Impacts of Genetic Improvement in Sorghum

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This chapter quantifies the impacts of sorghum genetic enhancement research, featuring the catalytic role of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in a research environment characterized by strong national agricultural research systems (NARS) and private sector institutions in Asia and weaker NARS in Africa. Impacts of sorghum improvement research are measured in terms of yield gain, reduction in unit production cost, technology spillover and improvement in yield stability. The results indicate substantial yield and stability gains accompanied by reductions in the unit costs of production from the adoption of improved sorghum cultivars. Countries with weak NARS, especially in Africa, benefited primarily from ICRISAT-developed varieties and through technology spillover. On the other hand, countries with strong NARS in Asia benefited largely from elite breeding materials developed by ICRISAT. An important policy implication arising from the study is the need for differential strategies for different regions to take into account the different research environments.

Introduction

Sorghum is a major world cereal crop, though not on the scale of rice or wheat. Some 85 countries cultivate sorghum in measurable quantities. The top five sorghum-growing countries, in terms of harvested area during 1994–1996, were India (1.23 million ha), Nigeria (0.60 million ha), Sudan (0.58 million ha), USA (0.39 million ha) and Niger (0.19 million ha). In terms of total sorghum production, the top five sorghum-producing countries are USA (1.62 million t), India (1 million t), Nigeria (0.66 million t), China (0.54 million t) and Mexico (0.42 million t). However, the highest sorghum yields were obtained in smaller producers: Italy (5898 kg ha^{-1}), France (5724 kg ha^{-1}) and Egypt (4620 kg ha^{-1}) (FAO, 1998).

Realizing the importance of the sorghum crop, donors and governments of different countries have invested substantial amounts of money to establish national and international research centres such as ICRISAT, which was founded in 1972. International research institutes in partnership with national research systems (both public and private) have made concerted efforts to develop improved sorghum cultivars and practices to increase yield and the social well-being of the producers and consumers of sorghum.

Human Resources Involved in Sorghum Improvement

Tables 9.1 and 9.2 report the level of scientific staffing involved in sorghum improvement. At ICRISAT, five sorghum breeders located in Asia and Africa are involved in breeding. Fifteen other scientists including agronomists, crop physiologists, genetic resources specialists, entomologists, pathologists and social scientists generate information for effective use by the breeders. In India, about 150 sorghum scientists in the public and private sector are working on this crop. In China, 200 scientists are working for sorghum improvement. The number of scientists working on sorghum in other Asian countries is also notable. However, in African countries the number of scientists working on this crop, with the exception of Ethiopia, Sudan and Kenya, is very low, generally between one and five scientists in each country. Usually African

Table 9.1. Number of sorghum scientists working in different countries (1999 or latest year).

Country	Latest year	Breeders	Agronomists	Seed technologists	Others*	Total
Asia						
China	1997	120	40	20	20	200
India	1998					150
Iran	1997	2	2	1	0	5
Pakistan	1997	5	9	0	0	14
Thailand	1998	11	12	6	7	36
Eastern and Central Africa[a]						
Burundi	1998	1	0	1	0	3
Eritrea	1998	1	4	0	0	5

Continued

Table 9.1. *Continued*

Country	Latest year	Breeders	Agronomists	Seed technologists	Others*	Total
Eastern and Central Africa[a] *Continued*						
Ethiopia	1998	15	15	0	20	50
Kenya	1998	3	8	0	7	18
Rwanda	1998					3
Sudan	1998	3	7	0	11	21
Uganda	1998	2	1	0	2	5
Southern Africa[b]						
Angola	1999	1	1			2
Botswana	1999	1	1	1 (all crops)	1	4
Lesotho	1999		1			1
Malawi	1999	1		1 (all crops)	1 (pests)	3
Mozambique	1999	1		2 (all crops)		3
Namibia	1999	1	1			2
Swaziland	1999		1			1
Tanzania	1999	2	2	1 (all crops)	1 (all crops)	6
Zambia	1999	2	1	1 (all crops)		4
Zimbabwe	1999	1	1	1 (all crops)	2 (pathology)	5
Western Africa[c]						
Burkina Faso	1991–92	2	3		3	8
Cameroon[d]	1991–92		1		3	4
Ghana[d]	1991–92		1		3	4
Mali	1991–92		3		4	7
Niger	1991–92		2		4	6
Nigeria	1991–92		1	5		6
Northern Africa						
Egypt	1998	13	8	1	3	25
West and Central Africa (Sorghum Research Network)[c]	1990–91					83
East Africa (Sorghum and Millet Network)[a]	1990–91					87

*Other disciplines that support varietal improvement, such as pathologists, entomologists, social scientists.

Notes:

[a]In East Africa, 70% of the researchers work on sorghum and millet as full-time researchers while 30% of them work on these two crops on a part-time basis and about 35% of the qualified scientists are based in two countries.

[b]For southern African countries, number of scientists indicates working both on sorghum and millet.

[c]In West and Central Africa, 38% are full-time researchers for sorghum, 62% are part-time researchers and about 25% of the qualified researchers are based at lead NARS.

[d]In both Cameroon and Ghana, one entomologist was working on a part-time basis for sorghum.

Sources: For Asia, ICRISAT Impact Monitoring Survey, 1997.
For Africa, ICRISAT Impact Monitoring Survey, 1998–2000.
For West Africa, Sanders *et al.* (1994) p. 53.

Table 9.2. Educational levels of sorghum scientists working in different countries (1999 or latest year).

Country	Latest year	BSc	MSc	PhD	Other	Total
Asia						
China	1997	108	44	18	30	200
India	1998					150
Egypt	1998	3	3	14	5	25
Iran	1997	2	3	0	0	5
Pakistan	1997	0	13	1	0	14
Thailand	1998	11	15	10	0	36
Eastern and Central Africa[a]						
Burundi	1998	1	2	0	0	3
Eritrea	1998	4	1	0	0	5
Ethiopia	1998	15	26	9	0	50
Kenya	1998	4	14	0	0	18
Rwanda	1998	3	0	0	0	3
Sudan	1998	1	4	16	0	21
Uganda	1998	0	3	2	0	5
Southern Africa[b]						
Angola	1999					2
Botswana	1999	1	1	2		4
Lesotho	1999	1				1
Malawi	1999		1	2		3
Mozambique	1999	2	1			3
Namibia	1999	1	1			2
Swaziland	1999	1				1
Tanzania	1999	1	3	2		6
Zambia	1999		3	1		4
Zimbabwe	1999	1	2	2		5
West Africa[c]						
Burkina Faso	1991–92					8
Cameroon	1991–92					4
Ghana	1991–92					4
Mali	1991–92					7
Niger	1991–92					6
Nigeria	1991–92					6
Northern Africa						
Egypt	1998	3	3	14	5	25
West and Central Africa (Sorghum Research Network, 18 Countries)	1991–92	33	27	23		83
East Africa (Sorghum and Millet Network, 8 Countries)	1990–91	29	31	27		87

Notes:
[a]In East Africa, 70% of the researchers work on sorghum and millet as full-time researchers while 30% of them work on these two crops on a part-time basis and about 35% of the qualified scientists are based in two countries.
[b]For southern African countries, number of scientists indicates working both on sorghum and millet.
[c]In West and Central Africa, 38% are full-time researchers on sorghum, 62% are part-time researchers and about 25% of the qualified researchers are based at lead NARS.
Sources: For Asia, ICRISAT Impact Monitoring Survey, 1997.
For Africa, ICRISAT Impact Monitoring Survey, 1998–2000.
For West Africa, Sanders *et al.* (1994) p. 53.

scientists are devoted to more than one crop, often sorghum and millet together. In other words, Asian NARS have devoted more resources to sorghum improvement than their African counterparts, not only in terms of quantity but also in terms of education levels.

