe. In west, central and northern Africa, the crop is grown in Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Egypt, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Mali, Mauritania, Morocco, Niger, Nigeria, Senegal, Sierra Leone, Sudan, Togo and Tunisia. In Latin America, the sorghum-growing countries are Argentina, Brazil, Colombia, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Peru, Uruguay and Venezuela. In Europe, it is grown in France, Italy, Spain, Albania and Romania.

Sorghum plant

The cultivated sorghum is a C_4 annual plant adapted to hot, semi-arid tropical and dry temperate areas of the world. It grows to a height of 50 cm to 6 m. It is cultivated both for its grain and fodder. The types used for grains have a large, erect and single culm terminating in a semi compact or compact head or panicle. The types used for fodder purpose are generally profusely tillering with succulent stems. Many of these fodder types have high ratoonability. The plants have a fibrous root system that may penetrate 5 to 8 ft into the soil that makes sorghum one of the hardiest cereal. Being a C_4 plant it has high water use efficiency. For the same reason, sorghum is grown in regions where most other crops fail to grow. The leaves look very much like those of maize and the number vary from 14 to 18, growing on alternate sides of the stem. Inflorescence commonly referred to as panicle varies from compact to open type. The plant is predominantly self-pollinated although cross-pollination up to 25% is reported depending on the extent of openness of the panicle. The plant is propagated through sexual seed.

Races unique to sorghum

Harlan and deWet (1972) developed a simplified classification of cultivated sorghum (*Sorghum bicolor* (L.) Monech) into five basic, and ten hybrid races that proved to be of real practical utility for sorghum researchers. The basic races are *bicolor, caudatum, durra, guinea and kafir* (Figure 1). The hybrid races are intermediate as expected. The 15 races of cultivated sorghum are identified by mature spikelets alone, although head type is sometimes helpful. The International Plant Genetic Resources Institute (IPGRI) Advisory Committee on Sorghum and Millets Germplasm has accepted and recommended this classification to be used in describing sorghum germplasm (IBPGR/ICRISAT 1980).

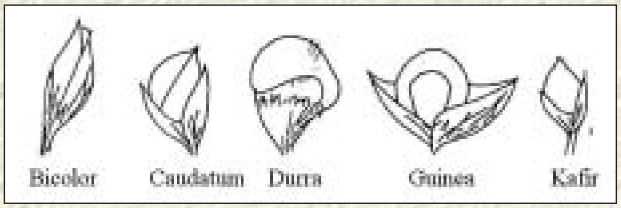

Figure 1. Sorghum classification by basic spikelet type.

Production constraints

The yield and quality of sorghum produce in Group I countries is affected by a wide array of biotic (pests and diseases) and abiotic stresses (drought and problematic soils). These are shoot fly (India and eastern Africa), stem borer (India and Africa), midge (eastern Africa and Australia) and head bug (India and western and central Africa [WCA]) among pests; grain mold (all regions), anthracnose (WCA and northern India) and *Striga* (all regions in Africa) among diseases; drought (all regions) and problematic soils – saline (some parts of India and Middle-East countries) and acidic (Latin America) – which together (except saline and acidic soils) cause an estimated total yield losses to the tune of US$3032 million (www.agbiotechnet.com/pdfs/0851995640).

In Group I countries the sorghum grain productivity was dismally low (0.7 t ha^{-1}) because of these production constraints and the use of traditional cultivars (low-yielding) and production practices when the ICRISAT was established. ICRISAT targeted its research primarily in Group I countries, although it had spillover effects in Group II countries as well by improving sorghum productivity through genetic and natural resources management that directly translates into food security in Africa and income gains through improved competitiveness for sorghum in Asia's sorghum-based industrial markets. We, at ICRISAT describe in this proposal how ICRISAT's partnership sorghum research turned around the fortunes of millions of resource-limited farmers in world's SAT through significant improvements in realized incomes not only from the higher productivity (thus assuring food security) of commercial crop, but also from hybrid seed production activities and broadened utility of sorghum.

ICRISAT's strategy and mission

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was established in 1972 with its headquarters at Patancheru, Andhra Pradesh, India. Sorghum is one of its five mandate crops. The low productivity levels in sorghum were due to the several reasons mentioned above. ICRISAT through crop improvement, natural resources management and socio-economic research aims to improve the living standards of the poor in marginal environments in SAT regions by increasing agricultural productivity and food security, and by reducing poverty and protecting the environment in partnership with national agricultural research systems (NARS) (Annexure I).

Breeding processes

The breeding processes involving partners have undergone changes at ICRISAT because of changes in external environment, donors' perceptions, NARS capacity and ICRISAT research management structures. The identification of geographic functional regions/research domains with a set of constraints has resulted from the gradual shift in breeding strategy from initial wide adaptability to specific adaptations and to trait-based breeding program for threshold traits through 1980s and 1990s (Figure 2). Threshold traits include yield stabilizing defensive traits as well as grain quality-evident traits. The ICRISAT-Patancheru based wide adaptability approach followed initially was abandoned by mid-1980s, and three research centers with regional mandates were established in Africa and one in Central America to take up breeding for region/production system-specific adaptations (Reddy et al. 2004). Thus, six 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 screening techniques (1976–79), (3) regional/ specific adaptations and resistance breeding (1980–84), (4) specific adaptation and resistance breeding (1985–89), (5) trait-based products and sustainable productivity (1990–94), and (6) trait-based products and upstream research (1995–present).

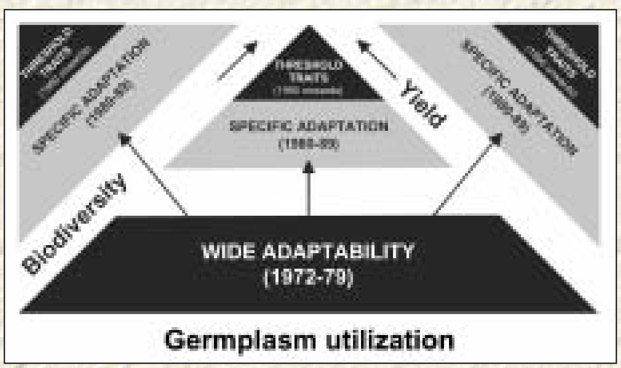

Figure 2. ICRISAT's sorghum breeding strategy from 1972 onwards.

Breeding products

Developing improved varieties in partnership with NARS for all SAT areas from ICRISAT-Patancheru was given major emphasis initially. Later on, hybrids as the target materials were also given considerable importance at ICRISAT-Patancheru. From 1995 onwards, partnership mode of conducting research to develop improved hybrid parents at ICRISAT-Patancheru for Asia, and finished products (varieties and hybrids) at other ICRISAT locations in Africa has been the focus for all regions in Africa. Over the years, several land race selections and improved cultivars with adaptation to different agro-climatic conditions, and resistance to biotic and abiotic constraints have been developed and released by exploiting the available and enhanced genetic diversity using strategic and applied research. The number of germplasm accessions/selections released as superior varieties through partnership research are 23 in Asia, 16 in southern and eastern Africa, 2 in western and central Africa, and 5 in Latin America (Annexure II). The notable among these are NTJ 2, and E 35-1 (a *Zera-zera* landrace from Ethiopia).

NTJ 2 (Figure 3): It was released for Andhra Pradesh state in India, which occupies several thousands of ha in the postrainy season sorghum belt. It is known for its excellent grain and fodder quality with terminal drought resistance, photoperiod sensitiveness and temperature insensitivity – the traits required for postrainy season adaptation in India. It was developed from a landrace in Ethiopia by ICRISAT-Patancheru and Acharya NG Ranga Agricultural University (ANGRAU) (Stenhouse et al. 1997).

Figure 3. NTJ 2, a dual purpose sorghum cultivar highly popular in India.

E 35-1 (a *Zera-zera* landrace from Ethiopia): It was recommended for release in Burkina Faso (Prasada Rao et al. 1989). It is known for its seedling establishment and drought resistant traits such as stay-green.

Partnership efforts by multi-disciplinary team of scientists at ICRISAT and in NARS programs have led to the release of 194 improved cultivars in

Africa, Asia and Latin America and Caribbean countries (Annexure III); SEA (60), Asia (50) – India (22) and others (28), WCA (50) and LA (34). Sorghum area, production and the number of released cultivars have increased over the years (Figures 4–8).

The significant success of ICRISAT partnership program, thus achieved is due to dynamic sorghum improvement program involving multidisciplinary team of scientists utilizing the strong genetic resource base of 36,744 accessions from 91 countries representing all the five basic and their hybrid races (30,853 landraces, 5434 breeding lines, 66 advanced cultivars and 421 wild) built at ICRISAT's Rajendra S Paroda Genebank, which were maintained, classified and evaluated (Table 1). 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 successfully captured both racial as well as geographical diversity. Nearly 4000 germplasm accessions were utilized to generate variability of which 557 lines have contributed to the development of the elite lines referred above. The tropical germplasm lines originating from Asia (175) have contributed most followed by temperate and tropical lines from Africa (139) and USA (105) (Table 2). These germplasm lines largely belonged to *Durra* (80) (predominantly represented by Asia) and *caudatum* (48) (predominantly represented by Africa) among the basic sorghum races and *guinea-caudatum* (71) (predominantly represented by

Figure 4. Sorghum area, production, productivity and number of cultivars released in SEA.

Figure 5. Sorghum area, production, productivity and number of cultivars released in Asia.

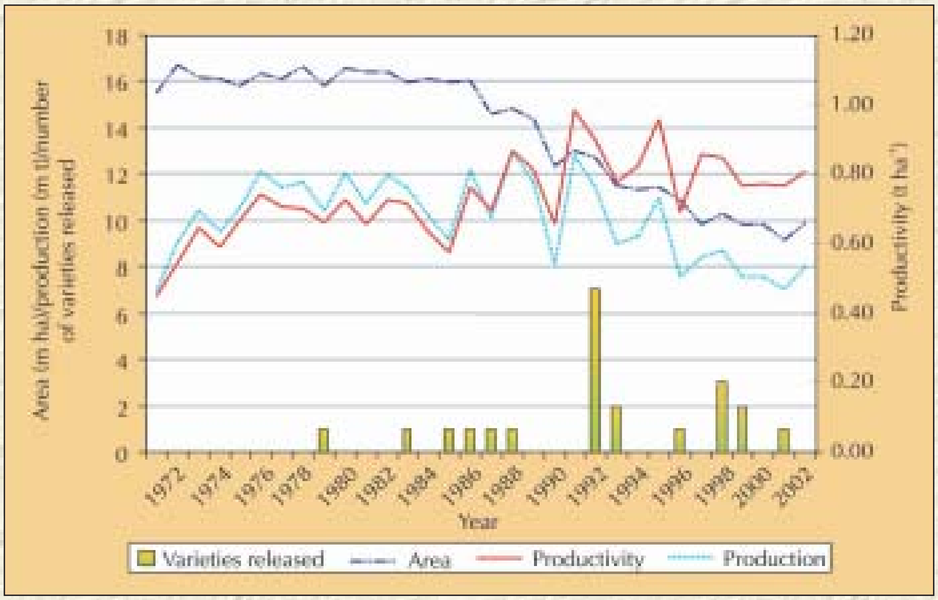

Figure 6. Sorghum area, production, productivity and number of cultivars released in India.

Figure 7. Sorghum area, production, productivity and number of cultivars released in WCA.

Figure 8. Sorghum area, production, productivity and number of cultivars released in Latin America.

