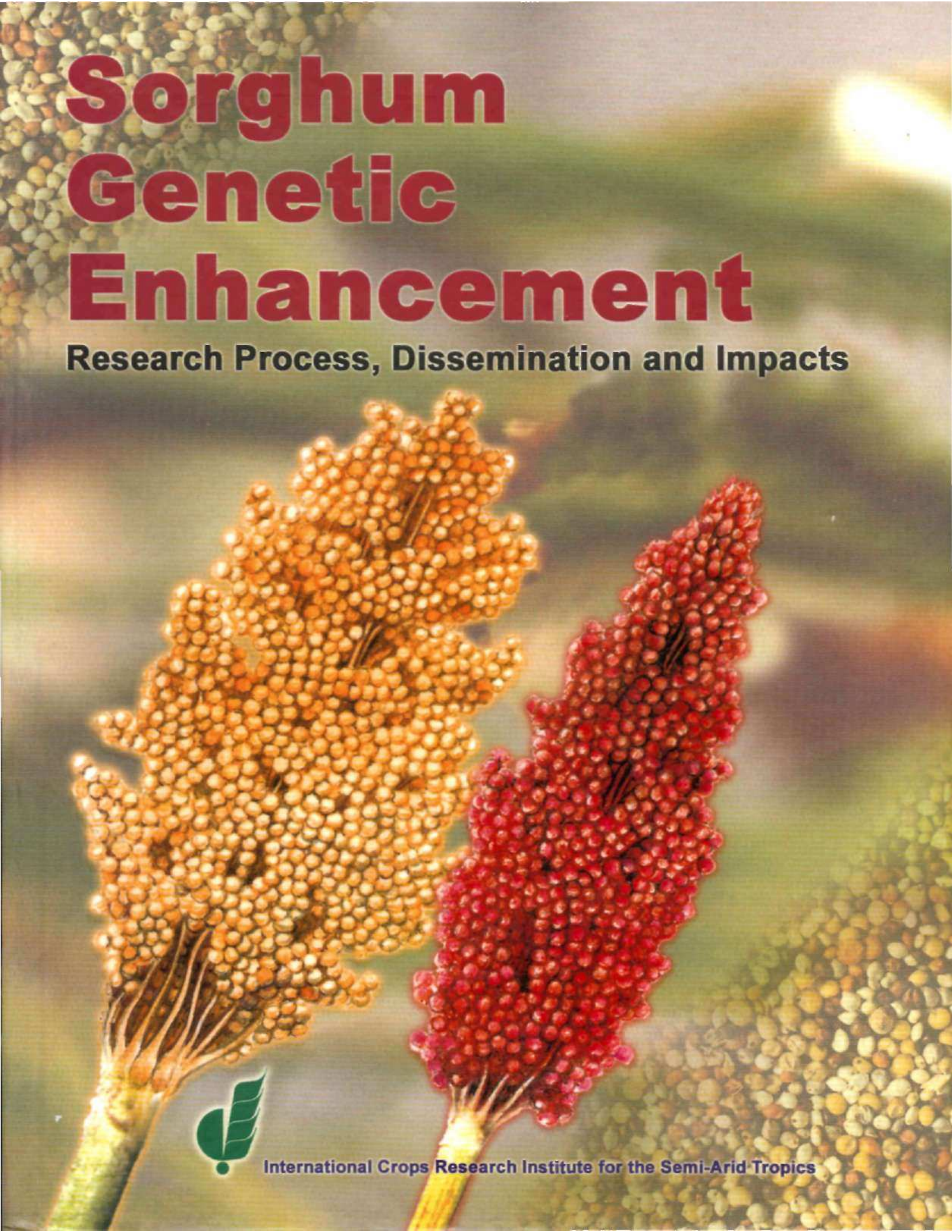
Sorghum Genetic Enhancement

Research Process, Dissemination and Impacts



International Crops Research Institute for the Semi-Arid Tropics

Citation: Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE. (eds.) 2004. Sorghum genetic enhancement: research process, dissemination and impacts. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 320 pp. ISBN 92-9066-470-3. Order code BOE 033.