Sorghum Genetic Enhancement Research: Objectives and Targets

Pre-breeding research

Collection, characterization and maintenance of landraces are essential for crop improvement, and ICRISAT has given high priority to this. As of December 1999, a total of 36,719 sorghum germplasm accessions from 90 countries have been conserved at ICRISAT. After collection and assembly, ICRISAT along with its NARS partners conducted evaluation trials to identify the useful traits available in the assembled germplasm. Scientists working on sorghum improvement request germplasm materials from ICRISAT. Based upon requests from different users, ICRISAT has distributed 239,742 items of sorghum germplasm to 99 countries (Kameswara Rao, Curator of Genetic Resources Unit, ICRISAT, personal communication). During evaluation trials, some landraces collected from different countries have been identified as superior to existing cultivars. A total of 23 varieties have been directly released from the distributed sorghum germplasm in 12 countries of Asia, Africa and Latin America (Table 9.3)

Sorghum breeding strategy at ICRISAT

Sorghum breeding research domains

During the preparation of ICRISAT's medium-term plan for 1994–1998, six sorghum research domains were explicitly defined for the first time. Table 9.4 summarizes the location and characteristics of each sorghum research domain.

Sorghum breeding research at ICRISAT

ICRISAT has been engaged in sorghum improvement since the early 1970s. Multidisciplinary teams of scientists are located in Asia at ICRISAT Centre (India); at regional centres in West Africa at Bamako (Mali) and Kano (Nigeria), eastern Africa at Nairobi (Kenya), southern Africa at Bulawayo (Zimbabwe), and in Latin America at El Batan (Mexico).

Table 9.3. 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
IS 6928	Sudan	India	Moti	1978	Induced mutant
IS 2940	USA	Myanmar	Shwe-ni 2	1979	
IS 8965	Kenya	Myanmar	Shwe-ni 1	1979	
IS 302	China	Myanmar	Shwe-ni 10	1980	
IS 5424	India	Myanmar	Shwe-ni 8	1980	
IS 30468	Ethiopia	India	NTJ2	1980	
IS 18758	Ethiopia	Burkina Faso	E-35-1	1981	
IS 4776	India	India	U P Chari-1	1983	Forage sorghum
IS 9302	South Africa	Ethiopia	ESIP 11	1984	
IS 9323	South Africa	Ethiopia	ESIP 12	1984	
IS 2391	South Africa	Swaziland	MRS 13	1989	
IS 3693	USA	Swaziland	MRS 94	1989	
IS 8511	Uganda	Mozambique	Mamonhe	1989	
IS 23520	Ethiopia	Zambia	Sima	1989	
IS 9321	South Africa	Mexico		1990	
IS 9447	South Africa	Mexico		1990	
IS 9468	South Africa	Mexico		1990	
IS 9830	Sudan	Sudan	Mugawim Buda-2	1991	
IS 2923	USA	Botswana	Mahube	1994	
IS 23496	Ethiopia	Tanzania	Pato	1995	
IS 3541	Sudan	India	CS 3541		Converted Zerazera
IS 3924	Nigeria	India	Swarna		
IS 18484	India (AICSIP)[1]	Honduras	Tortillerio		

Source: N. Kameswara Rao *et al.* (1998).

The breeding concepts, objectives and the research approach involving partners have undergone several changes since ICRISAT was established. External environment, donors' perceptions, the national agricultural research systems (NARS) capacity and the ICRISAT research administration structures are some of the most important factors that caused these changes. At ICRISAT Patancheru, six different periods can be identified (Reddy *et al.*, 1998):

Phase 1: Wide adaptability and high grain yield (1972–75)
Phase 2: Wide adaptability and screening techniques (1976–1979)
Phase 3: Regional adaptations and resistance breeding (1980–1984)
Phase 4: Specific adaptation and resistance breeding (1985–1989)
Phase 5: Trait-based breeding and sustainable productivity (1990–1994)
Phase 6: Intermediate products and upstream research (1995–present).

Table 9.4 Sorghum research domains.

Domain	Production system characteristic	Major constraints	Locations
SG I (wide applicability)	Rainy season, multipurpose grain, stalk, fodder (fodder emphasis). Wide adaptability (June–August sowing)	Grain mould, shoot fly, headbug	West Africa (southern tier), India (Tamil Nadu, S. Karnataka, Andhra Pradesh)
SG 2 (dual purpose, specific adaptability)	Rainy season, dual purpose (grain and fodder). Specific adaptation (June sowing). Medium to late maturing types	Stem borer, grain mould, midge, shoot fly, drought	E. and southern Africa, India (Andhra Pradesh, N. Karnataka, Maharashtra, Madhya Pradesh, Gujarat), Latin America (some areas)
SG 3 (dual purpose, fodder emphasis)	Rainy season, dual purpose (fodder emphasis). Early maturing	Shoot fly, stem borer	W. Africa (northern tier), E. Africa (Yemen, Somalia), India (E. Rajasthan), Latin America (some areas), China and Iran
SG 4 (forage sorghum)	Rainy season, forage types (thin stalk, tillering), late-maturing	Stem borer, leaf diseases	India (N. Gangetic plain), Pakistan
SG 5 (early sowing *rabi*)	Post-rainy season (early sown before October). Bold grain types, dual purpose	Shoot fly, stalk rot, head bugs	India (S. Andhra Pradesh, S. Karnataka)
SG 6 (late sowing *rabi*)	Post-rainy season (late sown–mid/late October). Bold grain, photoperiod sensitivity require temperature insensitive		India (Gujarat, S. Maharashtra, N. Karnataka)
SG 7 (irrigated)	Irrigated sorghum		Iran, Egypt, Wadmadani (Sudan)
SG 8 (extreme altitude)	Others		(i) High altitude: China (ii) Low altitude: Indonesia, Brazil, Ecuador, Venezuela

There were some variations in research activities in Africa. Obilana (1998) documents the experience of sorghum breeding within the Southern Africa Development Community (SADC)/ICRISAT Sorghum and Millet Improvement Programme (SMIP). The strategy of the SADC/ICRISAT SMIP involved, first, the development and testing of improved technology of better varieties and hybrids (Phases I and II, 1983/84 to 1992/93) and second, technology transfer and exchange (1992/93 to1997/98).

Research Products

Intermediate products

The focus of sorghum research and development activities at ICRISAT has involved a massive screening programme, the development of suitable materials, and the understanding of genetics and mechanisms for resistance. In particular, ICRISAT breeders have worked towards the development of improved varieties and hybrids. Hybrids are generally known to have significantly higher productivity than their parental pure lines. The discovery of cytoplasmic-genetic male sterility (CMS) facilitated large-scale production of male-sterile lines (A-lines) when pollinated by the respective maintainer line (B-lines). Commercial hybrids are produced from these seed parents (A-lines) upon pollination by a restorer line (R-line). In recent years, considerable effort has gone into producing A-, B- and R-lines with desirable characteristics.

The team effort of scientists in sorghum breeding, entomology and pathology in screening materials for resistance to various biotic and abiotic stress factors has resulted in the development of various male-sterile lines.

ICRISAT organized more than 150 trials/nurseries and supplied 146,000 seed samples during 1986–1997. Of the seed samples distributed, Asia received 66%, followed by Africa (23%) and the Americas (10%). Partially converted lines were the most common category (13.5% of total supply) followed by restorers (9.8%), hybrids (9.4%), varieties (9.1%), maintainers (8.3%) and male-sterile lines (8.0%) (Reddy *et al.*, 1998). Both public research institutes and private seed producers in India have received seed samples from ICRISAT. The total number of seed samples supplied to Indian NARS increased to 14,310 in 1997 from 2131 in 1986. In addition to the seed samples and germplasm lines supplied from ICRISAT Patancheru, southern African countries obtained sorghum genetic materials (breeding lines, varieties, hybrid parents, hybrids) from the ICRISAT/SADC Sorghum and Millet Improvement project (SMIP). Obilana (1998) reported that SMIP conducted 608 collaborative trials and supplied 18,524 genetic material samples to 11 SADC countries during 1983/84 to 1997/98.