Table 1. Status of classified sorghum germplasm accessions held at ICRISAT gene bank according to biological races and geographic origin

	Bicolor	Caudatum	Caudatum-bicolor	Drummondii	Durra	Durra-bicolor	Durra-caudatum	Guinea	Guinea-bicolor	Guinea-caudatum	Guinea-durra	Guinea-kafir	Kafir	Kafir-bicolor	Kafir-caudatum	Kafir-durra	Tetraploid wild	Un-classified	Total
Asia	529	685	420	2	4108	899	2059	819	41	359	84	4	63	43	42	51	1	46	10209
ICRISAT	2	72	16		3	1	11	15		32	1	1	19	1	3	2		353	179
India	344	142	114	2	3569	549	379	772	25	145	56	1	12	10	6	34	1	21	6161
WCA	107	1808	214	3	646	179	789	2677	185	679	30	1	7	4	7	4	2	8	7342
S&EA	381	4343	556	16	2762	1162	1056	809	70	1985	79	34	870	35	222	134	7	94	14521
LA& Caribbean	4	40	13	0	8	3	28	2	0	13	2	0	63	4	7	4	0	0	191
North America	333	325	169		151	60	276	74	22	184	17	65	238	42	111	65		16	2132
World	1445	7441	1439	21	7783	2348	4289	4782	329	3387	223	106	1274	135	404	270	14	639	35690

Table 2. Summary of origin of sorghum germplasm utilized to develop various categories of breeding products at ICRISAT

	Seed Parents		Improved Parents		
Region/Country	High yielding A-/B pairs	Trait specific A-/B pairs	Restorers	Varieties	Total
Asia	16	31	53	64	175
USA	12	25	33	35	105
WCA	1	11	24	44	81
SEA	2	8	18	30	58
ICRISAT[1]	-	6	14	30	50
South Africa	3	3	5	6	17
Australia	-	1	1	3	5
Latin America	-	2	2	-	4
Unknown	1	4	22	39	66

1. Breeding materials

Africa) and *durra-caudatum* (45) (predominantly represented by Asia and Africa) among the hybrid races (Table 3).

The formation of core collection (Prasada Rao et al. 1995) helped enhanced utilization of these genetic resources. The proposed formation of mini-core collection (about 10% of the core collection) following the strategy of Upadhyaya and Ortiz (2001) is expected to bring about further genetic gains from partnership research.

I. Impacts on livelihoods of resource-poor farmers and people

Adoption of improved cultivars

The worth of the improved cultivars is qualified by their successful adoption by the farmers and adoption is the precondition for creating impacts. Adoption levels of improved ICRISAT-bred sorghum cultivars are high in Asian countries, while comparatively low in African countries.

Table 3. Race-wise distribution summary of the sorghum germplasm accessions that contributed for developing various sorghum materials at ICRISAT-Patancheru

	Number of accessions				
	Seed parents		Improved		
Race	High yielding A-/B pairs	Trait specific A-/B pairs	Restorers	Varieties	Total
Bicolor (B)		1	10	1	12
Caudatum (C)	3	7	16	22	48
Caudatum bicolor (CB)		5	6	14	25
Durra (D)	6	13	31	30	80
Durra bicolor (DB)	1	1	4	9	15
Durra caudatum (DC)	5	5	11	24	45
Guinea (G)		2	2	7	11
Guinea caudatum (GC)	3	10	19	39	71
Guiea durra (GD)	2	1	2	3	8
Guinea kafir (GK)	1		1	2	4
Kafir (K)	4	4	8	6	22
Kafir bicolor (KB)	1	1		1	3
Kafir caudatum (KC)		1	2	1	4
Kafir durra (KD)	5	6	5	4	20
Unclassified	19	25	56	89	189
Total	50	82	173	252	557

Asia: India has the highest level of adoption of improved cultivars (65% of total sorghum area) in Asia of which more than 50% of the area is covered under cultivars with ICRISAT-bred improved germplasm content. Initially, when private sector seed companies were in their infancy, public sector-bred cultivars dominated the farmers' fields but as the private sector seed companies developed their own research and development infrastructure, they took the lead in the development and marketing of large number of hybrids based on ICRISAT-bred hybrid parents in India.
In India, more than 4 million ha is occupied by over 54 hybrids developed by seed companies based on ICRISAT-bred parental lines or their derivatives. An ICRISAT-private sector hybrid, JKSH 22, known for its high grain yield potential, bold grain and earliness (5–10 days compared to the most popular hybrid CSH 9) showed remarkable adoption covering 1500 ha in 1994 to 210,000 ha in 2002 (about 0.5% of the total rainy season sorghum area) (Figure 9). Apart from this, several other private sector hybrids with ICRISAT-bred hybrid parents or their derivatives such as MLSH 296, VIKI 540, GK 4009 and GK 4013 are widely adopted in India. In Pakistan, 21% of the area is under improved cultivars. Two varieties PARC-SS 1 (ICXV 107) and PARC-SS 2 (IRAT 408) were released in Pakistan, which account for nearly 50% of the area occupied by improved cultivars.

In China, hybrids take the lion's share of the total area sown to improved cultivars having ICRISAT-

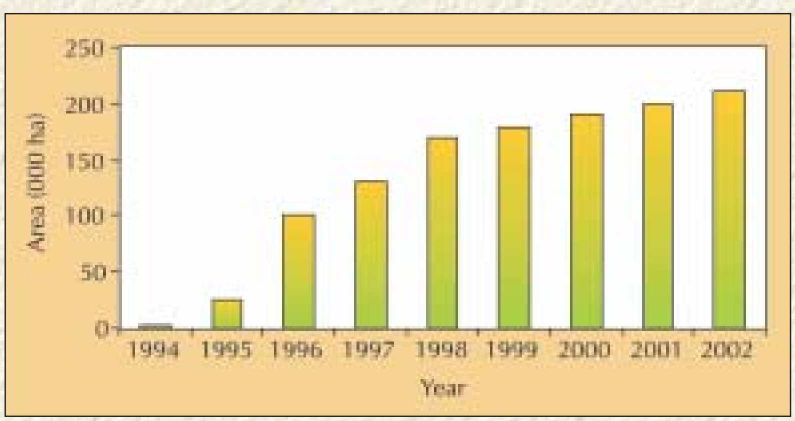

Figure 9. The area covered under JKSH 22, an ICRISAT-private sector partnership hybrid in India.

bred materials. In 1975–76, only local sorghums were in cultivation while in the mid-90s, all the area under improved cultivars was sown to 9 ICRISAT-bred varieties in Myanmar. In Thailand, improved cultivars having at least one ICRISAT-bred parent covered 10% of the country's total sorghum area in 1995–96.

Africa: The adoption of improved cultivars in African countries varied from 3% of total sorghum area in Sudan to 49% in Cameroon (Table 4).

Southern and Eastern Africa: The improved cultivars developed by ICRISAT in southern Africa currently occupy 15–50% of the area in eight Southern African Development Committee (SADC) member states. The levels of adoption of ICRISAT-bred varieties in Zimbabwe, Zambia, Malawi and Sudan in 1997 were 36%, 35%, 10% and 3%, respectively (Table 4). Although, in Zimbabwe, the sorghum variety SV 2 was released in 1987, it showed a rapid rise in adoption from 1991 onwards to reach 36% in 1994. The variety Gadam el Hamam has been adopted by Kenyan farmers who are impressed with its early maturity, drought tolerance and good taste. Another high yielding variety Pato has been adopted over approximately 36% of the area under improved sorghum varieties in Tanzania.

Western and Central Africa: The adoption levels were highest in Cameroon (49% of total sorghum area) followed by Mali (29%), Nigeria (28%) and Chad (27%) (Table 4). The sorghum variety S 35 that began diffusion in 1986 in Cameroon and in 1990 in Chad showed varying adoption ranging from 12 to 15% in Cameroon and 5 to 39% in Chad. CSM 63 E, an extra-short-duration variety with excellent grain quality, popularly known as Diacumbe, is making inroads with the farmers and is now grown in over 10% of the sorghum area in Mali. The adoption of this variety along with several other varieties (Tiemarifing, CSM 388, CE 151, Siguetana, ICSV 1063 BF and ICSV 1079 BF) in West Africa ranged from 20 to 30%. The adoption rates of improved varieties by the farmers are substantial in drought-prone regions of the Malian

Table 4. Level of adoption (% area) of different improved sorghum cultivars in Africa

Country	Region	Year	Percent area planted to: Cultivars with ICRISAT's contribution	Percent area planted to: All improved
Botswana	National	1997/98	33	33
Cameroon	Mayo Sava	1995	49	49
	Diamare	1995	14	14
	Mayo Danay	1995	12	12
Chad	Guera	1995	38	38
	Mayo Kebbi	1995	27	27
	Chari Baguirmi	1995	24	24
Egypt		1995/96	5	35
Lesotho		1997	4	4
Malawi		-	10	10
Mali		1995	29	29
Mozambique		-	5	5
Nigeria	Kano	1996/97	28	28
	Katsina	-	10	10
	Kaduna	-	29	29
	Jigawa	-	3	3
Sudan		1995/96	3	22
Zambia		-	35	35
Zimbabwe		-	36	36

Source: Deb et al. (2004); Ogungbile et al. (1999) for Nigeria; Rohrbach and Makhwaje (1999) for Botswana; Yapi et al. (1998) for Mali; and Yapi et al. (1999) for Cameroon and Chad.

bread basket (Mopti, Segou and Koulikoro) targeted by sorghum improvement research (Yapi et al. 2000). A hybrid called NAD 1 has been released, and both seed production and adoption are increasing in Niger and Nigeria. Similarly, hybrid ICSH 88902 has been released in Nigeria.

Egypt: In Egypt, 15% of the total sorghum area is under ICRISAT-bred improved pure line selections and hybrid parents. Of this 15% area, 8% area is covered under ISIAP Dorado, a short-statured, large- and hard-grained, high-yielding and white-grained/tan plant pure line selection. Besides these, three hybrids – Shadaweel 1, Shadaweel 2 and Shadaweel 6 – developed using ICRISAT-bred hybrid parents by Egyptian government sorghum improvement program are gaining popularity.

Latin America: In 1993, more than a fifth of the sorghum area in four Central American countries was sown to improved cultivars bred or introduced to the region through the ICRISAT program (often in collaboration with those of International Sorghum/Millet Collaborative Research Support [INTSORMIL] and NARS). This included almost half the sorghum area in Guatemala, a third in Honduras and a fifth in Nicaragua and El Salvador (CGIAR 1996).

Grain productivity

Gradually, the number of releases and the number of countries adopting improved sorghum hybrid cultivars have been expanding. This, along with the adoption of improved production technologies developed through natural resources management research resulted in an increase of annual sorghum grain productivity by 0.9% in Africa and 3.1% in Asia between 1971–73 to 2000–2002.

Asia: With a dramatic increase in productivity between 1971–73 to 2000–2002, India (by 280 kg ha^{-1}) is able to spare nearly 6 million ha and Asia (by 450 kg ha^{-1}) about 7.4 million ha of sorghum area to other competing crops, while still maintaining sorghum production of 1972 in 2000–2002. Several ICRISAT-Patancheru-bred improved cultivars such as ICSV 112, ICSV 745, SPV 351, CSH 11; ICRISAT-public sector partnership cultivars SPH 840 and PVK 801 and numerous (about 54) ICRISAT-private sector partnership hybrids in India and several varieties/hybrids with ICRISAT breeding product content in China, Myanmar and Thailand have contributed to increased productivity in Asia. The large-scale adoption of an ICRISAT-private sector hybrid JKSH 22 (Figure 10) known for its high grain yield potential, bold grain and earliness (5–10 days compared to CSH 9) resulted in significant improvement in sorghum yield levels on farmers' fields.

A dual-purpose grain mold resistant rainy season adapted sorghum variety PVK 801 (Figure 11) developed by ICRISAT in partnership with Marthwada Agricultural University, Maharashtra, India, is highly popular in Maharashtra state because of its higher grain and fodder yielding ability coupled with good grain and stover quality than the popular cultivar CSV 15. Another hybrid

Reasons for adoption

Farmers in Mali have cited early-maturity, high yield, good food quality and *Striga* resistance as reasons for the adoption of improved sorghum varieties. Ogungbile et al. (1999) mentioned that early-maturity, high yield, good food quality and ease of threshing and processing were main reasons for the adoption of improved sorghum varieties (ICSV 111 and ICSV 400) in Nigeria. Farmers of Chad cite early maturity, high yield and good food quality are among the most important reasons for the adoption of S 35 (Yapi et al. 1999). In India, high rate of adoption of ICRISAT-based hybrids is due to bold grain, higher grain and fodder productivity. The large-scale adoption of ICRISAT-bred improved cultivars by farmers of Africa and Asia is a clear indication that breeding efforts have been successful in addressing the farmers' preferences.

Figure 10. JKSH 22, highly popular ICRISAT-private sector partnership hybrid with high adoption level in India.

Figure 11. PVK 801, an ICRISAT–public sector partnership grain mold resistant variety highly popular in Maharashtra state in India.