Abstract

This volume covers 32 years of sorghum research across ICRISAT in partnership with NARS in Asia, Africa and Latin America and gives insights on the many facets of the research process, dissemination and impacts. The volume was completed through close collaboration among biological, natural and social scientists. The chapters document the flow of ICRISAT sorghum germplasm across regions and the genetic enhancement research process in partnership with NARS. It elaborates on ICRISAT's contribution to NARS breeding programs through capacity building and the supply of useful germplasm, breeding materials, hybrid parents and cultivars. It assesses the impacts of ICRISAT-NARS partnerships in genetic enhancement research on sorghum.

The contents include an introduction to the crop, trends in global sorghum production; conservation, utilization and distribution of sorghum germplasm; research-for-development targets; research processes and strategies in Asia, Africa and Latin America, its outputs and contributions to public and private sector institutions; applications of new tools, regional breeding and market-oriented needs of sorghum. 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' field, this book assessed the value of the germplasm to NARS and the seed sector. A systematic documentation and analysis of the use of ICRISAT germplasm is undertaken for understanding the role of its germplasm products in varietal development worldwide. Mechanisms to increase the efficiency of genetic enhancement research are explored through a better understanding of past activities and their impact on the development of new cultivars by ICRISAT and its partners. This facilitates exploitation of the world germplasm base and helps identify means of achieving greater utility.

Several chapters dealt with research partnerships and technology exchange, adoption of improved cultivars and lessons learned from adoption studies as well as critical factors influencing the uptake process. Important dimensions of the impacts of sorghum research are highlighted. Research benefits were measured in terms of increase in yields, reduction in per unit cost of production, increase in stability in sorghum yield and improved food security. The nature, extent and determinants of sorghum research spillover effects across continents and agro-ecological zones were also examined and quantified. The concluding chapter presents future directions for partnership and a research strategy for sorghum research-for-development, suggesting new and innovative partnerships among all players (ICRISAT, NARS, public- and private-seed sectors and NGOs). This book serves as a valuable resource and will be of significant interest to those working in plant breeding, crop science and agricultural economics.

Sorghum Genetic Enhancement: Research Process, Dissemination and Impacts

Edited by

MCS Bantilan, UK Deb, CLL Gowda, BVS Reddy, AB Obilana and RE Evenson

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India.
2004

Acknowledgment

This book was the product of many individuals. We especially thank all the authors and appreciate their generous contributions as well as their willingness to respond to our queries throughout the period during which the book was being prepared. In addition to the authors of the individual chapters, we acknowledge the many unnamed research assistants and support staff who meticulously collected and processed data. The GIS-based mapping and delineation of sorghum research domains would have been incomplete but for the efforts of FT Bantilan, Irshad Ahmed and Md. Moinuddin. We especially thank B Ramaiah, V Gopal Reddy, Prakasha Rao, B Bala Krishna Singh, AD Roy, M Lakshmi, GV Anupama, R Padmaja, S Archana, Kavitha Krishna, Srilaxmi, Vaijayanthi, Madhavi, Naresh, Pradeep, NVN Chari, TR Kapoor, H Padmini, VN Krishnan, K Muir, K Prabhakar, Lynnette Bwire and T David for their invaluable assistance. We also sincerely thank Smitha Sitaraman for editing and Ch Vengala Reddy for design assistance.

We gratefully acknowledge the cooperation and contributions of Yang Zhen, Wang Liangqun, BS Rana, Aziz Fouman Ajirlou, Daw Khin Mar Yee, Kanoktip Lertdprasertrat, Abdul Shakoor, Osman El Obeid Ibrahim, Osman El Nagouly, Clement Kamau, M Chisi, M Sadaan, LT Mpofu, Peter Setimela and I Akintayo in completing the Impact Monitoring Surveys in Asia and Africa. We also thank P Bramel, N Kameswara Rao, AB Obilana, D Rohrbach, M Mgonja, P Subrahmanyam, Joseph, Ranjit Bandopadhyay, RP Thakur, HC Sharma, Subash Chandra, FR Bidinger, Andy Hall and T Srinivas. Our interactions through the surveys and interviews certainly opened up channels of communications between biological and social scientists.