ICRISAT-bred varieties/hybrids and those derived from ICRISAT materials by the national breeders have been tested in the All India Coordinated Sorghum Improvement Project (AICSIP) trials since 1979/80. The average numbers of ICRISAT-derived varieties and hybrids entered into the advanced trials have increased over time. In collaboration with NARS, hybrids/varieties developed by ICRISAT have been tested in network trials for selecting for local conditions in Africa, Asia and Latin America. As a result, improved varieties and hybrids are released. The private sector is also marketing several hybrids developed from ICRISAT materials in India.

Release of improved cultivars

Table 9.5 shows the total number of improved sorghum cultivars (varieties and hybrids) released in different countries. A total of 405 improved sorghum cultivars are available in 43 countries of Asia, Africa and America. We have grouped the released sorghum cultivars as ICRISAT-bred (cultivars bred by ICRISAT breeders); ICRISAT-parent (cultivars developed by NARS based on ICRISAT parent materials and germplasm); ICRISAT-network (cultivars tested through ICRISAT network but not bred by ICRISAT scientists); and non-ICRISAT cultivars (cultivars released from other sources). A total of 146 sorghum cultivars were released from materials classified as ICRISAT-bred (64), ICRISAT-parent (29) or ICRISAT-network (53). Over time, the number of releases using ICRISAT-parent materials has been increasing. Up to 1975, 71 sorghum cultivars were released in 13 countries. These cultivars were mainly selections of landraces, except in India and China where hybrids were also released. The number of releases increased over time, and the number of countries having improved sorghum cultivars has also increased.

The first sorghum hybrid in India, CSH 1, was released in 1964. In 1999, 182 improved cultivars of sorghum were available in India for cultivation for grain, forage or dual purpose. Out of these 182 improved cultivars, 122 are 'notified' either by the national seed committee or by the state seed release committees. The remainder are mostly the research products of private seed companies. Out of these 122 notified cultivars, 23 were derived from ICRISAT materials. At least nine hybrids released by private seed companies are based on ICRISAT-parent materials. It is difficult to know the parentage of private hybrids due to confidentiality, but all private seed companies that have released hybrids in India have collaboration with ICRISAT. Private companies operating in India acknowledge that their research hybrids contain some input from ICRISAT material (ICRISAT/Rutgers University Study of Private Seed Sector, 1997).

Table 9.5. Number of released sorghum cultivars with ICRISAT content by period.

Country	Up to 1970	1971–75 (1976–80)		1981–85 (1986–90)				1991–95 (1996–98)				Total ICRISAT derived releases	TOTAL releases (up to 1998)
		ICRISAT network	All sources	ICRISAT -bred	ICRISAT -parent	ICRISAT -network	All sources	ICRISAT -bred	ICRISAT -parent	ICRISAT -network	All sources		
Asia													
China			4 (3)		0 (3)		5 (4)		2 (2)		6 (2)	7	24
India	9	0 (2)	16 (25)	2 (2)	2 (1)	1 (0)	31 (30)	3 (0)	9 (1)		43 (28)	23	182
Indonesia	5		4 (0)				2 (0)				2 (0)	0	13
Iran							0 (1)				2 (3)	0	6
Myanmar		0 (4)	0 (10)	4 (0)			8 (0)	3 (0)			3 (0)	11	21
Pakistan	3		1 (2)				0 (1)	0 (1)	0 (1)	0 (2)	0 (4)	4	11
Philippines								1 (0)		1 (0)	2 (0)	2	2
Thailand	2						1 (1)		1 (0)		3 (0)	1	7
Africa													
Botswana	4		3 (0)					1 (0)	2 (0)	1 (0)	4 (0)	4	11
Burkina Faso		1 (1)	1 (1)		0 (2)		0 (2)			1 (0)	1 (0)	5	5
Burundi						0 (2)	0 (2)					2	2
Cameroon					0 (1)		0 (1)					1	1
Chad					0 (1)		0 (1)					1	1
Côte d'Ivoire				0 (1)			0 (1)					1	1
Egypt	1		1 (1)								2 (3)	0	8
Ethiopia		0 (1)	0 (1)			3 (1)	3 (1)	0 (1)		1 (0)	1 (1)	7	7
Ghana				0 (1)			0 (1)					1	1
Kenya	1		1 (2)			4 (0)	4 (0)			2 (0)	2 (0)	6	10
Malawi							1 (0)	2 (0)			2 (0)	2	3
Mali								4 (0)			4 (0)	4	4
Mozambique	3			0 (2)		0 (3)	0 (5)	1 (0)			1 (0)	6	9
Namibia								0 (1)			0 (1)	1	1
Niger								2 (0)			2 (0)	2	2

Nigeria								4 (0)			4 (0)	4	4
Rwanda						2 (0)	0 (2)					2	2
Senegal		0 (1)	0 (1)									1	1
Sudan				1 (0)			1 (0)	5 (0)			5 (0)	6	6
Swaziland						0 (1)	0 (2)	2 (0)			1 (0)	3	3
Tanzania	1		2 (1)			0 (1)	0 (2)			1 (0)		2	6
Togo						0 (1)	0 (1)					1	1
Uganda	5		3 (0)								2 (0)	0	10
Zambia	1			1 (0)		0 (4)	1 (5)	1 (0)			2 (0)	6	9
Zimbabwe				0 (2)			1 (1)	0 (3)			1 (3)	5	6
Others													
Colombia									1 (0)	2 (0)	3 (0)	3	3
Costa Rica										1 (0)	1 (0)	1	1
Dominican Republic								1 (0)			0 (1)	1	1
El Salvador		0 (2)	0 (2)	1 (0)		0 (1)	1 (1)					4	4
Guatemala				1 (0)			1 (0)					1	1
Honduras				2 (0)		1 (0)	3 (0)					3	3
Mexico		0 (1)	0 (1)	0 (5)			0 (5)	2 (0)		1 (0)	3 (0)	9	9
Nicaragua				0 (1)		1 (0)	1 (1)					2	2
Panama										1 (0)	1 (0)	1	1
Paraguay										1 (0)	1 (0)	1	1
Total	35	1 (12)	36 (50)	12 (14)	2 (8)	12 (14)	64 (71)	32 (6)	15 (4)	13 (1)	104 (45)	146	405

Seven cultivars in China having ICRISAT parentage were released after 1987. In Pakistan, out of 11 improved cultivars, two (PARC SS1 and PARC SV1) have ICRISAT parentage, and two (PARC SH1 or CSH1, PARC SS2 or IRAT 204) were obtained through the ICRISAT network. One cultivar (Suphan Buri 1) was released in Thailand in 1993 from ICRISAT materials. Myanmar has released 21 varieties and 11 are directly from ICRISAT crosses (seven varieties) or direct introduction from the ICRISAT germplasm collection (four varieties). After 1982, all varieties released in Myanmar (seven) were direct introductions of ICRISAT crosses. Indonesia has released 13 improved sorghum varieties. Two were selections from local varieties and the other 11 were direct introductions. Pedigrees of these cultivars could not be traced. However, ICRISAT has had substantial collaboration with Indonesia.

Nigeria has four improved cultivars (ICSH 89002NG, ICSH 89009 NG, ICSV 111 and ICSV 400), and all are direct introductions from ICRISAT crosses after adaptive research trials. Egypt has seven recommended cultivars (four varieties and three hybrids). All cultivars released after 1980 in Botswana, Burkina Faso, Burundi, Cameroon, Chad, Ethiopia, Ghana, Mali, Mozambique, Namibia, Niger, Rwanda, Sudan, Tanzania, Togo and Zambia are either ICRISAT-bred or from the ICRISAT network. With the exception of one variety in Malawi and one hybrid in Zimbabwe, all released cultivars in Malawi and Zimbabwe in the 1980s and 1990s were from ICRISAT.

