Introduction

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AB Obilana and RE Evenson

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MCS Bantilan[1], UK Deb[2], CLL Gowda[1], BVS Reddy[1], AB Obilana[3] and RE Evenson[4]

1.1. The Crop

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop in the world, after wheat, maize, rice and barley. It is cultivated in wide geographic areas in the Americas, Africa, Asia and the Pacific. It is the second major crop (after maize) across all agroecologies in Africa. It is the third important cereal (after rice and wheat) in India. Sorghum was grown in 100 countries of the world in the year 2003, covering an area of approximately 44 million ha with grain production of 59 million t and average productivity of 1.34 t ha^{-1} (FAO website: http://www.fao.org). Sorghum occupies 24 m ha in Africa (mostly in Ethiopia, Mali, Nigeria and Sudan), 12 m ha in Asia (China, India, Myanmar, Pakistan, Saudi Arabia, Thailand and Yemen), 3.5 m ha in Central and South America (Argentina, Brazil, Colombia, Honduras, Mexico and Venezuela), 3.1 m ha in the USA and 0.5 m ha in Australia. Asia and Africa together contributed about 59% (34.5 million t) of the total world production in 2003. The crop is mainly grown in tropical and subtropical areas where agroclimatic conditions such as rainfall, soil and temperature are variable. Much of the crop is produced in the more marginal and stress-prone areas of the semi-arid tropics (SAT), mainly on smallholdings.

Sorghum is grown for a variety of uses. It is the staple food crop for millions of people in the SAT regions of Africa and Asia. Its grain is used as animal feed in Thailand, Australia, as well as the Americas, Japan and Europe. In Africa, the stalks are used as fuel, fencing and roofing material. The crop residue is often left *in situ* for livestock to browse upon. Sorghum is also grown for green forage. Varieties with sweet, juicy stems (sweet sorghum) are used to produce syrup. Sorghum grain is used to make bread, biscuits, starch, sugar, syrups, alcohol, beer and malt products. The industrial use of sorghum is, however, limited to Nigeria, South Africa and Zimbabwe. The demand for sorghum fodder and grain for feed purposes is increasing in Asia, particularly in India and China.

Sorghum is variously known in Africa: as *guinea-corn, dawa* or *sorgho* in West Africa, *durra* in the Sudan, *mshelia* in Ethiopia and Eritrea, *mtama* in East Africa, *kaffircorn* in South Africa and *mabele* or *amabele* in several countries in Southern Africa. In the Indian subcontinent, it is known as *jowar* (Hindi), *jonna* (Andhra Pradesh), *cholam* (Tamil Nadu) and *jola* (Karnataka). Sorghum was probably first domesticated in the savanna between Western Ethiopia and Eastern Chad 5000-7000 years ago (Doggett and Prasada Rao 1995). A complex of wild and weed races of *Sorghum bicolor* ssp. *verticilliflorum* is believed to be the progenitor of cultivated sorghum (Harlan 1972).

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1. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
2. Centre for Policy Dialogue, House 40/C, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.
3. International Crops Research Institute for the Semi-Arid Tropics, PO Box 39063, Nairobi, Kenya.
4. Yale University, New Haven, Connecticut, USA.

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Subjected to selection (both natural and human) and introgression with local wild and weedy types, primitive sorghum led to the evolution of cultivated races. From its place of origin sorghum spread – mostly through traders – to other areas: to India, China and Southeast Asia through the Middle East, and to the Americas through West, North and Southern Africa. It is now distributed from the sea level to 2200 m above sea level (asl) and from 50°N in Russia to 40°S in Argentina. While improved cultivars predominate in the Americas, China and Australia, traditional landraces are grown in large areas of Africa and some countries in Asia. Approximately 75% of the area under sorghum in India is now under improved varieties and hybrids, compared to 1% in the 1960s.