SPH 840 developed by ICRISAT in partnership with Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India, is also popular as its grain and fodder yield potential is better than highly popular hybrid CSH 16. The adoption of these cultivars in Maharashtra, a major sorghum growing state in India, has contributed to significant improvement in rainy season sorghum productivity.

Africa: The increased sorghum area in Africa (by 9 million ha) coupled with increased productivity (by 150 kg ha^{-1}) enhanced the total production by 10 million t from 1971–73 to 2000–2002, signifying its contribution to the regional/ national food security. A yield differential as high as 600 kg ha^{-1} was noted in Cameroon. Farm level yields of improved cultivars were 7–63% higher than the best local cultivars in Nigeria. Improved cultivar S 35 (Figure 12) had 51% yield advantage in Chad and 14% in Cameroon (Table 5), indicating its better genetic potential.

Figure 12. S 35, a high yielding cultivar widely cultivated in many African countries.

Table 5. Impacts of improved sorghum cultivars on grain yield in Africa.

Country	Region	Year	Improved cultivar	Yield (kg ha^{-1}) Local	Improved	Yield gain (%)
Cameroon	Mayo-Sava	1995	S 35	1220	1650	36
Cameroon	Diamare	1995	S 35	1450	1540	6
Cameroon	Mayo Danay	1995	S 35	1420	1470	4
Cameroon		1995	S 35	1360	1550	14
Chad	Guera	1995	S 35	710	1090	54
Chad	Mayo-Kebbi	1995	S 35	780	1190	53
Chad	Chari-Baguirmi	1995	S 35	810	1180	46
Chad		1995	S 35	760	1150	51
Nigeria		1996	ICSV 400	875	1165	33
Nigeria		1996	ICSV 400	1003	1073	7
Nigeria		1996	ICSV 400	865	1398	62
Nigeria		1996	ICSV 400	914	1212	33
Nigeria	Kano	1996	ICSV 111	875	1221	40
Nigeria	Katsina	1996	ICSV 111	1003	1274	27
Nigeria	Jigawa	1996	ICSV 111	865	1406	63
Nigeria		1996	ICSV 111	914	1300	42

Source: For Cameroon and Chad, Yapi et al. (1999) and for Nigeria, Ogungbile et al. (1999).
Latin America: Yields have doubled in Argentina, Nicaragua, Peru, El Salvador, Guatemala, Honduras and Mexico.

In general, countries with strong NARS benefited from elite germplasm and hybrid parental lines. On the other hand, countries with weak NARS benefited from finished products.

Costs of production

An analysis in India showed that the cost of unit production (cost per ton) using improved varieties decreased in the 1980s and 1990s compared to that in early 1970s (Table 6), despite the increase in the total cost of production because of the use of additional inputs. The increased productivity of improved cultivars has more than compensated the cost of additional inputs. In Maharashtra and Rajasthan states, the cost per ton in 1990s was 40% and 37%, respectively, compared to that in 1970s. The improved cultivar S 35 has a cost advantage of 12% in Cameroon and 25% in Chad

Table 6. Impact of improved sorghum cultivars on per ton production cost in India, 1971–1995.

	Average cost (Rs t^{-1})			Cost reduction (%) compared to early 1970s in	
States	Early 1970s[1]	Early 1980s[2]	Early 1990s[3]	Early 1980s	Early 1990s
Andhra Pradesh	270	NA	286	NA	-6
Karnataka	224	192	231	14	-4
Madhya Pradesh	223	169	208	24	7
Maharashtra	253	188	153	25	40
Rajasthan	309	264	195	14	37

Note: All costs are real cost of production. For Rajasthan, real cost is computed on the basis of 1992 prices and all other states based on 1989 prices.
1. Early 1970s indicate for Andhra Pradesh (average of 1973 and 1974), Karnataka (average of 1972–1974), Madhya Pradesh (1976), Maharashtra (average of 1972–974) and Rajasthan (average of 1972–1974).
2. Early 80s indicate for Karnataka (average of 1981–1983), Madhya Pradesh (average of 1981–1983), Maharashtra (average of 1982–1983) and Rajasthan (average of 1981–1983).
3. Early 1990s indicate for Andhra Pradesh (average of 1994–1995), Karnataka (1991), Madhya Pradesh (average of 1994–1995), Maharashtra (1995) and Rajasthan (1992).
Source: Estimated from cost of cultivation reports (various issues).

(Table 7) (Yapi et al. 1999). Cost of production per unit ton of sorghum grain using improved varieties is reduced by 25% (US$34 t^{-1}) compared with local varieties in Mali (Yapi et al. 2000).

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 (Deb and Bantilan 2003). 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 Southern African Development Committee member states together contributes an additional US$19 million per year in income streams. In Zambia and Zimbabwe, IRR from the adoption of cultivar ICSV 88060 is estimated at 11–15% and 22%, respectively.

Genetic diversity

The genetic diversity of cultivars in a crop species is essential for yield stability under ever-dynamic environmental conditions, as it acts as natural insurance against unexpected pests and disease outbreaks, resulting in major production losses. ICRISAT's trait-based breeding approach utilizing diverse germplasm helped capture not only the advantages of specific adaptation but also maintain the diversity in the improved varieties and hybrid parents. As a result, the cultivars adopted by farmers have greater genetic diversity contributing to the increased yield stability in all the sorghum-growing states in India (Deb and Bantilan 2003). In India, more than 4 million ha (80% of the total) of rainy season sorghum are planted with about 70 private sector hybrids, of which 54 are based on ICRISAT-

Food security and higher income

The adoption of the improved varieties has ensured food security to ever increasing mouths, especially in Africa through sustainable production as they are early maturing, which are known to reduce risks from late-season drought and to bring down the hunger gap by providing first food in the farming year. With increased yield productivity (Figure 13) coupled with reduction in unit cost of production, farmers adopting the improved varieties have more access to food for their families and for social ceremonies as well as a marketable surplus, thus raising their income levels. The cost saved on food is far greater than research costs as explained above.

Table 7. Impacts of improved sorghum cultivar (S 35) on cost of production in Cameroon and Chad, 1995.

		Production costs(CFA francs t^{-1})		
Country	Region	Local	Improved	Unit cost reduction (%)
Cameroon	Mayo-Sava	77,500	57,700	26
Cameroon	Diamare	63,500	58,900	7
Cameroon	Mayo Danay	50,000	49,300	1
Cameroon		63,161	55,607	12
Chad	Guera	89,296	65,825	26
Chad	Mayo-Kebbi	45,994	37,903	18
Chad	Chari-Baguirmi	67,765	49,947	26
Chad		80,805	60,817	25

Source: Yapi et al. (1999).

Figure 13. A happy African farmer with bountiful harvest of sorghum contributing to food security in Africa.

Gender perceptions

Women in Africa contributed significantly to the adoption of low tannin white grain improved cultivars since women perceived the grains to be of good milling/food quality. This helped in increased food availability at the household level in regions where it was promoted on a large scale. In India, although the demand for sorghum as food grain has declined over the years, acceptance of improved dual-purpose cultivars increased because of their improved stover palatability and digestibility, the traits preferred by women who dominate small farm dairies (Figure 14). Women are generally in the forefront of all livestock related activities. The additional income because of increased fodder quantity and superior quality ensures higher and regular income to the family.

Figure 14. An Indian woman carrying sorghum stover which contributes substantial dry matter to milking buffaloes in small and large dairies in India.

derived parental lines/improved germplasm. These have made substantial contributions to enhance biodiversity, productivity, yield stability, and also improved the livelihoods of poor farmers in the dry areas (Gowda et al. 2003).

Spillover impacts

Several varieties developed at one location exhibited their superior performance in another location/country/region. Details of such spillovers are described below:

Spillovers from Asia to Africa: A total of about 29 varieties, including germplasm accessions and advanced progenies have spilled over from ICRISAT-Patancheru into 17 African countries (Figure 15). In order to illustrate the spillover of sorghum technologies from ICRISAT-Patancheru to the African region/countries, selected examples are presented.

Variety S 35: It is an advanced generation breeding progeny (M 91019) developed at ICRISAT-Patancheru, which was introduced into ICRISAT-Nigeria and from these reintroduced into Cameroon and Chad where it was released as S 35 upon further testing. On the basis of its high and stable performance, S 35 was released in 1986 for wider use in large-scale seed multiplication. According to Kamuanga and Fobasso (1994), 20 t of S 35 seed was produced at the time of its release by the government's Seed Multiplication Project at Maroua.

Variety ICSV 111: It is a pure-line variety developed between 1980 and 1984 at ICRISAT-Patancheru through pedigree selection from a three-way cross. The ICRISAT program in Nigeria introduced ICSV 111 in 1988 from ICRISAT-Patancheru, and it was released in 1996. Farmers in Nigeria prefer this variety because of its high yield, early maturity, white grain, good food quality (good porridge-making quality) and juicy stalks (preferred by animals). It is also resistant to *Striga hermonthica*, an important parasitic weed in WCA.

Figure 15. Spillover impacts of important sorghum research products.

S 35 – a food securing and land saving sorghum variety

"When rains do not come on time or when they stop too soon, our own varieties give us nothing, so we sow this one", says a farmer Toralet of Niergui village (Guera in Chad) displaying a few panicles of S 35. "This is the sorghum that never fails", he adds. "I used to sow 2 ha of my own variety of sorghum each year in order to feed my family", said another farmer Issaka from the village of Niergui, Guera. "I now sow only 1 ha with S 35. I grow vegetables on half of the other hectare", he added. For Bouda, a farmer from the village of Tchigali II in Mayo-Kebbi in Chad, the short duration trait of S 35 variety is a real advantage, not just because it helps escape terminal drought, but also matures much earlier, thereby reducing the hunger period before the next harvest. "Ever since I first tried S 35 variety in 1992, I sow half a hectare of it each year. This way I can feed my family even as I wait for the sorghum of our ancestors to mature", he said (Yapi et al. 1999).

Variety ICSV 112: This (Figure 16) was developed at ICRISAT-Patancheru by pedigree selection from a multiple cross. The variety was released in India (as CSV 13 in 1987) and in several African countries – Zimbabwe (as SV 1 in 1987), Kenya (as CSV 13 in 1988), Swaziland (as MRS 12 in 1992), Malawi (as PIRIRA 2 in 1993), Mozambique (as Chokwe) in 1993 through the efforts of ICRISAT's Africa programs and their partners. It was also released in a few Latin American countries. ICSV 112 is a medium-maturing (110–120 days), rainy-season variety with moderate juicy stalks. The grain contains about 9.6% protein and 2.6% lysine (100 g^{-1} protein). Food prepared from the variety is good and comparable with that from CSH 5, a popular commercial sorghum hybrid in India.

Variety SV 2, A 6460: This is an example of a variety from ICRISAT-Patancheru tested and released by national programs in their own countries. The Department of Research and Specialist Services (DR&SS) of Zimbabwe introduced A 6460 from ICRISAT-Patancheru in 1980. It was evaluated and released as SV 2 (Figure 17) in 1987 for its earliness and higher grain yield. In on-station trials in Zimbabwe, SV 2 provided a grain yield of 3.38 t ha^{-1} that compares with 2.73 t ha^{-1} for local varieties. SV 2 flowered 13 days earlier than the local variety.

ICSV 400: A high yielding ICRISAT-Patancheru bred variety enjoys wide adoption in Nigeria and Ghana. Sales of ICSV 400 increased enormously to 4.5 million Naira (US$40,000) in 2001 because of the variety's suitability in the brewing industry. Virtually all Guinness Stout, one of Nigeria's most popular beverages, is brewed from ICSV 400.

Figure 16. ICSV 112, a high yielding popular variety released in several African and a few Latin American countries.

Figure 17. SV 2, an early-maturing and high-yielding variety developed in ICRISAT-Patancheru and released in Zimbabwe.

Spillovers from Africa to Asia: There are two good examples of sorghum lines introduced from Africa (IRAT 408 and IS 30468) through ICRISAT: (1) PARC SS 2, which was derived from a Malian line (IRAT 408) and introduced by ICRISAT through germplasm exchange to Pakistan and was released there in 1991. (2) NTJ 2, a selection by ICRISAT from an Ethiopian landrace introduced and released in Andhra Pradesh (India) in 1990. These lines were distributed to the national programs after some selections at Patancheru. NARS scientists evaluated them in national trials before their release.

Spillovers within Africa: Several varieties bred in one region excelled in their performance in other regions.