Varietal Diffusion and Adoption

Table 9.6 shows the rate of adoption of improved sorghum cultivars in different countries of the world. We consider four categories of modern variety adoption: percentage of area planted to ICRISAT crosses; percentage of area planted to varieties derived from ICRISAT parents; percentage of area planted to cultivars developed through ICRISAT networks; and percentage of area planted to non-ICRISAT cultivars. The rate of adoption is high in Asian countries, while it is comparatively low in African countries. Inter-country comparisons of adoption show that ICRISAT crosses are popular in African countries.

Extent of adoption

In India, the rate of adoption of improved sorghum cultivars in different districts is shown in Fig. 9.1. The rapid rate of adoption in Tamil Nadu and Maharashtra state is evident, while a very slow rate of adoption was observed in Rajasthan and Gujarat states. The rate of adoption

Table 9.6. Rate of adoption of different improved sorghum cultivars.

Country	Region	Year	Percentage of area planted to				
			ICRISAT-cross	ICRISAT-parent	ICRISAT-network	Others	All improved
Asia							
China		1998		9		89	98
India		1999	1	10	3	55	69
Iran		1995–96					87
Pakistan		1995–96					21
Thailand		1995–96		10			NA
Africa							
Angola	National	1997					17
Botswana	National	1997–98	33				33
Cameroon	Mayo Sava	1995	49				
	Diamare	1995	14				
	Mayo Danay	1995	12				
Chad	Guera, Mayo Kebbi, Chari Baguermi	1995	27				
	Guera	1995	38				
	Mayo Kebbi	1995	27				
	Chari Baguermi	1995	24				
Egypt		1995–96		5			35
Lesotho		1997	4				4
Malawi			10				10
Mali		1995	29				29
Mozambique			5				5
Myanmar		1995–96	10				10

Continued

Table 9.6. (*Continued*)

Country	Region	Year	Percentage of area planted to				All improved
			ICRISAT-cross	ICRISAT-parent	ICRISAT-network	Others	
Africa *Continued*							
Nigeria	Kano	1996–97	28				28
	Katsina		10				10
	Kaduna		29				29
	Jigawa		3				3
South Africa		1997					77
Sudan		1995–96	3			19	22
Swaziland		1997					50
Tanzania		1997					2
Zambia			35				35
Zimbabwe			36			36	

Source: ICRISAT Impact Monitoring Survey, 1997–2000; Ogungbile *et al.* (1999) for Nigeria; Rohrbach and Makhwaje (1999) for Botswana; SMIP (1999) for Angola, Lesotho, South Africa, Swaziland and Tanzania; Yapi *et al.* (1998) for Mali; Yapi *et al.* (1999) for Cameroon and Chad.

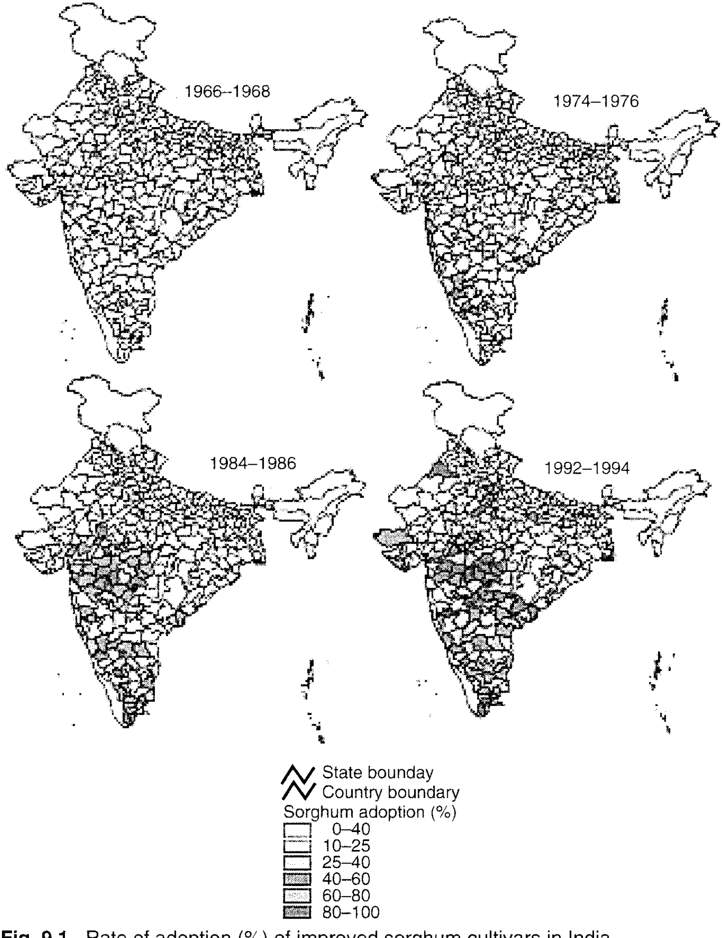

Fig. 9.1. Rate of adoption (%) of improved sorghum cultivars in India.

is higher (more than 80%) in central Maharashtra and in some districts of Andhra Pradesh. Later on we shall show that these districts have also gained in terms of yield increase. The trends in adoption of specific improved sorghum cultivars in India are shown in Fig. 9.2. The initial rapid adoption of CSH 1 is evident, as is the subsequent adoption of CSH 5, CSH 6 and CSH 9. MSH 51, popularly known as Mahyco 51, a cultivar from the private sector, has also been adopted by the

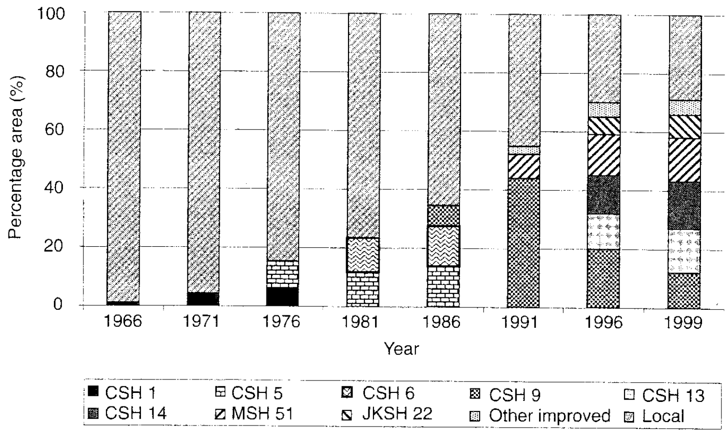

Fig. 9.2. Trends in adoption rate of different improved sorghum cultivars in India, 1966–1999.

farmers to a large extent. JKSH 22, another cultivar from the private sector, is also gaining ground. Improved open-pollinated varieties were less popular than the hybrids from the beginning (Rana *et al.*, 1997). Since the hybrids provide higher yield and are now readily available from a large number of private and public seed companies, the adoption of hybrids has taken off. Three phases in the spread of improved sorghum cultivars are observed in India. Until 1975, only CSH 1 was dominant, and it replaced traditional local cultivars. Between 1976 and 1986, the dominant improved sorghum cultivars were CSH 5 and CSH 6. This phase was characterized by the replacement of traditional and initial improved cultivars (CSH 1, CSH 2, CSH 4) by new cultivars (CSH 5, CSH 6). After 1986, the initial cultivars were replaced by new cultivars (CSH 9, MSH 51, JKSH 22) at a faster rate. During this period, Indian farmers made use of the large number of private-sector hybrids in the market.

In China, the rate of adoption of improved cultivars is the highest among all Asian countries. In 1995/96, essentially all of the sorghum area was under improved cultivars. Hybrids are more popular than varieties. Even in 1975/76, the rate of adoption of improved sorghum cultivars in China was 90%. The popularity of different hybrids in China has varied over time. In 1975/76, six sorghum cultivars occupied more than 60% of the total sorghum area. The variety Jin Za No. 5 covered about 19% of the sorghum area of China in 1975/76. In 1980/81, the most popular cultivar was Tie Za No. 6, covering 23% of the total sorghum area. Five other cultivars (Liao Za No.1, Liao Za No. 2, Jin Za

No. 83, Shen Za No. 4 and Tie Za No. 7) together covered about 30%. Only 5% of the sorghum area was under local cultivars in China in 1980/81. In 1985/86, only 2% of the total sorghum area was under local cultivars. Popular cultivars were Shen Za No. 5, Qiao Za No. 2, Liao Za No. 4 and Jin Za No. 94. In 1990/91, the rate of adoption of improved cultivars was 98%, and four cultivars (Long Si Za No. 1, Jin Za No. 12, Tie Za No. 10 and Liao Za No. 5) were popular. By the year 1995/96, 99% of the total sorghum area of China was under improved cultivars. Four improved cultivars (Long Za No. 3, Liao Za No. 6, Liao Za No. 7 and Liao Za No. 10) were popular. About 9% of the sorghum area in China is from ICRISAT parents.