Five basic races of cultivated sorghum – *Bicolor, Kafir, Guinea, Caudatum* and *Durra* (Figure 1.1) – are recognized (Harlan and de Wet 1972). The *Bicolor* race is characterized by open inflorescences and long, clasping glumes that usually enclose the grain at maturity. It is widely distributed in Africa and Asia. *Kafir* is found south of the equator in Africa, and exhibits symmetrical and nearly spherical grains with glumes shorter than the grain. *Guinea* is predominant in West Africa and is easily recognized by long and obliquely twisted, gaping glumes revealing grains at maturity. Grains of the race *Caudatum* are asymmetrical with a turtleback, pointed beak and short glumes. This race is distributed throughout Central Africa and is of recent origin. *Durra* exhibits obovate grains which are wedge-shaped at the base but slightly broad above the middle. Natural intercrossing among these five basic races gave rise to ten intermediate or hybrid races, which are found in geographical areas overlapping the basic races and also at experimental stations. From the breeding point of view, *Kafir, Caudatum* and *Durra*, having genes contributing to yield, have been exploited in crop improvement programs across the globe.

Sorghum is a relatively less researched crop than other cereals such as wheat, maize, rice and barley. It is a C_4 plant with an excellent daily growth rate and biomass (>18-22 g m^{-2}). Sorghum is an often cross-pollinated crop with 5-25% cross pollination depending on the cultivar and climatic conditions (House 1985). Up to 50% cross-pollination has been reported in the literature (Doggett 1988). However, from the breeding point of view, sorghum is considered a self-pollinated crop which normally follows classical breeding procedures such as hybridization, mass selection, pedigree selection and backcrossing. Due to the high levels of cross-pollination, controlled selfing through bagging is necessary to maintain pure lines. The number of generations to be selfed depends on the extent of heterogeneity and diversity among parents, the breeding objective and resources available. Large-scale seed multiplication of pure lines is done under isolation – 300 m apart from other sorghum crops. In nature, landraces are normally homogeneous and homozygous with few heterozygous loci.

Encouraged by results from natural hybridization and selection, attempts at deliberate crossing were made, wherein it was found that crosses between divergent cultivars exhibited high levels of heterosis (Conner and Karper 1927). The discovery of cytoplasmic genetic male sterility by Stephens and Holland (1954) based on the *milo-kafir* system was a milestone in sorghum research. It is widely used in the commercial exploitation of heterosis. Today, more than 30% of the sorghum area is under hybrids, which have yields about twice that of any local cultivar. Non-*milo* sources of cytoplasmic male sterility have also been identified (Schertz and Pring 1982). However, their commercialization has been hindered by the nonavailability of sufficient stable restorer lines. As of now, their usage has been reported in forage breeding programs. The availability of several single, recessive male sterile genes (ms_3, ms_7) serving as a genetic male sterility system allows population improvement through recurrent selection procedures involving random mating and selection.

Figure 1.1. The five basic races of sorghum.

Acknowledging this variability, farmers have over the centuries used their indigenous knowledge in achieving selection, improvement and utilization (Doggett 1965). Plant breeding, which involves hybridization and selection following testing, got firmly established with the rediscovery of Mendel's genetic studies at the beginning of the 20^{th} century. However, sorghum breeding in Africa did not begin until after the beginning of World War II in the late 1930s.

1.2. Background of the Study

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been involved in genetic enhancement of sorghum since its establishment in 1972. Its fundamental approach has been to develop various breeding materials – varieties, hybrid parents (A/B/R lines), segregating populations, lines and improved sources of disease and insect resistance – to strengthen the breeding programs of the national agricultural research system (NARS) and the seed sector. With the ultimate aim of increasing sorghum production worldwide, ICRISAT has readily made available its germplasm to NARS of developing and developed countries. Since NARS evaluation and selection of materials has led to the incorporation of ICRISAT germplasm into varieties released and grown in farmers' fields, it is important to assess the value of the germplasm to NARS and the seed sector. A systematic documentation and analysis of the use of ICRISAT germplasm is therefore essential for understanding the role of its germplasm products in varietal development worldwide. The feedback is also needed for devising strategies to strengthen the capacity of NARS to exploit useful traits. Mechanisms to increase the efficiency of genetic enhancement research need to be explored through a better understanding of past activities and their impact on the development of new cultivars by ICRISAT and its partners in NARS programs. This will facilitate exploitation of the world germplasm base and help identify means of achieving greater utility.

1.3. Sorghum Research Domains and Research Thrust

ICRISAT's research in sorghum improvement during the last 32 years has been conducted by multidisciplinary teams of scientists located at its center at Patancheru (India), and at regional centers at Bamako (Mali) and Kano (Nigeria) in West Africa, at Nairobi (Kenya) in Eastern Africa, at Bulawayo (Zimbabwe) in Southern Africa and at El Batan (Mexico) in Latin America. Special programs have been conducted at Cali (Colombia), in collaboration with the Centro Internacional de Agricultura Tropical (CIAT) and the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). ICRISAT scientists are involved in global research on sorghum improvement in collaboration with NARS scientists and other international programs such as the International Sorghum/Millet Collaborative Research Support Program (INTSORMIL).