Variety Macia (SDS 3220) (Figure 18): This is an open-pollinated, early-maturing, stay green and high-yielding variety developed at ICRISAT-Bulawayo, Zimbabwe, in 1989. It was released in Mozambique (as Macia in 1989), Botswana (as Phofu in 1994), Namibia (as Macia in 1998), Zimbabwe (as Macia in 1998) and Tanzania (as Macia in 1999). Farmers are benefiting from rapid and extensive adoption of the variety in these two countries (Botswana and Mozambique). Phofu is being planted by 21% of the sorghum farmers in Botswana. This was followed by a sequence of releases in three other SADC countries – Namibia (1998), Zimbabwe (1998) (it was released by SeedCo Ltd, a private seed company) and Tanzania (1999). This variety is being cultivated in an area of 0.1 million ha for its good taste and food quality in Botswana, Namibia, Zimbabwe, Mozambique,

Figure 18. Macia—Farmers in several southern African countries are benefitting from adoption of this early-maturing, high-yielding variety developed at ICRISAT-Bulawayo.

Eritrea and Tanzania, which represent SADC region of southern Africa. (Table 8).

Spillovers within Asia: Several varieties (21 in India and 23 in other Asian countries) have been released in Asia using ICRISAT-Patancheru-bred material.

China: Ten sorghum varieties using ICRISAT parental material were released from 1982 to 1997. These are Yuan 1-98, Yuan 1-28, Yuan 1-505 (all varieties), Liao Za 4, Liao Za 5, Liao Za 6, Liao Za 7, Zin Za 94, Jin XA 4, Liao Za 10, Zin Za 12, Gile Za 80 (all grain sorghum hybrids) and Longsi-1 (a forage sorghum hybrid).

Myanmar: Nine sorghum varieties (including germplasm accession) have been released in Myanmar from 1982 to 1994. These varieties were directly introduced from ICRISAT- Patancheru into the regional trials.

Table 8. 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.

Pakistan: Two varieties, ICSV 107 (PARC – SS1) and IRAT 408 (PARC – SS2), were released in Pakistan in 1991. Both the lines were introduced from ICRISAT-Patancheru.

The Philippines: Two sorghum varieties, IES Sor 1 and IES Sor 4, were developed using ICRISAT's germplasm and released in Thailand in 1996.

Spillovers to other regions: ICRISAT-Patancheru-bred varieties were introduced into ICRISAT's Mexico program (1978–93) where they were further improved in collaboration with the national programs. These and others developed at other ICRISAT Centers were evaluated jointly with the national programs in the Americas and Australia.

Central America: National programs after testing released a number of varieties – 5 in Mexico, 2 in Nicaragua, 3 in El Salvador, 3 in Honduras and 1 in Gautemala.

Latin America: Several varieties/segregating materials/improved germplasm/hybrids/ hybrid parents such as ICSV 112, ISIAP DORADO, M90362, M62641 and M90812, all bred at ICRISAT-Patancheru/ICRISAT-Mexico were released in Mexico as UANL-1-87 and Pacifico 301, ISIAP DORADO, UANL-1-287, Costeno 201 and Tropical 401, respectively. Similarly, ISIAP DORADO, M 90362, M 90361, ICSV-LM 90502, ICSV-LM 90503 and ICSV-LM 90508 were released in El Salvador as ISTMENNO, Agroconsa, Centa Oriental, Soberano, R.C.V. and Jocoro, respectively; ISIAP DORADO, M62650, IS 18484, and the hybrid ATx 623xTORTILLERO were released in Honduras as ISIAP DORADO, Sureno, Tortillero and Catracho, respectively.

Australia: As a result of the introduction of midge resistant cultivars such as ICSV 745 (Figure 19) from ICRISAT-Patancheru, India, grain yields in Australia is expected to increase by 5 to 50% in the midge-endemic areas. The expected gains to Australia in terms of yield are estimated to be at 2.5% that translates into a cost reduction of US$4.0 t^{-1} or a cost saving of US$4.7 million at the current average production levels. Australia made net gains at an average of US$1.14 million per year from the impact of ICRISAT's sorghum research. The benefits are well in excess of Australian financial contribution to ICRISAT (Brennan et al. 2004).

Figure 19. ICSV 745, a high-yielding, midge-resistant variety popular in Karnataka state of India with significant spillover impact in Australia.

Impacts from private sector

ICRISAT has been interacting with scientists in private and public sectors. The feedback from these scientists helped to shape the research programs at ICRISAT. Interaction, in particular with private sector helped to transfer the benefits of ICRISAT-developed products to farmers. Also, private sector benefited immensely which used ICRISAT's improved hybrid parents and marketed hybrids made either directly from these parents or their derivatives.

Midge resistant lines in Australia: From 1987 onwards**,** Pioneer has been testing selections, primarily for midge resistance (a total of 400–600 lines) from ICRISAT, imported through Pioneer's Indian program in Australia (Brennan et al. 2004). ICSV 197 has been the most successful and there are now 66 inbred pedigree lines in F_4 and F_5, with an average infusion of 13% of ICSV 197 in the restorer lines. Other progenies that are derived from ICRISAT material are in advanced stages of the program; their ICRISAT source materials include DJ 6514, PM 15952 and PM 15949. Pioneer's sorghum program in 1996 had a number of ICRISAT lines being evaluated for midge resistance and dual-purpose or forage sorghum, both as restorer lines and female lines. The lines in backcrossing stage have about 10% ICRISAT infusion, with a slightly higher level (13–15%) in the restorer lines. Pacific seeds, another private sector company, has developed and marketed forage sorghum hybrid using one parent from ICRISAT, and several more were being developed by pedigree crossing, especially using late-maturing B-lines in single crosses. Pacific seeds also uses screening techniques for midge resistance developed at ICRISAT (Brennan et al. 2004).

ICRISAT-Private Sector Sorghum Hybrid Parents Research Consortium: ICRISAT, in the beginning, interacted with scientists in private sector seed companies on an informal basis and supplied to them wide range of breeding products. However, for enhanced farm level adoption of hybrids developed from ICRISAT's intermediate/products, ICRISAT-led private sector Sorghum Hybrid Parents Research Consortium has been operational since 2000. The impacts of this consortium are briefly described below.

Cultivar adoption: The ICRISAT-PS partnership has greatly contributed to development and marketing of improved hybrids and varieties in Asia. In India, more than 4 million ha (80% of the total) of rainy season sorghum are planted with about 70 PS-based hybrids, of which 54 are based on ICRISAT-derived parental lines. These hybrids have made substantial contributions to enhance genetic diversity, productivity, yield stability, and also improved the livelihoods of poor farmers in the dry areas (Gowda et al. 2003). Scientists' Field Days and meetings provide opportunity for private seed companies to select breeding materials and to elicit feedback on the usefulness of materials, and also to set priorities (such as farmer or trade or industry preferences) for future research.

Benefits from seed production: Farmers on an average produced about 3.0 t ha^{-1} hybrid seed of JKSH 22, an ICRISAT-private sector partnership hybrid to obtain a profit of Indian Rs. 29,500 (US$630). Between 1994 and 2002, JKSH 22 seed production earned farmers, on an average, US$0.3 million per year. Based on the seed sales of JKSH 22, farmers in Maharashtra and other sorghum growing areas in India have earned an average of US$2.7 million every year for the last nine years from cultivating JKSH 22. Several seed villages in Andhra Pradesh and Karnataka states in India became prosperous by taking large scale hybrid seed production (personal communication from Ramakrishna 2003).

It is estimated that on an average, hybrid seed production fetches US$630 ha^{-1}, about three times the price of commercial crop. In the last three years, a total of 29,800 t of certified hybrid seed of ICRISAT-private sector hybrids was produced (Table 9), which gave a total income of US$18.8 million in India. Livelihoods and the environment in these villages (roads, temples, new houses) got better as a result of higher income accrued from hybrid seed production.

Table 9. Share of ICRISAT-private sector (PS) partnership sorghum hybrids seed production (certified) in total Indian sorghum seed production.

Year	PS hybrid seed		Total certified seed (t)
	Quantity (t)	Percentage (%)	
2001–02	11600	71	16410
2002–03	7200	63	11390
2003–04	11000	61	18000
Total	29800	65	45800

Resource mobilization: Sixteen PS seed companies working on sorghum in India, Egypt, Thailand and Indonesia have expressed their interest to join the revised Sorghum Hybrid Parents Research Consortium in 2004, which enables ICRISAT to mobilize financial resources to the tune of US$140,000 per year (Table 10) towards partial funding of crop improvement research at ICRISAT for developing elite sorghum hybrid parents to serve both public and private sectors. This resource mobilization is particularly significant at the crucial time of diminishing core funding to crop improvement research at ICRISAT. Thus, the Hybrid Parents Research Consortium for sorghum established at ICRISAT has emerged as a novel institution building for supporting agricultural research and enhancing impacts.

Table 10. Status of sorghum ICRISAT-private sector Hybrid Parents Research Consortium members and total resource mobilized since its inception in the year 2000.

Year	No. of consortium members	Amount accrued ($)
2000	7	35000
2001	9	45000
2002	12	60000
2003	12	60000
2004 (up to June)	16	140000
	Total	340000

Feedback on research agenda: The feedback received from private and public sectors scientists on the utilization and quality of ICRISAT-bred hybrid parents, the number of hybrids developed and marketed/released, extent of farm-level adoption of such hybrids and the constraints, if any for the adoption, and farmers' perceptions will be collected from the partners time to time and the information is summarized. This feedback is useful to improve and/or modify ICRISAT's sorghum breeding strategy.

II. Impacts on sustainable production systems

Genetic options – cultivars with improved resistance to biotic and abiotic stresses

During the initial periods of its inception (1972–75), ICRISAT placed high importance on developing varieties and hybrid parents with high yield potential. In subsequent years, genes conferring resistance to several biotic and abiotic yield constraint traits were identified and were introgressed into the varieties and hybrid parents to bring stability to their high yield potential through trait-based breeding approach. The hybrids developed from these parents in Asia and Latin America, and the varieties in Africa 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 conservation in SAT countries.

The potential gain by genetic enhancement of resistance to biotic and abiotic stresses via crop improvement is estimated to be around $736 million annually. In India, varieties bred for specific adaptation, ICSV 112 and ICSV 745, which are relatively early and resistant to foliar diseases (and ICSV 745 resistant to midge) introduced in Warangal district of Andhra Pradesh state 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 Melghat region of Maharashtra state in India.

Natural resources management options – vertisol technology

The adoption of dry seeding summer cultivation of sorghum, one of the components of vertisol technology under natural resources management developed by ICRISAT, has resulted in an increased yield by 38.4%, income by 98.5%, employment by 13.6% and a cost saving of 17.1% by farmers of Vidarbha region of Maharashtra state in India during 1996–97.

Another component of vertisol technology was developed for deep black soil regions with a relatively dependable rainfall, where the land is left fallow during rainy season. This technology is based on the concept of a small watershed as the basic resource management unit consisting of several components, including improved sorghum cultivars. Results from the operational-scale demonstrations of this technology at ICRISAT, India, were extremely encouraging. Substantially higher gross returns and profits were achieved by using improved sorghum/pigeonpea intercropping system (Figure 20) and management practices (US$197 ha^{-1} and US$142 ha^{-1}, respectively compared to US$36 ha^{-1} and US $21 ha^{-1}, respectively from the traditional systems of rainy-season fallow). The marginal rate of returns on the

Figure 20. Sorghum-pigeonpea intercropping system, a component of vertisol technology fetches higher marginal rate of returns to farmers in Andhra Pradesh state of India.

investments in 'Vertisol Technology' was 304% from sorghum/pigeonpea cropping systems (Flower 1994).

Thus, improved sorghum cultivars (especially short duration) could fit into different cropping systems and crop rotations leading to sorghum-based crop diversification and hence sustainable agroecosystems. Mixed crop-livestock systems (MCLS) are common, and indeed the dominant form of production systems of Indian SAT. Sorghum is considered as 'mother' crop in major growing areas of India and it is treated as a dual-purpose crop. Milk production is an important activity in these regions. Households that own ruminants depend on sorghum stover as the main source of fodder, especially in summer months. Because of growing demand for milk, the derived demand for sorghum fodder is also increasing (Kelly et al. 1993). While sorghum stover is an important source of fodder in both low-dairy and intensive-dairy villages, green fodder from forage sorghum cultivars are important in intensive-dairy villages. Village-level surveys have indicated that sorghum stover contributes between 20 to 45% of the total dry weight fed to dairy animals by small farm owners depending on the season. Milking buffaloes receive on an average 40% of their total dry matter as sorghum stover in small and large dairies in Hyderabad, India (Figure 21). Dry milk cows and buffaloes consume a much higher proportion of sorghum stover, often receiving neither concentrates nor green fodder.