Though Myanmar has 22 recommended improved varieties to cultivate, the rate of adoption remained low. In 1975/76, only local sorghums were in cultivation, while in 1995/96, all areas under improved cultivars (10%) were growing ICRISAT-bred varieties. The popular cultivars were Yezin White Grain 1, Yezin White Grain 2 and Yezin White Grain 3.

Local cultivars in Pakistan have always dominated sorghum cultivation. In 1980/81, only 7% of the total sorghum area in Pakistan was under improved cultivars, which had increased to 21% by 1995/96. However, as of 1995/96, no ICRISAT cultivars have been grown in Pakistan.

The large sorghum-growing area in Egypt is predominantly under local varieties. In 1975/76, only 5% of the area was under improved sorghum cultivars, which had increased to 35% (including 5% area under ICRISAT parents) in 1995/96. In 1975/76, Giza 114 was the only improved cultivar grown in Egypt, while in 1980/81, two cultivars – Giza 114 (4.4%) and Giza 15 (10.6%) – covered 15% of the total sorghum area. By the year 1985/86, Giza 114 was out of cultivation in Egypt, and Giza 15 became the most popular cultivar, covering 15% of the total sorghum area. Giza 15 is still popular in Egypt and covered about 17% of the total sorghum area in 1995/96. Other improved cultivars were Giza 113 and Dorado.

Local varieties are still dominant in Nigeria. Two ICRISAT-bred cultivars (ICSV 111 and ICSV 400) are gaining popularity among farmers of Nigeria. Ogungbile *et al.* (1997) conducted a study to determine the nature and extent and determinants of adoption of ICSV 111 and ICSV 400 in 1996. A survey was conducted in nine villages of Kano state, nine villages in Katsina state, six villages in Kaduna state and three villages in Jigwa state. A total of 219 farmers from 27 villages in four states were interviewed. The rate of adoption of improved cultivars was 28% in Kano, 10% in Katsina, 29% in Kaduna and 3% in Jigwa.

Yapi *et al.* (1998) studied the adoption and benefits of improved sorghum variety S 35 (an ICRISAT-bred variety) in Chad, based on farm survey data collected from 152 farmers from 28 villages in 17 districts for the year 1994/95. The study was conducted in three zones: Guera, Mayo-Kebbi and Chari-Baguirmi, which are located in the Sahelian and the Sahelian-Sudanian zones, where climate affects yield and consequently necessitates short-cycle crop varieties such as S 35. These three zones were target and distribution zones for S 35 in Chad. The adoption rate was higher in Guera (38%) than in Mayo-Kebbi (27%) and Chari-Baguirmi (24%). The lower adoption rates in Chari Baguirmi can be explained by farmers' preference for local red sorghum (*djigari*) rather than to white sorghums such as S 35, along with differences in climate and seed availability.

The same variety, S 35, was also grown extensively in northern Cameroon (Ndjomaha *et al.*, 1998). Ten years after introduction, S 35 was being grown on 50% of the rainfed sorghum area in the Mayo Sava zone.

Yapi *et al.* (1998) studied the adoption of improved sorghum cultivars in three regions – Koulikoro, Ségou and Mopti – of Mali. The area under improved cultivars ranged from 17% to 29% between 1990 and 1995 for all three regions.

Southern and Eastern Africa

Phofu is the most popular improved variety in Botswana. The adoption rate of Phofu in 1997/98 was 21% (Rohrbach and Makhwaje, 1999). The rates of adoption of ICRISAT-bred varieties in Sudan, Malawi, Zambia and Zimbabwe in 1997 were 3%, 10%, 35% and 36%, respectively (Table 9.6). The rate of adoption of improved sorghum cultivars in South Africa in 1997 was 77% but all are under non-ICRISAT cultivars. It should be mentioned here that South Africa came under ICRISAT partnership only in 1994/95, and ICRISAT cultivars are not yet released in South Africa.

Constraints to adoption as reported by the farmers

Ogungbile *et al.* (1999) report that in a survey of Nigerian farmers, low soil fertility was a widely mentioned constraint to adoption of improved varieties. It was the opinion of the farmers that the cultivars (ICSV 111 and ICSV 400) would not do well in marginal land without adequate fertilizer application. Another important constraint mentioned was insect damage. The varieties were reported to be susceptible to stem-borer attack. This was attributed to the sugary nature of the stem. Another problem was die-back, which prevents good crop establishment.

Lack of seeds was another major reason mentioned by most of the respondents in the Nigerian study for not growing the improved varieties. Inadequate supply and high cost of fertilizer also affected the adoption of the cultivars. Credit facilities would be needed to enable the farmers to purchase the necessary inputs (Ogungbile *et al.*, 1999).

Yapi *et al.* (1999) reported constraints to adoption of S 35 in Chad, as mentioned by farmers, to include bird damage, poor soil fertility, seed availability and seed cost.

Reasons for non-adoption in Cameroon were many. The most important reasons cited by farmers include losses due to birds, grain mould, high price of milling, regermination of seed, requirements for soil fertility, poor quality of beer, small stalks for construction, stalks disliked by animals and lack of seed (Ndjomaha *et al.*, 1998).

The most significant constraints to the adoption of improved sorghum cultivars, cited by Mali farmers, are lack of information about the existence and use of new varieties (58%), lack of seed (50%) and poor soil (13%). Lack of information and seed are the most important constraints in all three regions, and poor soil is only a problem in Mopti. In Ségou, there is a strong preference for local varieties. For sorghum in Koulikoro, the need to use fertilizer on improved varieties, bird damage, labour shortages and storage are constraints (Yapi *et al.*, 1998).

Dimensions of Impacts

Impacts on yield

For any crop, it can be difficult to interpret yield levels and changes in yield as measures of research impact. This is particularly true for crops such as sorghum that are customarily grown with few inputs on poor-quality land. Even small changes in the quantities of inputs used or the quality of the land planted to sorghum can have large effects on yield.

Global yield scenario

In the early 1960s, the yield level was very low in most of the developing countries, but by the mid-1990s, yield levels had gone up in Asia. Yield has increased in China, India, Pakistan and North Korea. Per hectare yield in China has increased more than 3 tonnes (3213 kg) and in India by 320 kg (65%). Adoption of hybrids in China is more than 94%. India has about 65% adoption of improved cultivars. Yield increase in Pakistan was by 104 kg (21%). Yield was doubled in North

Korea. However, sorghum yield in Thailand has decreased. In the 1960s, Thailand was growing sorghum for grain purposes, but since the late 1980s a large area under sorghum is now for fodder purpose, and they export dried fodder to Japan. FAO data do not record this fact. FAO data only report area harvested and grain production.

In Africa, yield has increased in South Africa, Egypt, Uganda, Ethiopia, Ghana, Burkina Faso, Lesotho, Nigeria and Namibia to a significant extent. Sorghum yield in South Africa tripled and the adoption rate of improved cultivars in South Africa is 77%. Yield has declined in Niger, Sudan, Mozambique, Rwanda, Kenya and Eritrea to a notable extent. In other African countries there has been no significant change. In many southern African countries, yield was lower in the 1990s than in the early 1960s. Among the explanations for this decline are low fertilizer use and a shift of sorghum cultivation to poorer land. Furthermore, breeders have emphasized developing cultivars with early maturity and yield stability, rather than high yield *per se*. A thorough analysis will be required to identify the reasons for decline in yield in many African countries.