Sorghum research activities at different locations were conducted under the implicit assumption of eight research domains delineated as homogeneous ecoregions in terms of soil and climatic conditions regardless of national boundaries. Table 1.1 summarizes the characteristics of the sorghum research domains (SRDs) while Figure 1.2 shows the areas in different countries in Asia and Africa that fall under these domains. These domains were: wide adaptability (SRD I), dual purpose with specific adaptability (SRD II), dual purpose with fodder emphasis (SRD III), forage sorghum (SRD IV), early-sown postrainy sorghum (SRD V), late-sown postrainy sorghum (SRD VI), irrigated sorghum (SRD VII) and extreme altitude sorghum (SRD VIII). Table 1.2 presents the complete set of production systems identified by ICRISAT for sorghum and other mandate crops.

Table 1.1. Characteristics of sorghum research domains.

Domain	Production system characteristics	Major constraints	Locations
SRD I (Wide adaptability)	Rainy season, multipurpose grain, stalk, fodder (fodder emphasis) and wide adaptability (June-Aug sowing)	Grain mold, shoot fly, headbug	West Africa (southern tier), India (Tamil Nadu, southern Karnataka, Andhra Pradesh)
SRD II (Dual purpose, specific adaptability)	Rainy season, dual purpose (grain and fodder), specific adaptation (June sowing) and medium-to-late-maturing types	Stem borer, grain mold, midge, shoot fly, drought	East and Southern Africa, India (Andhra Pradesh, northern Karnataka, Maharashtra, Madhya Pradesh, Gujarat), Latin America (some areas)
SRD III (Dual-purpose, fodder emphasis)	Rainy season, dual purpose (fodder emphasis) and early maturing	Shoot fly, stem borer	West Africa (northern tier), East Africa (Yemen, Somalia), India (eastern Rajasthan), Latin America (some areas), China, Iran
SRD IV (Forage sorghum)	Rainy season, forage types (thin stalk, tillering) and late maturing	Stem borer, leaf diseases	India (northern Gangetic plain), Pakistan
SRD V (Early-sown postrainy)	Postrainy season, dual purpose (early: sown before Oct). Large grain types, dual purpose.	Shoot fly, stalk rot, headbugs	India (southern Andhra Pradesh, southern Karnataka)
SRD VI (Late-sown postrainy)	Postrainy season (late sown: mid/late Oct), large grain, photoperiod sensitivity required and temperature-insensitive		India (Gujarat, southern Maharashtra, northern Karnataka)
SRD VII (Irrigated)	Irrigated sorghum		Iran, Egypt, Wad Medani (Sudan)
SRD VIII (Extreme altitude)	Others		(i) High altitude: China; (ii) Low altitude: Indonesia, Brazil, Ecuador, Venezuela

Source: ICRISAT (1992).