Figure 21. Milking buffaloes receive 40% of total dry matter from sorghum stover in small and large dairies in Hyderabad, India.

III. Innovations in science and their sharing

Innovations in research and sharing of technologies so developed out of such innovations are the keys for increased impact in the farmers' fields. Innovative strategic and upstream research information developed at ICRISAT – ideas, concepts, methods, techniques and intermediate products – that were inputs for further research has contributed immensely to increased efficiency of breeding processes of ICRISAT and those of NARS partners.

Strategic research

Leads in strategic research areas helped to hasten the delivery of outputs both within ICRISAT and NARS programs in Asia and Africa.

- Reliable and cost effective screening techniques and identication of resistance sources for various abiotic (drought [Reddy 1986], soil acidity [Reddy and Rangel 2000] and salinity [Krishnamurthy et al. 2003]) and biotic (shoot fly [Nwanze 1997] (Figure 22), stem borer [Sharma 1997], midge [Sharma et al. 1988], grain mold [Bandyopadhyaya and Mughogho 1988] (Figure 23), downy mildew [Pande and Singh 1992], anthracnose [Pande et al. 1994] and *Striga*).
- Genetics of several traits of economic importance and use in adaptation such as resistance to shoot fly, stem borer, midge, grain mold, *Striga* and stay-green, a known trait conferring terminal drought resistance.
- Diversification of cytoplasm and nuclear base of cytoplasmic-nuclear male sterility-based sorghum hybrids.

Figure 22. Field screening for resistance to shoot fly.

Figure 23. Field screening for grain mold resistance under sprinkler irrigation.

- Method of producing heterotic landrace pollinator-based hybrids for postrainy season adaptation, which provided impetus for the private sector to develop and market postrainy season adapted sorghum hybrids for the first time in India.
- An approach to breeding for drought tolerance and grain yield potential was formulated and used at ICRISAT and transferred to NARS (Reddy 1986).
- The moving average concept to improve selection efficiency for yield constraints.
- Methods of developing hybrids parents (Asia) and varieties (Africa) resistant to grain mold and shoot fly for rainy season and shoot fly for postrainy season in Asia and varieties resistant to drought, *Striga* and other biotic stresses in Africa.
- Superiority of single crosses *vs.* three-way cross forage hybrids for both hybrid and commercial seed yield.
- Efficient method of A-line development involving simultaneous selection for resistance and grain yield and converting the maintainer selections into male-sterile lines was used effectively to develop male-sterile lines for resistance to pests and diseases in the shortest possible period of four years (Reddy et al. 2004).
- Efficient method of breeding for grain yield and resistance involving selection for resistance on family basis. Selecting individual single plants within the selected resistant family based on grain yield was most effective (ICRISAT 1995).
- The ICRISAT's collaborative research with International Livestock research Institute (ILRI) based at ICRISAT-Patancheru, India dispelled farmer's notion that the improved ICRISAT-bred sorghum cultivars are inferior to the local land race cultivars and has established for the first time in India that these improved cultivars are at par with popular local landrace cultivars for farmer-preferred stover quality traits such as stem sweetness, leafiness and digestibility.
- The variability for stover quality traits due to genotypes (ICRISAT-bred improved cultivars) was far greater than management intervention factors such as plant density, fertility levels and spacing indicating vast scope for genetic options for the improvement of these traits.
- A total of 62,161 and 55,334 seed samples representing various categories of breeding materials (A- and B-lines, restorers, varieties and others) have been supplied to several public sector scientists in India and abroad, respectively, from 1986 to 2003.
- A total of 51,428 and 2243 seed samples representing various categories of breeding materials (A-/B-lines, restorers, varieties and others) have been supplied to several private sector seed companies since 1986 in India and abroad, respectively.
- These breeding materials had multiplier effect, with public and private research organizations further developing 54 finished products (hybrids) simultaneously, specifically for targeted production areas testifying the utility and impact of ICRISAT-bred hybrid parents.

Upstream research

Tremendous developments in plant molecular marker and transgenic technologies, ingenuity of farmers and information technologies have been increasingly used to address more intractable and difficult-to-breed traits such as *Striga,* stem borer, shoot fly and drought resistance.

- Quantitative trait loci (QTLs) conferring resistance to these yield constraints such as shoot fly, stem borer, stay-green and *Striga* have been identified (Figures 24–25).

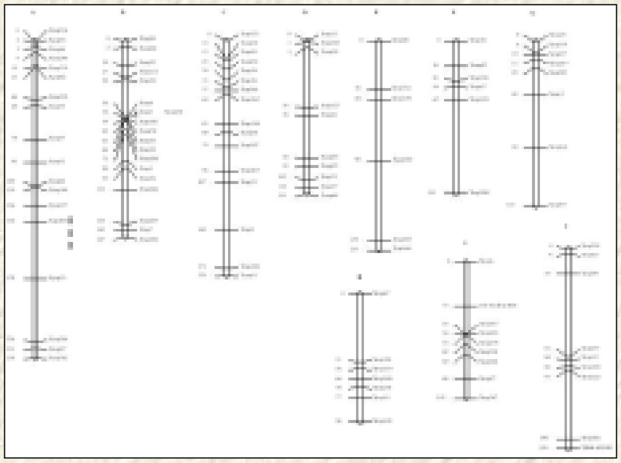

Figure 24. QTL linkage map for shoot fly resistance from BTx 623 (Shoot fly resistant) x IS 18551 (Shoot fly susceptible).

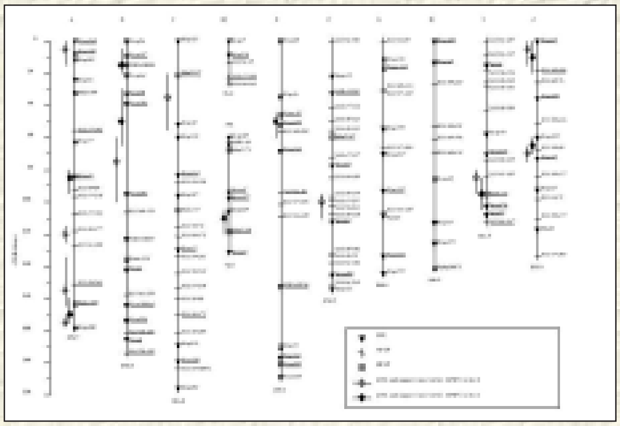

Figure 25. QTL linkage map for Striga *resistance from N 13 (*Striga *resistant) x E 36-1 (*Striga *susceptible).*

- 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 (Figure 26).

Figure 26. Fully developed transgenic sorghum shoots resistant to stem borer ready for rooting and transplantation to the glasshouse.

- Farmer participatory plant breeding has started showing significant benefits in Africa and Asia (Figures 27 and 28). A variety Tieble was identified as a high yielding variety in the participatory varietal trial in a Gonsolo village in Mali in Africa in 2000. By 2002, nearly all the households in this village and the surrounding five villages have sown seed of this new variety. Farmer participatory evaluation of ICRISAT-Patancheru-bred varieties (ICSV 111, ICSV 400) along with local cultivars in collaboration with the Institute for Agricultural Research (IAR), Zaria, Nigeria, facilitated farmer acceptance of these improved cultivars and are grown in 30% of the sorghum areas in Kano, Katsina and Jigwa regions of Nigeria. Productivity gains from these cultivars ranged from 27 to 62% (Tabo et al. 1999). Farmer participatory varietal selection facilitated the release of the variety SPV 1359 for postrainy-season cultivation in Maharashtra and Karnataka states in India during 1999–2000.

Figure 27. A woman farmer selecting sorghum panicles from segregating generations at ICRISAT.

Figure 28. An Eritrean farmer tasting stover quality in sorghum lines introduced from ICRISAT .

- Stratification of test sites in Africa to help reduce resources utilization in multilocation testing of advanced breeding lines and development of GIS maps.
- Computerization of seed dispatches, 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.

Alternate uses and methods of technology sharing

Research on alternative uses of grain and sweet stalked sorghums has helped broaden the demand for sorghum and innovative mechanisms of technology sharing ensuring higher income to farmers. Sorghum is suitable in the production of a variety of food and non-food products. Apart from traditional foods, sorghum is extensively used in the preparation of other foods such as snacks, "predigested" weaning food, pop sorghum etc. Besides these, the industrial sorghum-based food products include alcoholic beverages (Burukutu, dolo, pito, talla), sour/opaque beers (Marisa, busaa, merrisa, urwaga, mwenge, munkoyo, bantu beer, kaffir beer, sorghum beer, utshwala, utywala, ikigage) and European-type beers. Rainy season sorghum (which is frequently affected by grain mold and hence fetch lower price) is increasingly being used in the poultry feed rations in Andhra Pradesh state in India for broiler production as a result of the establishment of farmer – poultry feed and products industry – user coalition facilitated by ICRISAT. Sorghum has a great potential in ethanol production too.

- ICRISAT research helped to bring out the full potential of the sorghum use in confectionary food preparations and other industries (Figure 29).
- Novel technology exchange mechanisms, such as farmer-scientist-industry-user coalition building for use of sorghum in poultry feed, have been successfully established by ICRISAT.
- The development of high yielding, sweet stalked sorghum varieties and hybrid parents (for hybrid development) attracted several private industries in India to venture into ethanol production from sweet stalk sorghum as a supplement to sugarcane molasses to meet the possible increased demand following the Indian government's policy to blend 5% ethanol in petrol and likely increase of this proportion to 10%.

Figure 29. Use of sorghum in confectionary and brewing industries has broadened the demand for sorghum and thereby higher income to sorghum producers.

- National Research Center for Sorghum (NRCS), Hyderabad, India in collaboration with ICRISAT has developed a sweet stalk sorghum hybrid (NSSH 104) for the first time in India by involving ICSA 38 (an ICRISAT-bred sweet stalk seed parent) and SSV 84 (NRCS-bred male parent/R-line) and is being recommended for release as special purpose sorghum.
- Tie-up with Rusni Distilleries Pvt Ltd, Hyderabad, a private sector based in India, to incubate ethanol production technology from sweet sorghum cultivars developed at ICRISAT.
- A novel mechanism of public-private partnership sorghum consortium, first of its kind in CGIAR, is established successfully at ICRISAT to enhance the adoption of hybrids and to receive continuous feedback on the performance of the breeding materials.

Publications

The information on strategic research, breeding processes and products are published in refereed journals, conference proceedings, posters and success story fliers. These publications not only serve as vehicles to share the information but they also reflect the quality and innovations in science. ICRISAT has so far produced 886 publications (from 1977 to 2004) (Annexure IV). These are

- Refereed journal articles – 427
- Book chapters – 49
- Conference papers – 291
- Others – 119

Capacity building

ICRISAT is instrumental in enhancing research and development capabilities of NARS in Asia, Africa and Latin America in various aspects of sorghum improvement through training of 1302 NARS scientists from 1974 to 2004. Of these, 8 were visiting scientists (VS), 20 postdoctoral fellows (PDF), 107 research scholars (RS), 219 research fellows (RF), 783 in-service long-term (6 months) and 119 in-service short-term trainees and 46 apprentices. Further details are given in Table 11.

ICRISAT conducts well-designated short-term training courses regularly in specific areas to impart expertise to the scientists of NARS – both private and public sectors – apart from the long-term capacity building exercises in various disciplines mentioned earlier (Figures 30 and 31). Courses on sorghum hybrid parents development, grain mold assessment, screening for resistance to diseases and pests etc, are some of the examples. More than 200 sorghum scientists from private and public sectors took advantage of these short-term focused courses. Training at ICRISAT was shown to be demand driven. National program employers sent 46% of the participants, and another 30% were sent through collaborative research projects. The overwhelming majority of participants (94%) reported that their training at ICRISAT was necessary for their jobs. Participants indicated that their practical skills and subject knowledge had been enhanced through training at ICRISAT. Most participants (90%) returned to their jobs immediately after training at ICRISAT. Currently, 56% of them continue in the same job, while 42% have changed jobs. For more than half the participants, promotion or improvement in status was attributed to training at ICRISAT. Nearly 37% of the participants later went on to obtain a higher degree (MSc or PhD). Ninety-five percent of participants have shared the knowledge and skills

Table 11. Number of trainees from Asia, Africa and Latin America who were imparted training at ICRISAT.