By contrast sorghum yields in European countries have increased substantially. Yield has almost doubled in Italy and France, tripled in Greece and risen fivefold in Spain. In the Americas, yields have doubled in Argentina, Nicaragua, Guatemala and Peru. There were also significant increases in yield in Colombia, Mexico and the USA.

District level impact situation in India

Figure 9.3 portrays the yield scenario in different sorghum growing districts of India for *kharif* sorghum, which was the focus of India's research programme. In Fig. 9.3, we see that yield gains for rainy season (*kharif*) sorghum in Maharashtra and Andhra Pradesh were high where adoption rates were also high. Yield increased at least 750 kg ha^{-1} in these districts and more than 1 tonne in many districts. In the dry season (*rabi*) sorghum, research was less, and fewer improved cultivars were developed, and yield increases were lower (Fig. 9.4).

Yield gain at the farm level

Table 9.7 summarizes the farm-level yield gain information from different studies conducted in Africa. These data are, of course, problematic because they compare yields of improved varieties with yields of local cultivars for farmers who have adopted improved varieties. Obviously this gives a less satisfactory measure of yield advantages for other farmers for whom such yield differences are presumably smaller. None the less, the data offer some useful perspectives. Yields

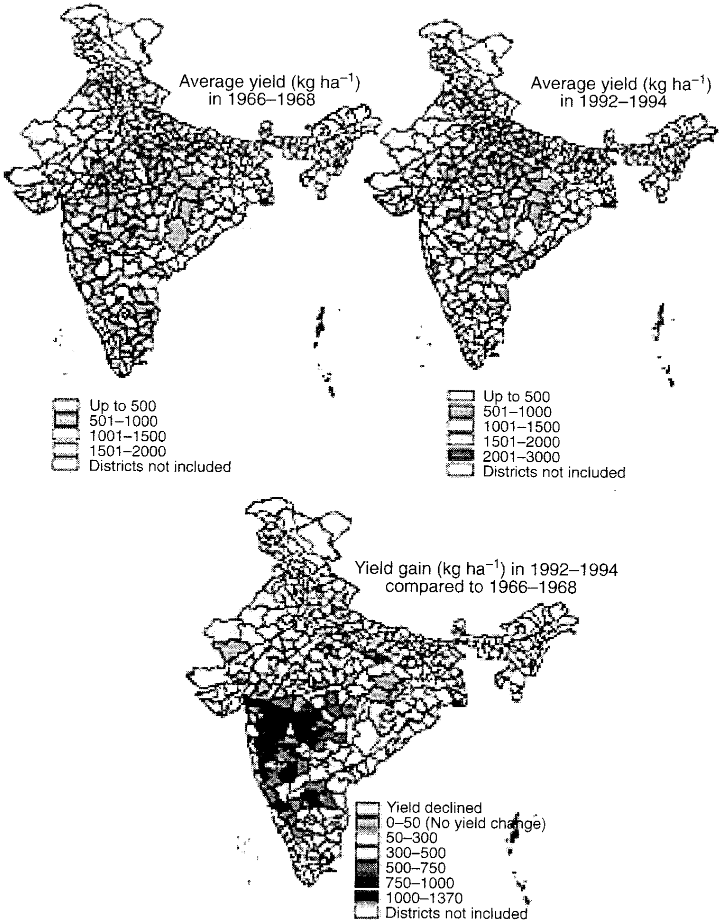

Fig. 9.3. Average yield and yield gain in *kharif* sorghum in India.

of improved cultivars were 7%–63% higher than the best local cultivars in Nigeria. Improved sorghum variety S 35 had 51% yield advantage in Chad and 14% in Cameroon. Ndjomaha *et al.* (1998) reported that during the period 1986–1995, the per hectare difference in productivity between S 35 and the local variety was 432 kg in Mayo Sava, 89 kg in Diamaré, and 52 kg in Mayo Danay regions of Cameroon.

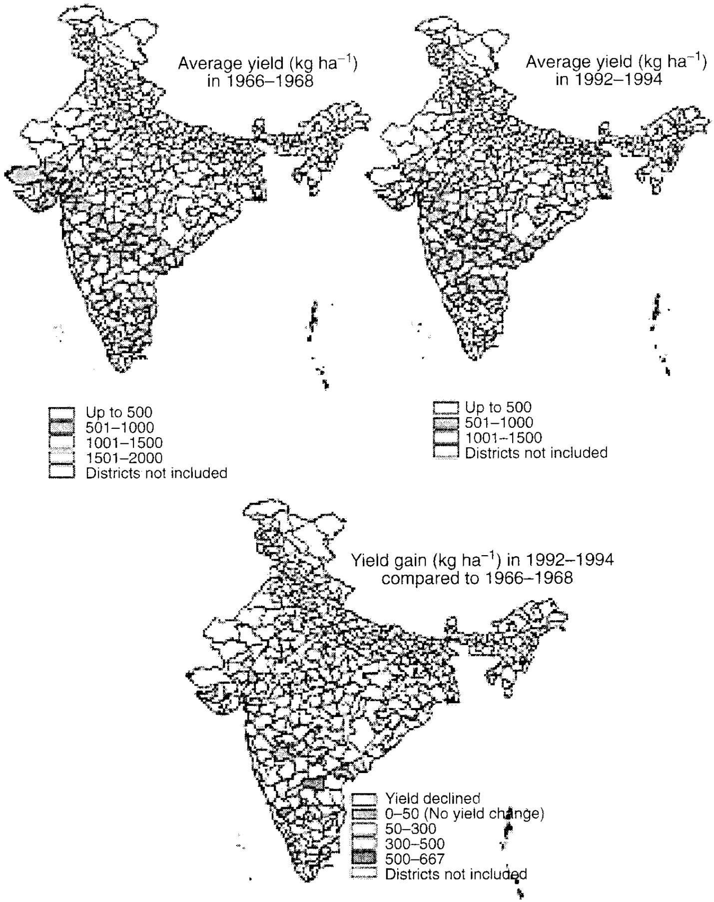

Fig. 9.4. Average yield and yield gain in *rabi* sorghum in India.

These differences indicate a better genetic potential for S 35 in Mayo Sava than in the other two areas, probably because rainfall is more congruent with the 300–800 mm research recommendation. In Mali, sorghum yields increased from 620 kg ha^{-1} with the best local variety to 940 kg ha^{-1} for improved varieties and increases in profits by 51% (Yapi *et al.*, 1998). These yields are consistent with those found in previous studies.

Table 9.7. Impacts of improved sorghum cultivars on yield.

Country	Region	Year	Improved cultivar	Yield ($kg\ ha^{-1}$) of Local	Yield ($kg\ ha^{-1}$) of 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	Kano	1996	ICSV 400	875	1165	33
Nigeria	Katsina	1996	ICSV 400	1003	1073	7
Nigeria	Jigawa	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).

Impacts on cost of production

An alternative measure of productivity gains is the unit cost of production. An analysis in India shows that real cost per tonne of sorghum production decreased in the 1980s and 1990s compared with that of the early 1970s. In Maharashtra, the cost per tonne in the 1990s was 40% below the level in the 1970s. In Rajasthan, this figure was 37% (Table 9.8).

The same measure is available for a few locations in Africa (Table 9.9).[1] S 35 has a cost advantage of 12% in Cameroon and 25% in Chad (Yapi *et al.*, 1999). Using improved varieties of sorghum reduced production costs as much as 25% (US$34 t^{-1}), compared with local varieties in Mali. The absolute production cost per hectare was higher for improved varieties because of additional inputs, but the higher productivity still provided these economies. With this higher productivity, farmers have the opportunity to reduce the area sown to sorghum and diversify their farming to grow other crops either for the market or for their own consumption.

[1] The studies in Africa are specifically for areas of high research impact.

Table 9.8. Impact of improved sorghum cultivars on per tonne production cost in India, 1971–1995.