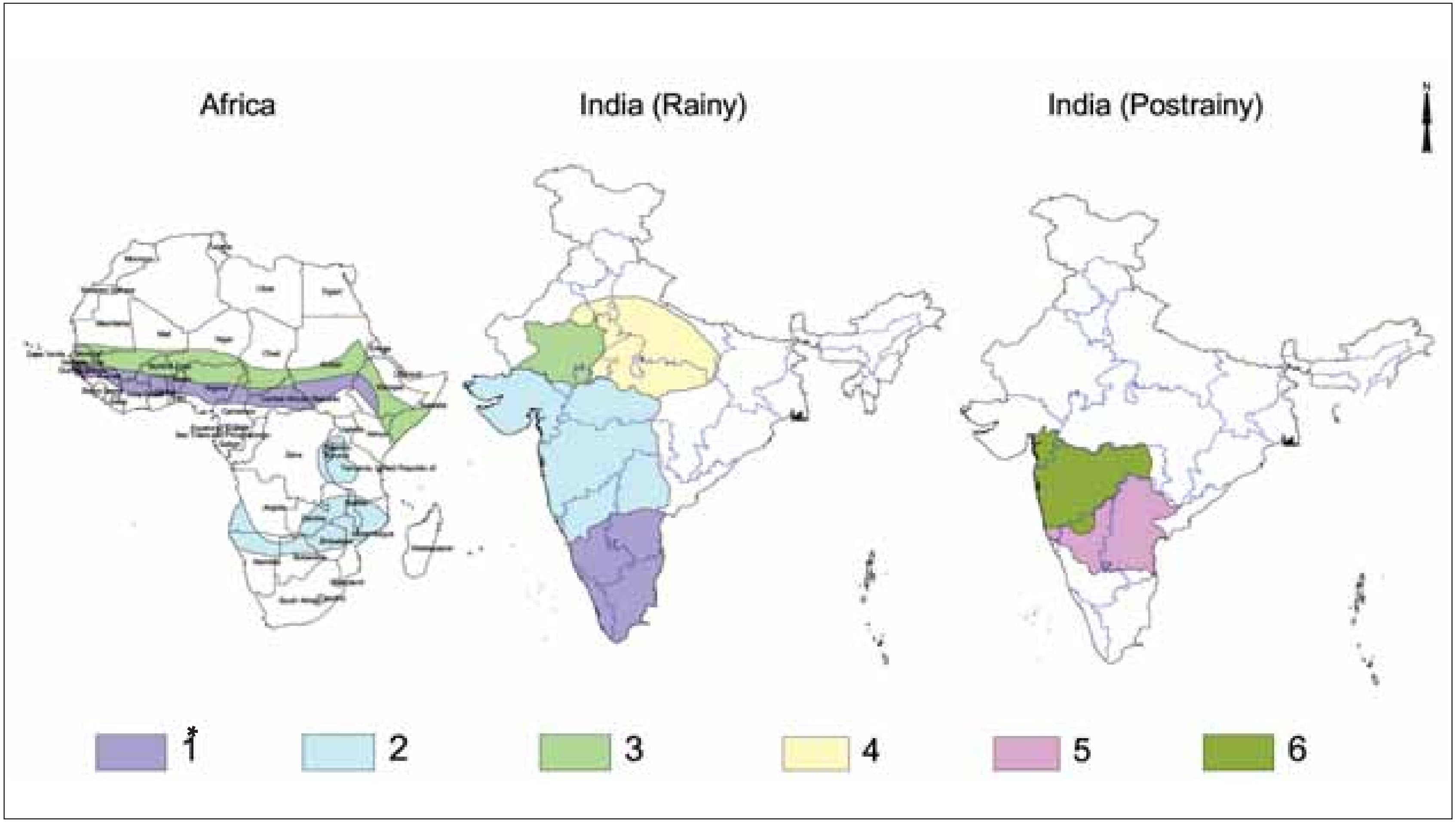

Figure 1.2. Sorghum research domains in Africa and India.

* For details of sorghum research domains, see Table 1.1.

Table 1.2. Production Systems identified by ICRISAT.