	Categories of trainees						
Region	VS	PDF	RS	RF	In-Service - 6 months	In-Service Short-Term	Apprentice
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
Totals	8	20	107	219	783	119	46

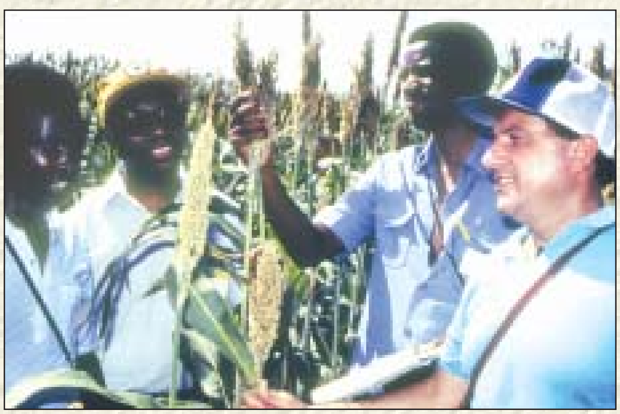

Figure 30. Sorghum scientist imparts training to researchers at Africa.

Figure 31. Principal sorghum scientist imparts training to Asian and African budding scientists at ICRISAT.

with peers, and 55% were involved in training other staff. About 80% of the participants are still applying the skills and knowledge gained at ICRISAT, indicating relevance, usefulness and sustainability of learning. Nearly, 73% participants expressed that their job performance was enhanced by more than double through their exposure to ICRISAT.

These training courses also helped ICRISAT to generate additional funds. For example, in 2004, sorghum group at ICRISAT-Patancheru earned about US$10,000 by offering course on hybrid parents development.

Other means of capacity building are farmers' and scientists' field days. ICRISAT conducts sorghum scientists' (both ICRISAT and NARS) field days in Africa and Asia (Figures 32 and 33). It also conducts almost every year farmers' field days in collaboration with NARS in each region (Figures 34 and 35). These field days also help to get feedback from the participants on research/ products and thus help to shape up ICRISAT's research portfolio.

Figure 32. Director General –ICRISAT along with other scientists listens to principal sorghum breeder during ICRISAT Scientists field day.

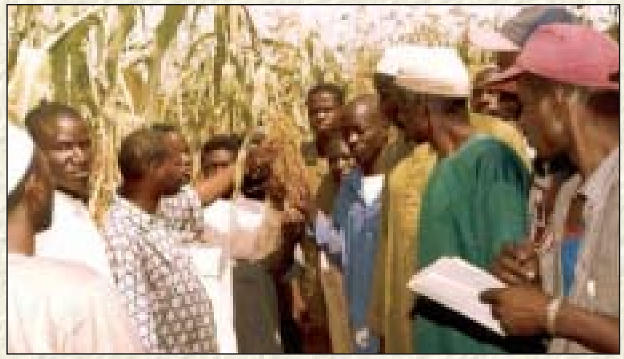

Figure 34. Farmers sharing the knowledge gleaned from more than 30 years of ICRISAT's sorghum research in sorghum field day conducted by ICRISAT in Africa.

Figure 33. NARS sorghum scientists participated in sorghum scientists field day at ICRISAT, Patancheru.

Figure 35. Indian farmers observing sorghum panicles at farmers' field day at ICRISAT.

IV. Partnership/collaboration – the way forward

Public sector networks

Apart from the informal interaction with scientists in NARS, formal networks were established for various regions to provide a common platform to test the materials pooled from various organizations within the region, to enhance the germplasm, breeding material and technology exchange and adoption of improved partnership products and to provide continuous interaction among the members in networks. These are Cereals and Legumes Asia Network (CLAN) for countries in Asia, Sorghum and Millet Improvement Program (SMIP) for Southern and Eastern Africa (SEA), West African Sorghum Improvement Program (WASIP) for countries in West Africa and Latin America Sorghum Improvement Program (LASIP) for Latin American countries. Apart from this, formal partnership projects developed with Indian Council of Agricultural Research (ICAR) are being implemented with scientists in India. In addition, various special projects – CGIAR's challenge program on HarvestPlus and identification/development of salinity tolerant sorghum lines – are being implemented with strong collaboration with National Institute of Nutrition, India, and International Center for Biosaline Agriculture, Dubai, respectively.

Public-private sector partnerships

ICRISAT became sensitive to increasing role and research capabilities of private sector seed companies in India and other countries (Egypt, Thailand, Indonesia etc) and realized that traditional partnership with public sector breeding programs, though important and significant, was no longer the sole route to farm-level adoption of the hybrids developed from ICRISAT-bred parental lines. Consequently, ICRISAT, established path-breaking and trend-setting partnerships with private sector seed companies, in the form of "Hybrid Parents Research Consortium for Sorghum", the first of its kind in the entire CGIAR system, which started functioning from January 2000. This successful concept is now being applied across the entire CGIAR system.

Conclusions

Sorghum team at ICRISAT in partnership with NARS-private and public sectors, advanced research institutions and other sister CGIAR centers, in tune with the external environment, tailored over time its research agenda, breeding processes, and targeting products catering to the needs of farmers and sorghum-based entrepreneurs such as private sector seed industry, poultry feed manufacturers and even biofuel manufacturers. Significant impacts in terms of release of partnership cultivars, adoption, increase in grain productivity and sorghum-based food security and sustainable production systems, and decrease in cost of production contributed significantly to the improved livelihoods of resource-poor farmers and low-income people in the SAT. The increased demand for hybrid seed production driven by increased popularity and enhanced adoption of hybrids together with broadened utilization of sorghum in food/

confectionary industry and poultry feed manufacturing and its potential use in biofuel production have transformed sorghum into a commercial crop while still serving as a staple food crop for millions of poor in the SAT.

The impact of ICRISAT's sorghum breeding research has contributed to food security and improved economy throughout the semi-arid tropics. But we fully realize that this is not enough. We must continue to respond to change while striving towards our vision of reducing world poverty and improving livelihoods.

Looking ahead

In large parts of Africa and some parts of Asia, sorghum still remains critically important for rural household food security. Since many sorghum producing countries especially in Africa continue to experience food deficits because of periodic drought coupled with several production constraints, the gains in grain productivity needs to be addressed by intensified research on no-cost input technologies that stabilize productivity such as host-plant resistance to drought, grain mold, shoot fly, stem borer in Africa and India and *Striga* in Africa. Also, integration of genetic and natural resources options needs greater focus to combat these productivity constraints.

With the increased sorghum productivity levels in Asia, farmers are left with surplus after meeting household food security. As a result, sorghum is being pushed to more marginal lands leaving the traditional sorghum belts to other more remunerative crops such as maize, soybean etc. To make sorghum more competitive, research would focus on improving productivity further through genetic resources management and on developing improved technologies to utilize sorghum in bakery, brewing, poultry feed and ethanol industries. Further, forging partnerships between ICRISAT and private industries to take advantage of complementary roles of ICRISAT's expertise in developing research products suitable to these alternate uses and technical expertise of private industries in the production of these products in Asia would also receive major attention.

Science with a Human Face

Research by ICRISAT and its partners will continue to generate international public goods (IPGs) for worldwide impact, to benefit farmers, consumers and sorghum-based entrepreneurs. Such a research endeavor to reduce poverty, malnutrition and environmental degradation is truly "Science with a Human Face". And the benefits are flowing.

Acknowledgements

The tremendous research achievements of ICRISAT's partnership research efforts and their impact on the livelihoods of millions of poor in ICRISAT mandate research target areas in Africa, Asia and Latin America would not have been possible without judicious support from several national governments in Africa, Asia, America and Australia, and liberal funding from donor agencies such as UNDP, UNEP, USAID, DFID, ADB, World Bank, IADB, GTZ, IFAD, CFC, USDA, ICRISAT-Private Sector Hybrid Parents Research Consortium for sorghum, Sehgal Family Foundation, and other organizations.

Collaborative research with advanced research institutes such as Institute for Genomic Diversity of Cornell University and sister organizations of Consultative Group on International Agricultural Research (CGIAR) such as International Livestock Research Institute (ILRI) based at ICRISAT, Centro Internacional de Agrocultura Tropical (CIAT), International Sorghum/Millet Collaborative Research Support Program (INTSORMIL) and International Center for Biosaline Agriculture (ICBA), International Rice Research Institute (IRRI) and Centro Internacional de Mejoramiento del Maïz y del Trigo (CIMMYT) has been highly valuable in exploiting the complementary expertise to develop technologies which had significant impacts on farmers, consumers and sorghum-based entrepreneurs as described in the text.

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About ICRISAT

The semi-arid tropics (SAT) encompass parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, chickpea, pigeonpea and groundnut; these five crops are vital to life for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research that can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services and publishing.

ICRISAT was established in 1972. It is supported by the Consultative Group on International Agricultural Research (CGIAR), an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Program (UNDP), the United Nations Environment Programme (UNEP) and the World Bank. ICRISAT is one of 15 nonprofit, CGIAR-supported Future Harvest centers.

Annexure I. ICRISAT's Partners in Sorghum Improvement Research

Afghanistan	Agricultural Research Institute, Kabul
Argentina	Dekalb, Buenos Aires
Australia	Australian Centre for International Agricultural Research (ACIAR)
	Hermitage Research Station, Queensland
	Pacific Seeds Pvt Ltd, Queensland
Botswana	Department of Agricultural Research, Gaborone
Brazil	Centro Nacional de Pesquisa de Milho e Sorgo, Sete Lagoas
	Commercio de Industria Matsuda Imp e Expt Ltda, Tavares
	Empresa Pernambucana de Pesquisa Agropecuaria, Recife
	Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Sete Lagoas
	Milta Pesquisa Agricola Ltda, Uberlandia
	Secao de Entomologia Instituto Agronomica, Campinas SP
	Sementes Agroceres SA, Parana
	ZENECA Sementes, Cravinhos SP
Burkina Faso	Institut National d'Etudes et de Recherches Agricoles (INERA)
Burundi	Sorghum Program, Bujumbura
China	Chinese Academy of Agricultural Sciences (CAAS), Beijing
	Kiaoning Academy of Agricultural Sciences, Shenyang
	Liaoning Academy of Agricultural Sciences, Liaoning
	Shenyang Normal University, Shenyang
	Sorghum Institute of Shanxi Academy of Agricultural
Sciences, Shanxi	
Colombia	Centro Internacional de Agricultura Tropical (CIAT), Cali
	CORPOICA, La Libertad, Villavicencil-Meta
Egypt	ARC, FCRI Sorghum Research Station, Giza
	Misr Hytech Seed International SAE, Cairo
	Shandweel Agricultural Research Station, Sohag
El Salvador	Centro Nacional de Technologia Agricola (CENTA), La Libertad
Eritrea	National Agricultural Research Institute (NARI), Halhale
	National Sorghum Improvement Project, Asmara
Ethiopia	Nazareth Research Center, Nazareth
	Melkassa Agricultural Research Center, Nazareth
	Institute of Agricultural Research (IAR), Melkassa
France	Centre de cooperation internationale en recherche agronomique pour le developpement (CIRAD), Montpellier
Germany	University of Hohenhein, Stuttgart
Ghana	Nyamkpala Agricultural Experiment Station, Tamale
	Savanna Agricultural Research Institute (SARI), Nyankpala-Tamale
India	
National	All India Coordinated Sorghum Improvement Project (AICSIP), Hyderabad
	Indian Agricultural Research Institute (IARI), New Delhi
	Indian Council of Agricultural Research (ICAR), New Delhi