	Average cost (Rs t^{-1})			Cost reduction (%) compared to early 1970s in	
States	Early 1970s[a]	Early 1980s[b]	Early 1990s[c]	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.
[a]Early 1970s indicate for Andhra Pradesh (average of 1973 and 1974), Karnataka (average of 1972–1974), Madhya Pradesh (1976), Maharashtra (average of 1972–1974) and Rajasthan (average of 1972–1974).
[b]Early 80s indicate for Karnataka (average of 1981–1983), Madhya Pradesh (average of 1981–83), Maharashtra (average of 1982–1983), Rajasthan (average of 1981–1983).
[c]Early 1990s indicate for Andhra Pradesh (average of 1994–1995), Karnataka (1991), Madhya Pradesh (average of 1994–1995), Maharashtra (1995), Rajasthan (1992).
Source: Estimated from cost of cultivation reports (various issues).

Table 9.9. 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).

Impact on average yield and instability in yield

Deb *et al.* (1999) conducted a study to quantify the impact of improved sorghum cultivars on yield increase and instability in sorghum yield in India. They measured instability (using the Cuddy-Della Valle index) as well as mean yield of sorghum for two periods: 1966/67 to 1980/81, and 1981/82 to 1993/94. During the first period (1966/67 to 1980/81) percentage of HYV sorghum area to the total sorghum area in India was less than 20%, while in the second period (1981/82 to 1993/94) it was above 20%. The coefficient of genetic diversity among the improved cultivars was also very low in the first period and increased significantly during the second period (Deb and Bantilan, 1998). Therefore, Period 1 can also be treated as a low genetic diversity period while Period 2 can be considered as a genetically diversified sorghum cultivation period. Table 9.10 presents data on average yield and yield variability in sorghum for the two periods. Average yields in India during Period 1 were 582 kg, and 748 kg in Period 2. In all the states except Gujarat, the measured coefficient of variation in yield decreased from the first period to the second period. An implication of this finding is that food security has been strengthened over time through the reduction in year-to-year yield fluctuation.

A more detailed analysis of the changes in yield stability is presented in Deb *et al.* (1999).

Impact on genetic diversity

The genetic diversity in a crop species is related to its stability and improvement. Genetic uniformity increases the possibility that an unexpected pest or disease could cause a major loss in production. Deb and Bantilan (1998) computed genetic diversity in sorghum cultivars for India and measured the relationship between genetic diversity and yield stability.

Table 9.10. Average yield and relative variability in yield of sorghum in different states of India.

	Period I (1966–80)		Period II (1981–93)		Percentage change	
State	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV (%)
Andhra Pradesh	521	23.02	661	21.66	26.84	−5.91
Gujarat	499	31.55	551	42.51	10.38	34.76
Karnataka	985	26.65	957	23.08	−2.91	−13.40
Madhya Pradesh	729	24.08	896	19.52	22.76	−18.96
Maharashtra	609	29.50	902	26.51	17.99	−6.71
Rajasthan	300	58.62	412	50.77	37.47	−13.40
Tamil Nadu	943	28.13	1113	26.24	17.99	−6.71
INDIA	582	10.59	748	13.02	28.47	22.97

Source: Deb *et al.* (1999).

Three types of genetic diversity indices – average, recommended and weighted – were computed following Souza *et al.* (1994). *Average diversity* estimates are based on the average coefficient of diversity (COD) of each variety grown in a given region in a given year. *Weighted diversity* was based on a weighted average of the COD of each variety weighted by the proportion of the area sown to each variety in a given region in a given year. *Recommended diversity* was based on the average COD of each cultivar recommended by either public or private research system or notified by the seed certification agency for a given region in a given year. Deb and Bantilan (1998) explore this topic in detail. All three diversity measures showed increases over time. Interestingly, the level of weighted diversity was much higher in 1994 than in 1966, in all states of India. Analysis shows that sorghum breeders were using different parental materials to develop new improved cultivars rather than depending only on a few parent materials.

The relationship between genetic diversity and yield instability is interesting. Genetic diversity in sorghum cultivation has increased in Andhra Pradesh, Karnataka, Madhya Pradesh and Tamil Nadu, while the index of yield instability has decreased in these states. In Maharashtra, genetic diversity at the end of Period 1 and at the end of Period 2 was almost the same. The variability situation was also similar in these two periods. In Rajasthan, genetic diversity has decreased but relative variability has increased. In other words, yield stability has increased in all the major sorghum-producing states of India with the increase in genetic diversity. Thus, the results suggest that sorghum germplasm research in India has contributed to an increase in genetic diversity and has thereby helped to reduce instability in sorghum yield.

Spillover impacts

Deb and Bantilan (1998) quantified potential spillover impacts of sorghum varieties using International Sorghum Varieties and Hybrid Adaptation Trials (ISVHAT) and All India Coordinated Sorghum Improvement Project (AICSIP) trial data. ISVHAT data used in the study include experimental trials conducted during 1989–1992 in 59 locations of 26 countries of Asia, Africa and Latin America. AICSIP data cover trials conducted at more than 80 locations in India in 1975/76 to 1995/96. They assumed the performance of a variety as a function of environmental variables (location dummy, year dummy) and technology variables (vintage of the variety, origin of the variety). The model was estimated separately for each sorghum domain (see Table 9.4 for description of domains). The results showed that ICRISAT crosses performed well in most sorghum domains, especially in SD1 (rainy season, multipurpose), SD2 (late maturing, dual purpose), SD3 (early maturing, dual purpose) and SD8(ii) (low latitude). ICRISAT cultivars bred at Patancheru enjoyed a yield advantage of 277 kg ha^{-1} in SD1, 354 kg ha^{-1} in SD3 and 175 kg ha^{-1} in SD2. In other words, yield advantage was as high as 27% in low altitude environments, 15% in SD1 (rainy season, multipurpose), 13% in SD2 (late maturing, dual purpose) and 7% in SD3 (early maturing, dual purpose). The positive yield advantage of ICRISAT-Patancheru bred materials indicates the potential of ICRISAT cultivars to spillover to these test domains. This also indicates that ICRISAT-Patancheru is a suitable location for breeding targeted for wide adaptability.

Brennan and Bantilan (1999) quantified spillover impacts of ICRISAT research on breeding programmes and agricultural production in Australia. They identified ICRISAT germplasm lines released in Australia by breeders and adopted by Australian farmers. For sorghum, the most significant contribution from ICRISAT to Australian agriculture has been the introduction of improved midge resistance combined with desirable white grain and tan plant colour through material such as ICSV 745 and PM 13654. There are several advanced breeding lines that have resistance and other characteristics incorporated from ICRISAT-derived material. As a result, industry experts expect that hybrids with this resistance will be available to growers in the near future, with a significant economic impact on the sorghum industry. On the basis that such resistance is likely to increase yield by 5% in the 50% of the crop affected by midge each year, the expected gains to Australia in terms of yield are estimated at 2.5%. That translates into a cost reduction of US$4.02 per tonne, or an annual cost saving of US$4.69 million at recent average production levels.

Other spillovers can be documented. Macia, a variety released in Mozambique, was also released in Botswana, Tanzania and Namibia (Table 9.11). Similarly, S 35 was developed in India and was adopted in the farmers' fields of Cameroon and Chad. ICSV 111 was developed in India and was released in Burkina Faso, Chad and Nigeria. ICSV 1079 BF was developed in Burkina Faso and cultivated by farmers in Benin, Ghana and Nigeria. SPV 475 was developed for India and is now cultivated in Malawi, Swaziland and Zimbabwe. Seredo was developed for Uganda but is also cultivated by farmers of Ethiopia, Kenya and Tanzania.

These examples show that breeders were successful in generating technology with wide adaptability and technology spillover potential. The results do not sustain this 'location specificity' argument (at least in terms of yields) when the international research system is considered as a source of research spillovers. Sorghum cultivars originating from a collaborative ICRISAT-NARS international research system have proven to be highly transferable within sorghum domains and across different countries around the world.