Production System (PS)	Description	Location
Asia		
PS1	Transition zone from arid rangeland to rainfed land, short-season millet/pulse/livestock	Eastern margins of Thar desert (India)
PS2	Subtropical lowland, rainy and postrainy season, rainfed, mixed cropping	Central/eastern Indo-Gangetic plain (India)
PS3	Subtropical lowland, rainy and postrainy season, irrigated, wheat-based cropping	Western Indo-Gangetic plain (India)
PS4	Tropical, high-rainfall rainy and postrainy season, rainfed, soybean/wheat/chickpea	Central India
PS5	Tropical lowland, rainfed/irrigated, rice-based cropping	Eastern India, Myanmar, Thailand, Southeast Asia
PS6	Tropical lowland, short rainy season, rainfed, groundnut/millet	Saurashtra peninsula (India)
PS7	Tropical, intermediate rainfall, rainy season, sorghum/cotton/pigeonpea	Eastern Deccan plateau (India), central Myanmar
PS8	Tropical, low rainfall, primarily rainfed, postrainy season, sorghum/oilseed	Western Deccan plateau (India)
PS9	Tropical, intermediate-length rainy season, sorghum/ oilseed/pigeonpea interspersed with locally irrigated rice	Peninsular India
PS10	Tropical upland, rainfed, rice based	Eastern India, Southeast Asia
PS11	Subtropical, major groundnut and sorghum	China
PS12	Subtropical, intermediate elevation, winter rainfall and rainfed, wheat based	West Asia and North Africa
West and Central Africa		
PS13	Transition zone from arid rangeland to rainfed, short-season (<100 days), millet/cowpea/livestock	Sahelian Western Africa and southern margins of the Sahara desert
PS14	Intermediate season (100-125 days), rainfed, millet/sorghum/cowpea/groundnut based	Northern Sudanian Zone
PS15	Intermediate season (125-150 days), rainfed, mixed, sorghum based	Southern Sudanian Zone
PS16	Long season (150-180 days), rainfed, mixed, maize based	Northern Guinean Zone
PS17	Humid, bimodal rainfall, mixed, root crop based	Southern Guinean and Forest Zones
PS18	Low-lying areas prone to inundation, postrainy season, sorghum/millet/groundnut based	Sahelian and Sudanian Zones
Southern and Eastern Africa		
PS19	Lowland, rainfed, short season (<100 days), sorghum/millet/rangeland	Sahelian Eastern Africa and margins of the Kalahari desert
PS20	Semi-arid, intermediate season (100-125 days), sorghum/maize/rangeland	Eastern Africa and parts of Southern Africa
PS21	Intermediate season (125-150 days), sorghum/maize/ finger millet/legumes	Eastern and Southern Africa
PS22	Lowland, subhumid, mixed, rice/maize/groundnut/ pigeonpea/sorghum	Coastal areas of Eastern and Southern Africa
PS23	Highland, rainfed, long season (150-180 days), sorghum/maize/teff	Highland zones of northeastern and Eastern Africa
PS24	Highland, semi-arid, rainfed, intermediate season (100-120 days), mixed maize/sorghum/wheat/barley/pastoral	Highland zones of Eastern and Southern Africa
Latin America		
PS25	Tropical, upland, rainfed, maize/sorghum intercropping	Central America and Hispaniola
PS26	Tropical, intermediate elevation, subtropical summer rainfall, rainfed and irrigated, sorghum	Mexico and Colombia, northern Argentina
PS27	Tropical and subtropical coastal plains, rainfed/irrigated	Mainly Pacific coast of Central America
PS28	Tropical, subhumid, rainfed, acid-soil savanna	Llanos of Colombia and Venezuela
PS29	Intermediate elevation, semi-arid, rainfed, acid soil	Northeastern and central Brazil

Source: ICRISAT (1992).

ICRISAT's sorghum breeding strategy evolved from 1972 onwards (Figure 1.3). There have been six phases in the evolution of sorghum enhancement research.

- 1972-75: breeding for wide adaptability and higher grain yield
- 1976-79: breeding for wide adaptability and screening techniques
- 1980-84: regional adaptation and resistance breeding
- 1985-89: specific adaptation and resistance breeding
- 1990-94: trait-based breeding and sustainable productivity
- 1995 onwards: intermediate products and upstream research.

The Institute had a massive screening program to identify germplasm with desirable traits. These efforts related to grain yield and agronomic desirability, resistance to biotic and abiotic stresses, conversion programs, populations for multiple resistance and sorghum varieties with special traits (high lysine content, sweet sorghums and forage sorghums). Recent research thrusts included the development of suitable materials for resistance and tolerance to abiotic (drought, low temperature, acidic soils) and biotic (*Striga*, diseases, insect pests) constraints, yield enhancement, yield stabilization and genetic diversification. Research has also been conducted on the genetics and mechanisms of resistance to diseases, insect pests and *Striga*; and the development of screening techniques and breeding concepts.