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Annexure I. *Continued*

	National Research Center for Sorghum (NRCS), Hyderabad
	Central University of Hyderabad, Hyderabad
State Agricultural/ Other Universities	Acharya NG Ranga Agricultural University, Hyderabad
	CCS Haryana Agricultural University, Hisar
	CS Azad University of Agriculture and Technology, Kanpur
	GB Pant University of Agriculture and Technology, Pantnagar
	Gujarat Agricultural University, Surat
	Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Indore
	Mahatma Phule Agricultural University, Rahuri
	Marathwada Agricultural University, Parbhani
	National Bureau of Plant Genetic Resources (NBPGR), Hyderabad
	National Institute of Nutrition, Hyderabad
	Tamil Nadu Agricultural University (TNAU), Coimbatore
	Dr Punjabrao Deshmukh Krishi Vidyapeeth, Akola
	Udaipur Agricultural University, Udaipur
	University of Agricultural Sciences, Bijapur
	University of Agricultural Sciences, Dharwad
	University of Mysore, Mysore
	Osmania University, Hyderabad
Private Seed Companies	Advanta India Ltd, Bangalore
	Ajeet Seeds Ltd, Nagpur
	Ankur Seeds Pvt Ltd, Nagpur
	Basant Agro-Tech (India) Ltd, Akola
	Bioseed Research India Ltd, Hyderabad
	Emergent Genetics India Pvt Ltd, Hyderabad
	Ganga Kaveri Seeds Pvt Ld, Hyderabad
	Godavari Hybrid Seeds Co Ltd, Nizamabad
	Green Gold Seeds Ltd, Aurangabad
	JK Agri Genetics Ltd, Hyderabad
	Kanchan Ganga Seed Co Pvt Ltd, Hyderabad
	Kaveri Seed Co Pvt Ltd, Secunderabad
	Krishidhan Seeds Ltd, Jalna
	Mahendra Hybrid Seeds, Jalna
	Mahodaya Hybrid Seeds Pvt Ltd, Jalna
	Monsanto India Ltd, Aurangabad
	Nuziveedu Seeds Ltd, Secunderabad
	Pioneer Seeds Corporation, Hyderabad
	Proagro Seed Co Pvt Ltd, Aurangabad
	Tulasi Seeds Pvt Ltd, Guntur
	Vibha Agrotech Ltd, Hyderabad
	Vikki's Agrotech Ltd, Hyderabad
NGOs	Andhra Pradesh Poultry Federation, Hyderabad
	Federation of Farmers' Association (FFA), Hyderabad

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Annexure I. *Continued*

	Janaki Feeds, Hyderabad
	Vasantdada Sugar Institute, Pune
	Venkateswara Hatcheries Ltd, Hyderabad
Indonesia	Center for Food and Nutrition Studies (CFNS), Bogor
	Indonesian Research Institute for Cereals, South Sulawesi
	National Nuclear Energy Agency, Jakarta
	Research Institute for Maize and Cereals, South Sulawesi
	PT Benihinti Suburintani (BISI), Jawa Timur
Iran	Agricultural Biotechnology Research Institute of Iran (ABRII), Karaj
	Agricultural Research, Education and Extension Organization, Tehran
	Seed and Plant Improvement Institute (SPII), Karaj
	University of Isfahan, Isfahan
Kenya	Kenya Agricultural Research Institute (KARI), Embu
	National Dryland Farming Research Station
	The International Centre for Insect Physiology and Ecology (ICIPE), Nairobi
Mali	Association Conseil pour le Développement (ACOD)
	Association des Organizations Professionnelle Paysanne (AOPP)
	Cabinet de Etude Keita (CEK-Kala Saba)
	Compagnie Malienne Development Textile (CMDT)
	Institut d'Economie Rurale (IER)
	Office de la Haute Vallée du Niger (OHVN)
	Peace Corps
	Point Sud
	Service Local d'Appui Conseil de Amenagement et Equipement Rural (SLACAER)
	Union Locale des Producteurs de Cereal (UPLC)
	World Vision
Mexico	Instituto Nacional de Investigaciones Forestales Agropecuarias (INIFAP)
Mozambique	National Sorghum and Pearl millet Program (INIA), Maputo
Myanmar	Central Agricultural Research Institute (CARI), Pyinmana
	Myanmar Agriculture Service, Yangon
Namibia	Ministry of Agriculture, Water and Rural Development, Plant Production Research, Windhoek
Niger	Institut National de Research Agronomique de Niger (INRAN)
	Veterinaires Sans Frontieres
Nigeria	Aahmedu Bello University, Zaria
Pakistan	Institute of Field and Horticultural Crops, Pakistan
	National Agricultural Research Centre, Islamabad
	Pakistan Agricultural Research Council, Islamabad
Philippines	Benquet State University, Benquet
	Central Mindanao University, Bukidnon
	DA-Regional Crop Protection Center, Isabela
Puerto Rico	USDA-ARS-TARS, Mayaguez

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Annexure I. *Continued*

Rwanda	Rwanda Agricultural Research Institute, Butare
Senegal	Institut Senegalais de Recherche Agronomique (ISRA)
Sudan	Agricultural Research Technology Corporation (ARTC), Wad Medani
Tanzania	Tanzanian Agriculture Research Organization, Ministry of Agriculture and Food Security, Dar-es-Salaam
Thailand	Charoen Pokphand Group Co Ltd, Bangkok Department of Agriculture, Bangkok Field Crops Research Institute, Bangkok Khon Kaen University, Khon Kaen National Corn and Sorghum Research Center, Kasetsart University, Nakhon Ratchasima
USA	Institute for Genomic Diversity, Cornell University, New York Mississippi State University, Mississippi Purdue University, Indiana Texas A&M University, College Station and Lubbock University of Nebraska, Nebraska USDA-Agricultural Research Services, Georgia University of Georgia, Athens, Georgia
Yemen	Agricultural Research Station, Hodeldah AREA (Al-Kadam), Hodeidah Surdid Experiment Station, Hoheida Province
Zambia	Zambia Seeds Co Ltd, Lusaka Sorghum and Millet Improvement Program, Fringila
Development Investors	Asian Development Bank (ADB) Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklng (BMZ) Canadian Development Agency (CDA) Common Fund for Commodities (CFC) Department for International Development (DFID) Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) Food and Agriculture Organization of the United Nations (FAO) ICRISAT-Private Sector Sorghum Hybrid Parents Research Consortium International American Development Bank (IADB) International Development Research Center (IDRC) International Fund for Agricultural Development (IFAD) Sehgal Family Foundation United National Development Programme (UNDP) United Nations Environment Programme (UNEP) United States Agency for International Development (USAID) World Bank
CGIAR Centers	Centro Internacional de Agrocultura Topical (CIAT), Colombia Centro Internacional de Mejoramiento del Maïz y del Trigo (CIMMYT), Mexico International Centre for Biosaline Agriculture (ICBA), United Arab Emirates International Livestock Research Institute (ILRI), Kenya/Ethiopia International Rice Research Institute (IRRI), The Philippines

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Annexure II. Details of sorghum germplasm accessions or selections released as superior varieties in different countries.

Accession number	Country of origin	Country of release	Released name	Year of release	Remarks
Asia					
IS 302	China	Myanmar	Shwe-ni 10	1980	
IS 5424	India	Myanmar	Shwe-ni 8	1980	
IS 8965	Kenya	Myanmar	Shwe-ni 1	1980	
IS 2940	USA	Myanmar	Shwe-ni 2	1981	
IS 4776	India	India	UP Chari-1	1983	Forage sorghum
IS 33844	India	India	Parbhani Moti	2002	
IS 3922 x IS 1151	Nigeria, India	India	604		Cross progeny
IS 3922 x IS 1122	Nigeria, India	India	302		Cross progeny
IS 2954 x IS 18432	USA, India	India	370		Cross progeny
IS 2950 x IS 1054	USA, India	India	R 16		Cross progeny
IS 3687 x IS 1151	USA, India	India	148/168		Cross progeny
IS 18484 x IS 3924	India, USA	India	SPV 297	1985	
IS 4283 x IS 18478	India, India	India	CO-25	1985	
IS 33892	Ethiopia	India	NTJ 2	1990	
IS 3541	Sudan	India	CS 3541		Converted Zera-zera
IS 6928	Sudan	India	Moti	1978	Induced mutant
IS 3924	Nigeria	India	Swarna		
IS 3922 x IS 1151	Nigeria, India	India	604		Cross progeny
IS 3922 x IS 1122	Nigeria, India	India	302		Cross progeny
IS 2954 x IS 18432	USA, India	India	370		Cross progeny
IS 2950 x IS 1054	USA, India	India	R 16		Cross progeny
IS 3687 x IS 1151	USA, India	India	148/168		Cross progeny
IS 18484 x IS 3924	India, USA	India	SPV 297	1985	
Southern and Eastern Africa					
IS 3923	Zimbabwe	Botswana	Mahube	1994	
IS 18758	Ethiopia	Burundi	Gambella 1107	1990	
IS 29415	Lesotho	Eritrea	Shiketi	2000	
IS 9302	South Africa	Ethiopia	ESIP 11	1980	
IS 9323	South Africa	Ethiopia	ESIP 12	1984	
IS 8193	Uganda	Kenya	Kari Matama	2001	
IS 8571	Tanzania	Mozambique	Mamonhe	1989	
IS 8193	Uganda	Rwanda		2001	
IS 21219	Kenya	Rwanda		2001	
IS 25395	Kenya	Rwanda		2001	
IS 13444	Zimbabwe	Sudan	Arous el Rima	2001	Drought tolerant
IS 9830	Sudan	Sudan	Mugawim Buda-2	1991	
IS 2391	South Africa	Swaziland	MRS 13	1989	
IS 3693	USA	Swaziland	MRS 94	1989	
IS 23496	Ethiopia	Tanzania	Pato	1995	
IS 23520	Ethiopia	Zambia	Sima	1989	
Western and Central Africa					
IS 18758	Ethiopia	Burkina Faso	E 35-1	1983	
IS 15401	Cameroon	Mali	Soumalemba	2001	
Latin America and Carribbean					
IS 18484	India	Honduras	Tortillero 1	1984	
IS 9468	South Africa	Mexico	Marvilla no SOFO 430201092	2000	
IS 13809	South Africa	Mexico		1990	
IS 9321	South Africa	Mexico		1990	
IS 9447	South Africa	Mexico		1990	

Annexure III. Details of released sorghum varieties and hybrids with ICRISAT-breeding product content in different countries.

S.No.	Origin	Released Name	Country	Year
Asia				
1	A 3681	Yuan 1-98	China	1982
2	A 3872	Yuan 1-28	China	1982
3	A 3895	Yuan 1-505	China	1982
4	A 6072	Yuan 1-54	China	1982
5	SPL 132A	Liao Za 4	China	1988
6	-	Liao Za 5	China	1996
7	-	Liao Za 6	China	1996
8	-	Liao Za 7	China	1996
9	-	Jin Za 94	China	1996
10	3197A_2 x Jin Liang 5 (D 71278-4 is converted to 3197 A_2)	Jin XA 4	China	1992
11	MR 741 R-line used as its male parent	Longsi-1 (a forage hybrid)	China	1997
12	(SPL 132B x TAM 428B) is its female parent	Liao Za 10	China	1997
13	IC-A line converted to A2 and used as its female parent	Jin Za 12	China	1997
14	IC-A line converted to A2 and used as its female parent	Gile Za 80	China	1997
15	E 1966 (IS 33892)	NTJ 2	India	1990
16	ICSV 1	CSV 11	India	1984
17	ICSH 153	CSH 11	India	1986
18	ICSV 112	CSV 13	India	1987
19	ICSV 145	SAR 1	India	1988
20	ICSV 239	BSR 1	India	1989
21	ICSV 745	DSV 3	India	1993
22	ICSV 197	ICSV 197	India	1993
23	Parent Source	CSH 14	India	1993
24	Parent Source	PJH 55	India	1993
25	Parent Source	PJH 58	India	1993
26	Parent Source	PKH 400	India	1993
27	Parent Source	PSH 8340	India	1993
28	Parent Source	CSV 15	India	1994
29	Parent Source	MLSH 36	India	1994
30	ICSA 91001 x ICSR 90017	ASH 1	India	1997
31	Parent Source	JKSH 22	India	1999
32	ICSH 86686	PSH 1	India	1999
33	PVK 400	PVK 400	India	1999
34	Parent Source	SPH 840	India	2000
35	GD 34553	PVK 801	India	2000
36	GD 31-4-2-3	Parbhani Moti (SPV 1411)	India	2002
37	IS 8965	Shwe ni 1	Myanmar	1980
38	IS 2940	Shwe ni 2	Myanmar	1981
39	M 90906	YEZIN 1 (Schwe phyu 1)	Myanmar	1984
40	M 36335	YEZIN 3 (Schwe phyu 3)	Myanmar	1984
41	M 36248	YEZIN 2 (Schwe phyu 2)	Myanmar	1984
42	M 36172	YEZIN 4 (Schwe phyu 4)	Myanmar	1984
43	ICSV 735	YEZIN 6	Myanmar	1996