For the help rendered during the Rapid Appraisal survey in India, we thank KB Krishna Rao, Mohan Rao, Sudeep Rao and N Prabhakar Reddy, Mahyco Seeds, Viswananda Agency(Adilabad district); SB Atale, RS Wadhokar, Jilani, BD Bhole, RS Raut, WY Coawande, Dinesh Shah and Sudesh Shah, Mangal Das (Akola); RA Quereshi, Samreet, Thorat, R Chopra, Rabbani and Subhash M Katkar (Jalna); Purushottam Joshi, GD Kolhe, Probodh K Chauhan, VB Chaudhuri, WS Bhagwan and Rajesh Sharma (Aurangabad); DN Gaikwad, Basavraj Mastoli, BK Jejurker, NB Sheikh and DL Thambale (Pune); KV Sarvesh, CK Chowdappa, M Govind Raju, PK Mishra, JN Gupta, VK Jaiprakash and Hanumantha Reddy (Bangalore); and Basant Pratap Singh, SD Tiwari, SS Bhatnagar, AD Majumdar, RR Singh and MP State Seed Certification Agency (Bhopal).

We received valuable comments from peer reviewers: John Stenhouse, BL Agarwal, Fred Rattunde, SN Nigam, LJ Reddy, Tom Hash, P Parthasarathy Rao and James Ryan. The authors also wish to express their appreciation to ICRISAT, the UNDP, the US University linkage programme of the USAID and Yale University for supporting this initiative. We thank the Centre for Policy Dialogue (CPD) for allowing UK Deb to continue work on this book.

Finally, we sincerely thank Jun, Anamika, Susheela, Ramanamma, Moladi, Judy and our children for their unending support and understanding.

Editors

Acronyms

AICSIP	All India Coordinated Sorghum Improvement Project
ARIs	Advanced Research Institutes
ARSHAT	Asian Regional Sorghum Hybrids Adaptation Trial
ARSVAT	Asian Regional Sorghum Varietal Adaptation Trial
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIRAD	Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement
CLAIS	Comisi6n Latinoamericana de Investigadores en Sorgo
COD	Coefficient of Diversity
COP	Coefficient of Parentage
CORPOICA	Corporacion Colombiana de Investigation Agropecuaria
EACSSN	Eastern Africa Co-operative Sorghum Screening Nursery
ECA	East and Central Africa
EGBON	Early Generation Bold grain Observation Nursery
FAO	Food and Agriculture Organization of the United Nations
FCRI	Field Crops Research Institute
GAU	Gujarat Agricultural University
HCN	hydrocyanic acid
HYV	high-yielding variety
IARC	International Agricultural Research Center
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and Communication Technology
IDB	Inter-American Development Bank
IDMRS	ICRISAT Data Management and Retrieval System
IGFRI	Indian Grassland and Fodder Research Institute
IITA	International Institute of Tropical Agriculture
INTSORMIL	International Sorghum/Millet Collaborative Research Support Program
IPGRI	International Plant Genetic Resources Institute
IPR	Intellectual Property Rights
ISPYT	International Sorghum Preliminary Yield Trials
ISVHAT	International Sorghum Varieties and Hybrids Adaptation Trials
LASIP	Latin American Sorghum Improvement Program
MFR	multifactor resistant
MPKV	Mahatma Phule Krishi Vidyapeeth
MTA	Material Transfer Agreement
NARS	national agricultural research system
NBPGR	National Bureau of Plant Genetic Resources
NGOs	Nongovernmental Organizations

NPGS	National Plant Germplasm System
NRCS	National Research Centre for Sorghum
ORSTOM	Institut Francais de Recherche Scientifique Pour le Developpement en Cooperation
PEQIA	Post-Entry Quarantine Isolation Area
PS	Production System
PVB	Participatory Varietal Breeding
PVS	Participatory Varietal Selection
RAU	Rajasthan Agricultural University
RDBMS	Relational Database Management System
RFLP	Restriction Fragment Length Polymorphism
SADC	Southern African Development Community
SAT	Semi-Arid Tropics
SDLBON	Sorghum Durra Large grain Red B-line Observation Nursery
SEPON	Sorghum Elite Progeny Observation Nursery
SINGER	System-wide Information Network for Genetic Resources
SLBBON	Sorghum Leaf Blight B-lines Observation Nursery
SMIP	Sorghum and Millet Improvement Program
SRD	Sorghum Research Domains
SRGB	Regional Genebank
TNAU	Tamil Nadu Agricultural University
UAS	University of Agricultural Sciences
UNCED	United Nations Conference on the Environment and Diversity
USDA	United States Department of Agriculture
VASAT	Virtual Academy for the Semi-Arid Tropics
WAS HAT	West Africa Sorghum Hybrid Adaptation Trials
WASIP	West African Sorghum Improvement Program
WCA	West and Central Africa
WCASRN	West and Central Africa Sorghum Research Network
WTO	World Trade Organization