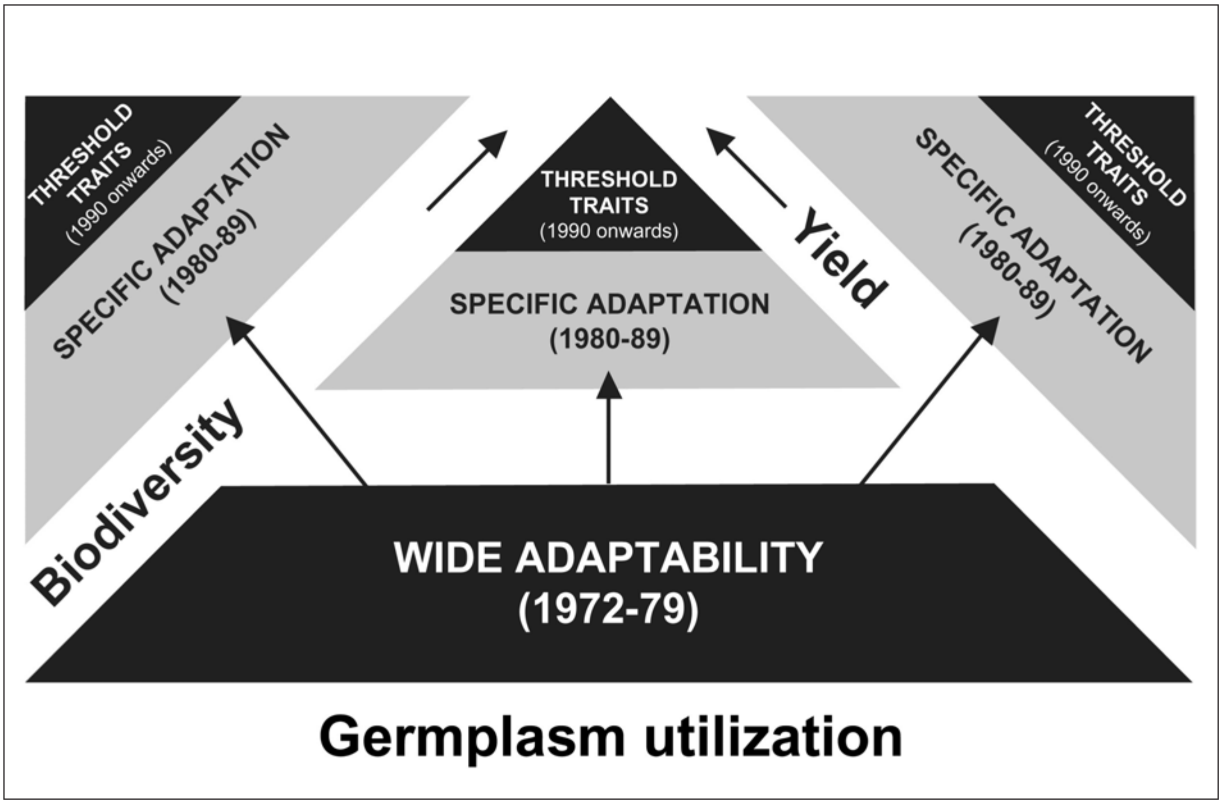

Figure 1.3. ICRISAT's sorghum breeding strategy from 1972 onwards.

1.4. Resources Involved in Sorghum Genetic Enhancement

1.4.1. Financial Resources

In 2001, the Consultative Group on International Agricultural Research (CGIAR) spent approximately US$ 5.3 million on sorghum research. This represents about 1.8% of CGIAR's total commodity investment. The INTSORMIL Central America Regional Program had a budget of $90 000 in 1999.

1.4.2. Human Resources

Tables 1.3 and 1.4 depict the level of scientific manpower engaged in sorghum improvement in developing countries. At ICRISAT, five sorghum breeders located in Asia and Africa are working with 15 other scientists (including agronomists, crop physiologists, genetic resources specialists, entomologists, pathologists and social scientists) on crop improvement. In India, about 150 scientists are working on sorghum in the public and private sectors. In China, this number is 200. However, in the African countries, except in Ethiopia, Egypt, Sudan and Kenya, the number of scientists working on sorghum is small – an average of one to five in each country. African scientists often work on more than one crop, say both sorghum and millet together. In other words, Asian NARS have devoted more resources to sorghum improvement than their African counterparts. They also tend to have better qualified scientists (measured in terms of the level of formal education).

1.5. Objectives of the Study

The broad objective of this study was to document ICRISAT's contribution to sorghum improvement and its impact on the global community. The specific objectives of the study were:

- To document the collection, conservation, use and distribution of sorghum germplasm
- To document the research process of sorghum genetic enhancement; identify the products and services delivered by ICRISAT and its contribution to improving the sorghum crop worldwide
- To document the research partnerships and technology exchange activities involving ICRISAT
- To quantify the impacts of sorghum genetic enhancement research on the efficiency of NARS breeding programs, crop productivity, genetic diversity and yield stability and on technology spillover.