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Annexure III. ***Continued***

S.No.	Origin	Released Name	Country	Year
44	ICSV 758	YEZIN 7	Myanmar	1996
45	ICSV 804	YEZIN 5	Myanmar	1996
46	ICSV 107	PARC-SS 1	Pakistan	1991
47	IRAT 408	PARC-SS 2	Pakistan	1991
48	PSB Sg 93-20	IES Sor 1	Phillipines	1993
49	ICSV 126/PSB Sg 94-02	IES Sor 4	Phillipines	1994
50	-	Suphanburi-1	Thailand	1996
Southern and Eastern Africa				
51	SDS 3220	PhofuU/Macia	Botswana	1994
52	IS 3923 (SDS 2583)	Mahube	Botswana	1994
53	SDSH 48	BSH 1	Botswana	1994
54	-	Mmabaitse (BOT 79)	Botswana	1994
55	-	5D X 160	Burundi	1989
56	-	Gambella-1107	Burundi	1990
57	E 35-1	Gambella-1107	Ethiopia	1980
58	76 TI #23	76 TI #23	Ethiopia	1980
59	M 36121	M 36121	Ethiopia	1980
60	IS 9302	IS 9302	Ethiopia	1980
61	IS 9323	ESIP 12	Ethiopia	1984
62	ICSV 1	Dinkmash	Ethiopia	1988
63	Diallel Pop 7-682	Melkamash	Ethiopia	1988
64	-	Seredo	Ethiopia	1990
65	ICSV 112	CSV 13	Kenya	1988
66	KAT 83/369	KARI/MTAMA I	Kenya	1994
67	IS 8193	KARI MTAMA 2	Kenya	2001
68	PGRC/E216740	KARI MTAMA 3	Kenya	2001
69	IS 76 T1#23	IS 76	Kenya	2001
70	ICSV 1	PiriraA 1	Malawi	1993
71	ICSV 112	Pirira 2	Malawi	1993
72	SDS 3220	Macia	Mozambique	1989
73	IS 8571	Mamonhe	Mozambique	1989
74	ICSV 112	Chokwe	Mozambique	1993
75	SDS 3220	Macia	Namibia	1998
76	-	5 DX 160	Rwanda	1980
77	-	1 Kinyamka	Rwanda	1980
78	IS 25395		Rwanda	2001
79	IS 21219		Rwanda	2001
80	IS 8193		Rwanda	2001
81	IESV 92043 DL		Somalia	2001
82	CR 35:5		Somalia	2001
83	Gedam el Hammam		Somalia	2001
84	ATx623 × K 1597 (Karper-1597)	Hageen Durra	Sudan	1983
85	ICSV 1007 HV	Mugawim Buda 1	Sudan	1991
86	IS 9830	Mugawim Buda 2	Sudan	1991
87	ICSV 1001 BF	Framida	Sudan	1991
88	M 90393	Ingazi (M 90393)	Sudan	1992
89	IS 13444	Aroos Elrimal	Sudan	2000
90	SDSV 1513	MRS 13	Swaziland	1989
91	SDSV 1594-1	MRS 94	Swaziland	1989
92	ICSV 112	MRS 12	Swaziland	1992

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Annexure III. *Continued*

S.No.	Origin	Released Name	Country	Year
93	2Kx17	Tegemeo	Tanzania	1988
94	-	Pato	Tanzania	1995
95	SDS 3220	Macia	Tanzania	1999
96	-	Seredo	Uganda	1980
97	-	Epuripur (Tegemeo)	Uganda	1995
98	ICSV 2	ZSV 1	Zambia	1983
99	-	WSH 287	Zambia	1987
100	WSV 387	Kuyuma (MR4/4606 T 11)	Zambia	1989
101	IS 23520	SimaA	Zambia	1989
102	ICSA 104(SPL 177A)	MMSH 413	Zambia	1990
103	-	MMSH 375	Zambia	1990
104	-	ZSV 12	Zambia	1995
105	ICSV 112	SV 1	Zimbabwe	1985
106	A 6460	SV 2	Zimbabwe	1987
107	-	ZWSH 1	Zimbabwe	1992
108	SDS 3220	Macia	Zimbabwe	1998
109	-	SV 3	Zimbabwe	1998
110	-	SV 4	Zimbabwe	1998
Western and Central Africa				
111	ICSV 111		Benin	1999
112	-	IRAT 204	Burkina Faso	1980
113	IS 18758	E 35-1	Burkina Faso	1983
114	ICSV 1001 BF	Framida	Burkina Faso	1986
115	ICSV 1049	ICSV 1049	Burkina Faso	1989
116	Sariago-B	BF 83-48-2-1	Burkina Faso	1992
117	Sariabo 13		Burkina Faso	2000
118	Sariabo 14		Burkina Faso	2000
119	ICSV 111	S 35	Cameroon	1987
120	ICSV 111	S 35	Chad	1989
121	ICSV 1001 BF	Framida	Cote'd Ivoire	1986
122	ICSV 1063	ICSV 1063	Cote'd Ivoire	2000
123	ICSV 210	Bushuka	Eritrea	2000
124	PP 290 (INTSORMIL)	Shambuko	Eritrea	2000
125	89 MW 5003	Shieb	Eritrea	2000
126	89 MW 5056	Laba	Eritrea	2000
127	IS 29415	Shiketi	Eritrea	2000
128		Framida	Ghana	1986
129	ICSV 111	Kaapala	Ghana	1997
130	Malisor-1	Malisor-1	Mali	1987
131	Malisor-4	Malisor-4	Mali	1987
132	Malisor-5	Malisor-5	Mali	1987
133	Malisor-7	Malisor-7	Mali	1987
134	ICSV 1095 BF	ICSV 1095 BF	Mali	1991
135	ICSV 1063 BF	ICSV 1063 BF	Mali	1993
136	ICSV 1079 BF	ICSV 1079 BF	Mali	1993
137	ICSV 401	ICSV 401	Mali	1994
138	CSM 335	Tieble	Mali	2001
139	CSM 485	Kossa	Mali	2001
140	CSM 660	Ngolofing	Mali	2001
141	Nazongola Anthocyane	Nazomble	Mali	2001

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Annexure III. *Continued*

S.No.	Origin	Released Name	Country	Year
142	Nazongola Tan	Nazondje	Mali	2001
143	IS 15401	Soumalemba	Mali	2001
144	CGM 19/9-1-1 (Pedigree: 87-38 x 57-26)	Marakanio	Mali	2001
145	CIRAD 406	Soumba	Mali	2001
146	ICSV 1079 (Framida x E 35-1)	Yagare	Mali	2001
147	M 90038	SEPON 82	Niger	1993
148	ICSV 1007 BF	SRN 39	Niger	1993
149	ICSH 89002(NG)	ICSH 89002(NG)	Nigeria	1995
150	ICSH 89009(NG)	ICSH 89009(NG)	Nigeria	1995
151	ICSV 111	ICSV 111	Nigeria	1995
152	ICSV 400	ICSV 400	Nigeria	1997
153	NR 71176	NR 71176	Nigeria	1997
154	NR 71182	NR 71182	Nigeria	1997
155	NSSH 91001	NSSH 91001	Nigeria	1997
156	NSSH 91002	NSSH 91002	Nigeria	1997
157	-	IRAT 204	Senegal	1980
158	ICSV 1001 BF	Framida	Togo	1986
159	SEPON 82 x S 34	Sorvato 1	Togo	1998
160	Framida x S 34	Sorvato 28	Togo	1998
Latin America and Caribbean				
161	A 3895	ICA YANUBA	Colombia	1992
162	-	Sorghica PH 302	Colombia	1992
163	-	HE 241	Colombia	
164	M 90362	Escameka	Costa Rica	1991
165	ISIAP DORADO	INIAP 201	Ecuador	1987
166	Sel from crosses from Chapingo	CENTA S–2	El Salvador	1976
167	ATx623 × Sweet Sudan	CENTA SS –41 (Forage hybrid)	El Salvador	1978
168	[(GPR 148 × E 35-1)-4-1 × (CS 3541 deriv.)]-1-1	ISIAP DORADO	El Salvador	1981
169	M 90361	CENTAa Oriental	El Salvador	1987
170	M 90362 (male parent of hybrid)	AGROCONSA I	El Salvador	1987
171	ICSV LM 90502 (M 36285 × 77C3-1)bk-5-1-2-3-1-bk	Soberanno	El Salvador	1996
172	ICSV LM 90503 (M 35585 × CS 3541)-31-bk-5-2-2-3-1-1-7-bk	RCV	El Salvador	1996
173	ICSV LM 90508 (PP 290 × 852-2235)bk-4-6-3-1-bk	Jocoro	El Salvador	1997
174	M 90975	ICTA Mitlan 85 (ICTA C-21)	Guatemala	1985
175	IS 18484 (CS 3541)	Tortillero 1	Honduras	1984
176	ATx623 × Tortillero	Catracho	Honduras	1984
177	M 62650 = M 90281 = SPV 387	Sureño	Honduras	1985
178	-	VARIADAD 110	Mexico	1978
179	Sel from crosses from E. Africa	Valles Altos 110	Mexico	1978
180	ISIAP DORADO	Blanco 86	Mexico	1986
181	ICSV 112	UANL-I-187	Mexico	1987
182	M 90362	UANL-I1-287	Mexico	1987
183	M 62641	Costeño 201	Mexico	1989
184	SPV 475 = ICSV 112	Pacifico 301	Mexico	1990
185	M 91057	Istmeño	Mexico	1991
186	PP 290	Perlita	Mexico	1991
187	M 90812	Tropical 401	Mexico	1991

...Continued

Annexure III. ***Continued***

S.No.	Origin	Released Name	Country	Year
188	IS 9468	Maravilla, No. SOF-043-201092	Mexico	2000
189	SEPON 77	Nica-Sor (T-43)	Nicaragua	1985
190	ICSV 112	Pinollero 1	Nicaragua	1990
191	ISIAP DORADO	Alanje Blanquito	Panama	1991
192	ISIAP DORADO	DORADO	Paraguay	-
193	ISIAP DORADO	ISIAP DORADO	Venezuela	1985
194	ICSV-LM 90501	Sureña-1	Dominican Republic	1993

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About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political, international organization for science-based agricultural development. ICRISAT conducts research on sorghum, pearl millet, chickpea, pigeonpea and groundnut – crops that support the livelihoods of the poorest of the poor in the semi-arid tropics encompassing 48 countries. ICRISAT also shares information and knowledge through capacity building, publications and ICTs. Established in 1972, it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

Contact information:

ICRISAT-Patancheru
(Headquarters)
Patancheru 502 324
Andhra Pradesh, India
Tel +91 40 23296161
Fax +91 40 23241239
icrisat@cgiar.org

ICRISAT-Nairobi
(Regional hub ESA)
PO Box 39063, Nairobi, Kenya
Tel +254 20 524555
Fax 524001
icrisat-nairobi@cgiar.org

ICRISAT-Niamey
(Regional hub WCA)
BP 12404
Niamey, Niger (Via Paris)
Tel +227 722529, 722725
Fax 734329
icrisatsc@cgiar.org

ICRISAT-Bamako
BP 320
Bamako, Mali
Tel +223 2223375
Fax 223 2228683
icrisat-w-mali@cgiar.org

ICRISAT-Bulawayo
Matopos Research Station
PO Box 776,
Bulawayo, Zimbabwe
Tel +263 83 8311-15
Fax +263 83 8253/8307
icrisatzw@cgiar.org

ICRISAT-Lilongwe
Chitedze Agricultural Research Station
PO Box 1096
Lilongwe, Malawi
Tel +265-1-707297/071/067/057
Fax 707298
icrisat-malawi@cgiar.org

ICRISAT-Maputo
c/o INIA, Av. das FPLM No 2698
Caixa Postal 1906
Maputo, Mozambique
Tel +258-1-461657
Fax 461581
icrisatmoz@panintra.com

www.icrisat.org

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