Table 9.11. Sorghum germplasm spillovers.

Cultivar	Production system* and country where originally selected	Spillover into
5D X 160	Uganda	Rwanda; 20, 21 Burundi
Dinkmash	India	19, 20 Ethiopia
Gambella 1107	Ethiopia	20, 21 Burundi
Ingazi	India	19, 20 Kenya
Macia	Mozambique	19 Botswana, Tanzania, Namibia
Melkamash	India	20 Ethiopia
Seredo	Uganda	19 Ethiopia; 20, 21 Kenya; 20 Tanzania
SPV 475	India	20 Malawi, Swaziland, Zimbabwe
SRN 39	India	19 Sudan, 20 Kenya, 20 Ethiopia
Tegemeo	Uganda	19, 20 Tanzania; 20 Burundi
S 35	India	Cameroon, Chad
CE 151	Senegal	Mauritania
CE 145-66	Senegal	Mauritania
Malisor 84-1	Mali	Côte d'Ivoire
BF 83-3/ 48-2-2	Burkina Faso	Senegal
IRAT	Niger	Burkina Faso, Chad
ICSV 111 IN	India	Benin, Ghana, Nigeria, Senegal, Togo
ICSV 1079 BF	Burkina Faso	Mali, Togo
ICSV 1083 BF	Burkina Faso	Togo
ICSV 1089 BF	Burkina Faso	Senegal, Mali, Togo
ICSV 400	India	Nigeria

Notes:
*Production system 8 (PS 8) is tropical, low rainfall, primarily rainfed, post-rainy season crops are sorghum/oilseed. Western Deccan Plateau of India is the location included in PS 8. Production system 19 (PS 19) covers lowland, rainfed, short-season (less than 100 days) and suitable for sorghum/millet/rangeland, and located in Sahelian eastern Africa, and margins of the Kalahari Desert. Production system 20 (PS 20) covers semi-arid, intermediate season (100–125 days) and suitable for sorghum/maize/rangeland; and located in eastern Africa and parts of southern Africa. Production system 21 is intermediate season (125–150 days) suitable for sorghum/maize/finger millet/legumes and located in eastern and southern Africa. Agro-ecological details of each production system are given in the ICRISAT Annual Report, 1993.
Source: *ICRISAT Southern and Eastern Africa Highlights* (1996), p. 30.

Returns on research

Previous studies have attempted to compute the economic impacts of ICRISAT-NARS research. For example, the net present value (NPV) of benefits from sorghum variety S 35 are 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 (Yapi *et al.*, 1999). Improved sorghum cultivars in Mali are estimated to have generated an NPV of US$16 million with an IRR of 69% (Yapi *et al.*, 1999). Other estimates have put the rate of returns from sorghum research in Zambia at 11–15% and in Zimbabwe (for ICSV 88060) at 22%.

Summary and Conclusions

Asian NARS have devoted more resources than their African counterparts to sorghum improvement. ICRISAT has worked to develop collaborative strategies appropriate for both sets of parties. ICRISAT has collected and assembled a large quantity of sorghum germplasm from all over the globe. Breeding research effort was large and evolved over time to have complementarities with the growing capacity of some national systems. As a result, a large proportion of released sorghum cultivars has been developed either by ICRISAT or by its partners using ICRISAT materials. In Africa almost all the cultivars released in the 1980s and 1990s are either ICRISAT-bred or acquired through ICRISAT networks. Where improved cultivars were adopted by the farmers, they appear to have increased yield, reduced the cost of production, and decreased yield variability. In general, countries with strong NARS benefited from elite germplasm and parental materials. On the other hand, countries with weak NARS benefited from finished products. Therefore, two distinct breeding strategies are required for strong NARS and weak NARS. For strong NARS, ICRISAT should develop parental materials and elite germplasms. Countries with weak NARS will benefit more if ICRISAT develops more finished products jointly with them.

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References

Brennan, J.P. and Bantilan, M.C.S. (1999) *Impact of ICRISAT Research on Australian Agriculture.* Economic Research Report no. 1, Australian Centre for International Agricultural Research, Canberra, Australia.

Deb, U.K. and Bantilan, M.C.S. (1998) Impacts on genetic diversity. In: Deb, U.K. and Bantilan, M.C.S. (eds) *Spillover Impacts of Sorghum Germplasm Research.* Socio-Economics and Policy Program, ICRISAT, Patancheru, India. Mimeo.

Deb, U.K., Bantilan, M.C.S. and Bantilan, F.T. (1998) Nature, extent and determinants of technology spillover. In: Deb, U.K. and Bantilan, M.C.S. (eds) *Spillover Impacts of Sorghum Germplasm Research.* Socio-Economics and Policy Program, ICRISAT, Patancheru, India. Mimeo.

Deb, U.K., Joshi, P.K. and Bantilan, M.C.S. (1999) Impact of modern cultivars on growth and relative variability in sorghum yields in India. *Agricultural Economics Research Review* 12 (2), 84–106.

FAO (1998) FAO statistical database.

Kamuanga, M.L. and Fobasso, M. (1994) Role of farmers in the evaluation of an improved variety: the case of S35 in northern Cameroon. *Journal for Farming System Research and Extension* 4(2), 93–110.

Ndjomaha, C., Yapi, A. and Adamri, A. (1998) Impact of sorghum S35 in extreme north Cameroon. In: Bantilan, M.C.S. and Joshi, P.K. (eds) *Assessing Joint Impacts: Proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT.* ICRISAT Patancheru, India, pp. 26–27.

Obilana, A.B. (1998) Sorghum improvement. *International Sorghum and Millet News Letter* 39, 4–17.

Obilana, A.B., Monyo, E.S. and Gupta, S.C. (1997) Impact of genetic improvement in sorghum and pearl millet: developing country experiences. In: *Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet*, 22–27 September 1996, Lubbock, Texas. INTSORMIL and ICRISAT, pp. 119–141.

Ogungbile *et al.* (1999) *Factors Influencing Awareness and Adoption of ICSV 111 and ICSV 400 Sorghum Varieties.* Socio-Economics and Policy Program, ICRISAT, Patancheru, India. Mimeo.

Rana, B.S., Swarnalata Kaul and Rao, M.H. (1997) Impact of genetic improvement on sorghum productivity in India. In: *Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet*, 22–27 September 1996, Lubbock, Texas. INTSORMIL and ICRISAT, pp. 141–165.

Reddy, B.V.S., Deb, U.K., Stenhouse, J.W. and Prakasha Rao (1998) Sorghum genetic enhancement research process at ICRISAT. In: Deb, U.K. and Bantilan, M.C.S. (eds) *Spillover Impacts of Sorghum Germplasm Research.* Socio-Economics and Policy Program, ICRISAT, Patancheru, India. Mimeo.

Rohrbach, D.D. and Makhwaje, E. (1999) *Adoption and Impact of New Sorghum Varieties in*

Botswana. PO Box 776, Bulawayo, Zimbabwe: Southern African Development Community (SADC)/ International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Sorghum and Millet Improvement Program (SMIP) (Semiformal publication).

Sanders, J.H., Bezuneh, T. and Schroeder, A.C. (1994) *Impact Assessment of the SAFGRAD Commodity Networks.* Mimeo.

Souza, E., Fox, P.N., Byerlee, D. and Skovmand, B. (1994) Spring wheat diversity in irrigated areas of two developing countries. *Crop Science* 34, 774–783.

Yapi, A., Kergna, A.O., Debrah, S.K., Sidibe, A. and Sango, O. (1998) Impact of sorghum research in Mali. In: Bantilan, M.C.S. and Joshi, P.K. (eds) *Assessing Joint Impacts: Proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT.* ICRISAT, Patancheru, India, pp. 76–93.

Yapi, A., Debrah, S.K., Dehala, G. and Njomaha, C. (1999) *Impact of Germplasm Research Spillovers: The Case of Sorghum Variety S35 in Cameroon and Chad.* Impact Series No. 3. ICRISAT, Patancheru, India.