1.6. Scope of the Book

The research reported in this book was completed through close collaboration among economists, breeders and genetic resource specialists. Plant protection scientists and agronomists too were consulted for their inputs. The study documents the flow of ICRISAT sorghum germplasm across regions and the genetic enhancement research process in partnership with NARS. It also documents ICRISAT's contribution to NARS breeding programs through human resource capacity building and supply of germplasm and parental materials. It assesses the impacts of ICRISAT-NARS genetic

Table 1.3. Number of scientists working on sorghum in different developing countries categorized by expertise.

Country	Latest year	Breeders	Agronomists	Seed technologists	Others[1]	Total
Asia						
China	1997	120	40	20	20	200
India	1998	NA[6]	NA	NA	NA	150
Iran	1997	2	2	1		5
Pakistan	1997	5	9			14
Thailand	1998	11	12	6	7	36
East and Central Africa[2]						
Burundi	1998	1		1	1	3
Eritrea	1998	1	4			5
Ethiopia	1998	15	15		20	50
Kenya	1998	3	8		7	18
Rwanda	1998	NA	NA	NA	NA	3
Sudan	1998	3	7		11	21
Uganda	1998	2	1		2	5
Southern Africa[3]						
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 (entomology)	3
Mozambique	1999	1	NA	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
West Africa[4]						
Burkina Faso	1991-92	2	3		3	8
Cameroon[5]	1991-92		1		3	4
Ghana[5]	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)[4]	1990-91	NA	NA	NA	NA	83
East Africa (Sorghum and Millet Network)[2]	1990-91	NA	NA	NA	NA	87

1. Scientists working in other disciplines that support varietal improvement, such as pathology, entomology and social sciences.
2. In East Africa, 70% of the researchers work on sorghum and millet as full-time researchers and 30% of them part-time. About 35% of the qualified scientists in this region are based in two countries.
3. For Southern African countries, the numbers indicate scientists working on both sorghum and millet.
4. In West and Central Africa, 38% are full-time researchers and 62% part-time. About 25% of the qualified researchers are based at lead NARS.
5. In both Cameroon and Ghana, one entomologist was working part-time on sorghum.
6. NA = Not available.

Source: For Asia, ICRISAT Impact Monitoring Survey, 1997.
For Africa, ICRISAT Impact Monitoring Survey 1998-2000.
For West Africa, Sanders et al. 1994.

Table 1.4. Number of scientists working on sorghum in different developing countries categorized by educational qualification.

Country	Latest year	B.Sc	M.Sc	Ph.D	Others[1]	Total
Asia						
China	1997	108	44	18	30	200
India	1998	NA[5]	NA	NA	NA	150
Iran	1997	2	3			5
Pakistan	1997		13	1		14
Thailand	1998	11	15	10		36
Eastern and Central Africa[2]						
Burundi	1998	1	2			3
Eritrea	1998	4	1			5
Ethiopia	1998	15	26	9		50
Kenya	1998	4	14			18
Rwanda	1998	3				3
Sudan	1998	1	4	16		21
Uganda	1998		3	2		5
Southern Africa[3]						
Angola	1999	NA	NA	NA	NA	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[4]						
Burkina Faso	1991-92	NA	NA	NA	NA	8
Cameroon	1991-92	NA	NA	NA	NA	4
Ghana	1991-92	NA	NA	NA	NA	4
Mali	1991-92	NA	NA	NA	NA	7
Niger	1991-92	NA	NA	NA	NA	6
Nigeria	1991-92	NA	NA	NA	NA	6
Northern Africa						
Egypt	1998	3	3	14	5	25
West and Central Africa (Sorghum Research Network, 18 countries)[4]	1990-91	33	27	23		83
East Africa (Sorghum and Millet Network, 8 countries)[2]	1990-91	29	31	27		87

1. Scientists working in other disciplines that support varietal improvement, such as pathology, entomology and social sciences.
2. In East Africa, 70% of the researchers work on sorghum and millet as full-time researchers and 30% of them part-time. About 35% of the qualified scientists in this region are based in two countries.
3. For Southern African countries, the numbers indicate scientists working on both sorghum and millet.
4. In West and Central Africa, 38% are full-time researchers on sorghum and 62% part-time. About 25% of the qualified researchers are based at lead NARS.
5. NA = Not available.

Source: For Asia, ICRISAT Impact Monitoring Survey, 1997.
For Africa, ICRISAT Impact Monitoring Survey, 1998-2000.
For West Africa, Sanders et al. 1994.

enhancement research on sorghum. Quantification of impacts was confined to direct estimation of benefits to farmers in terms of increase in yield, reduction in per unit cost of production, yield stability and diversity in sorghum cultivars. Though genetic enhancement research at ICRISAT has had other types of impacts, they were not included within the purview of research. For example, ICRISAT materials were extensively used in sorghum conversion programs in USA[5]. In 1998, out of 30 partially converted lines, 11 were from ICRISAT (Rosenow et al. 1998).

The book is presented in four parts – Part I: The crop and the book; Part II: Sorghum genetic enhancement process; Part III: Technologies, technology exchange and technology adoption; and Part IV: Impacts of improved cultivars and future directions. The book examines ICRISAT's contribution to sorghum improvement. Chapter 2 analyzes global sorghum production trends. It quantifies the changes in average output in the 1990s compared to the 1970s, and estimates the relative contribution of area and yield to those changes. In most of the countries, the area under sorghum has declined while the yield has increased.

Chapter 3 focuses on utilization and distribution of sorghum germplasm. It documents ICRISAT's germplasm collection missions and the number and types of materials collected in different countries. This is followed by an account of the germplasm material sent to different countries and the cultivars developed and released from them.

Chapter 4 chronicles ICRISAT's genetic enhancement research on sorghum in Asia, its outputs and contributions to public and private sector institutions.

Chapter 5 records the sorghum breeding research conducted in Africa, with details of trends in breeding strategies, methodologies, germplasm movement and use, achievements and impacts in West and Central Africa (WCA), East and Central Africa (ECA) and Southern Africa. Research-for-development targets, application of new tools to broaden the scientific horizons, regional breeding and market-oriented needs of sorghum are also discussed.

Chapter 6 documents the breeding strategy and outputs and proposes a network strategy for Latin America. It summarizes the implications, particularly for acid soil-tolerant sorghum cultivars.

Chapter 7 deals with research partnership and technology exchange and documents ICRISAT's partnership with the NARS, Advanced Research Institutes (ARIs), private sector organizations and Non-Governmental Organizations (NGOs).

Chapter 8 documents the adoption of improved cultivars in Asia, Africa and Latin America, and identifies the critical factors influencing the uptake process. It reports on farmers' perceptions on adoption constraints. The adoption level of improved cultivars was related to the existence of preferred traits in the new cultivars, the options (number of cultivars) and the availability of seeds and profitability of new cultivars.

Chapters 9, 10 and 11 present the various dimensions of the impacts of sorghum research. The productivity impacts of improved cultivars are analyzed in Chapter 9. Their impacts were measured in terms of increase in yields, reduction in per unit cost of production and increase in stability of sorghum yield. The impact of sorghum genetic enhancement research on genetic diversity and yield stability is dealt with in Chapter 10. The number of improved sorghum cultivars

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5. The Sorghum Conversion Program is a cooperative germplasm utilization project between the Texas Agricultural Experiment Station of the Texas A&M University System, and the United States Department of Agriculture of the Agriculture Research Service (USDA-ARS), Mayaguez, Puerto Rico. Its objective is to transform tall, late-maturing exotic sorghums into shorter, non-photoperiod sensitive, earlier-maturing types which can easily be utilized in the USA and other sorghum improvement programs. Maturity and height in sorghum are controlled largely by a few major genes. The Conversion Program utilizes backcrossing to transfer a few major desired height and maturity genes into converted genotypes.

and their rate of adoption in the countries studied have increased over time. Genetic diversity among improved sorghum cultivars has increased in India. This indicates that sorghum breeders in India are using different parental materials to develop new cultivars rather than relying on a few parental materials. The impact of sorghum genetic enhancement research on yield instability in different states of India during 1966/67-1980/81 and 1981/82-1993/94 reveals that yield instability fell during the latter period compared to the former. Chapter 11 deals with the spillover impacts of sorghum research. The nature, extent and determinants of sorghum technology spillover (potential and realized) from sorghum research are examined and quantified.

Future directions for partnership and a research strategy for sorghum with the goal of attaining food security and maintaining diversity in sorghum cultivation are described in the concluding chapter. It features a separate strategy for sorghum enhancement research at ICRISAT, suggested to meet the needs of NARS with varying capacities. New and innovative partnerships among all players (ICRISAT, ARIs, public and private sector NARS and NGOs) are recommended for enhancing the impacts in farmers' fields and increasing the efficiency and effectiveness of research for development.

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