Contents

PART IV: Impacts of Improved Cultivars and Future Directions

Preface

International collaboration in agricultural research has had a productive past. Going back to the mid 1940s, the Rockefeller Foundation participated in crop improvement with the National program in Mexico. In 1957, it took part in the All India research program for the improvement of maize, later expanded to include sorghum, pearl millet, wheat and rice. Hybrids of maize, sorghum and pearl millet contributed to the establishment of public and private sector seed companies. Lessons were learned about traits, such as grain quality, crucial for farmer acceptance.

These successes were instrumental in anticipating how to expand international input into agricultural development on a multinational scale. In 1972, India's agricultural research base led to its identification as the location for the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) with a mandate for sorghum, pearl millet, chickpea, pigeonpea and later groundnut. A multidisciplinary staff was established and research began. The world collection of sorghum being maintained in Hyderabad by the All India Coordinated Sorghum Improvement Project came under ICRISAT management. Regional trials and nurseries were initiated and a training program was activated. In time, regional stations were established in western, eastern, and southern Africa, and in Mexico.

This book covers 32 years of sorghum research across ICRISAT and describes many facets of its activities. The countries where sorghum is grown, the manpower involved and changes in area, production and yield during this period are presented in considerable detail.

Improved cultivars must possess traits of importance to farmers, failing which they will have no impact in user communities. For example in India, pearly white grain is desired to produce an array of foods. However, in parts of Africa where birds are a severe problem, high tannin sorghum varieties are necessary. There has been an interest in high lysine grain originally from Ethiopia, or sweet grain commonly used as a snack.

The authors have identified the range of uses of sorghum and emphasized the importance of breeding for end use. That farmer-preferred traits vary with location and season and change over time suggests the need to respond to farmers' changing needs in a crop improvement endeavor. Given that availability of a diverse array of germplasm plays a significant factor in breeding for end use, ICRISAT's role in preservation, characterization and distribution of sorghum germplasm is described. There are indications that the use of diverse germplasm in India over the years has resulted in greater genetic diversity among released cultivars.

The effect of environment on the expression of genetic traits is emphasized, and makes for riveting reading, particularly for those involved with genetics, plant breeding and crop improvement. The importance of evaluation in different environments is stressed. Determining the contribution of cultivars that have been developed in one environment and moved to another is described lucidly. So is the significance of regional collaboration in research, development and evaluation, which contributes to joint research on traits of concern and their prioritization. Collaboration with the NARS takes the form of seed exchange, a two-way street where the NARS receive and contribute to regional trials and nurseries and to specific requests. Stress is laid on collaboration with private companies, providing them with useful breeding materials, hybrid parents and cultivars and encouraging them to contribute.The importance of increasing participation across agencies is stressed.

The book highlights the problem of seed availability, which contributes to the lack of impact of new cultivars, particularly in Africa. The role of both public and private sector seed agencies is recognized.

The authors have accumulated a wealth of information enabling them to describe in great detail the range of sorghum improvement activities ICRISAT has been involved in over the past 32 years. It is an excellent contribution demonstrating what can be achieved by an international center. For this, the authors deserve congratulations. This book presents numerous insights derived from extensive experience, providing a valuable resource for students and those involved with crop improvement.

Leland House

PART I: The Crop and the Book

Introduction

1

MCS Bantilan, UK Deb, CLL Gowda, BVS Reddy,
AB Obilana and RE Evenson

Introduction

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, *kaffircom* 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).

[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.

Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE. 2004. Introduction. Pages 5-18 *in* Sorghum genetic enhancement, research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

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.

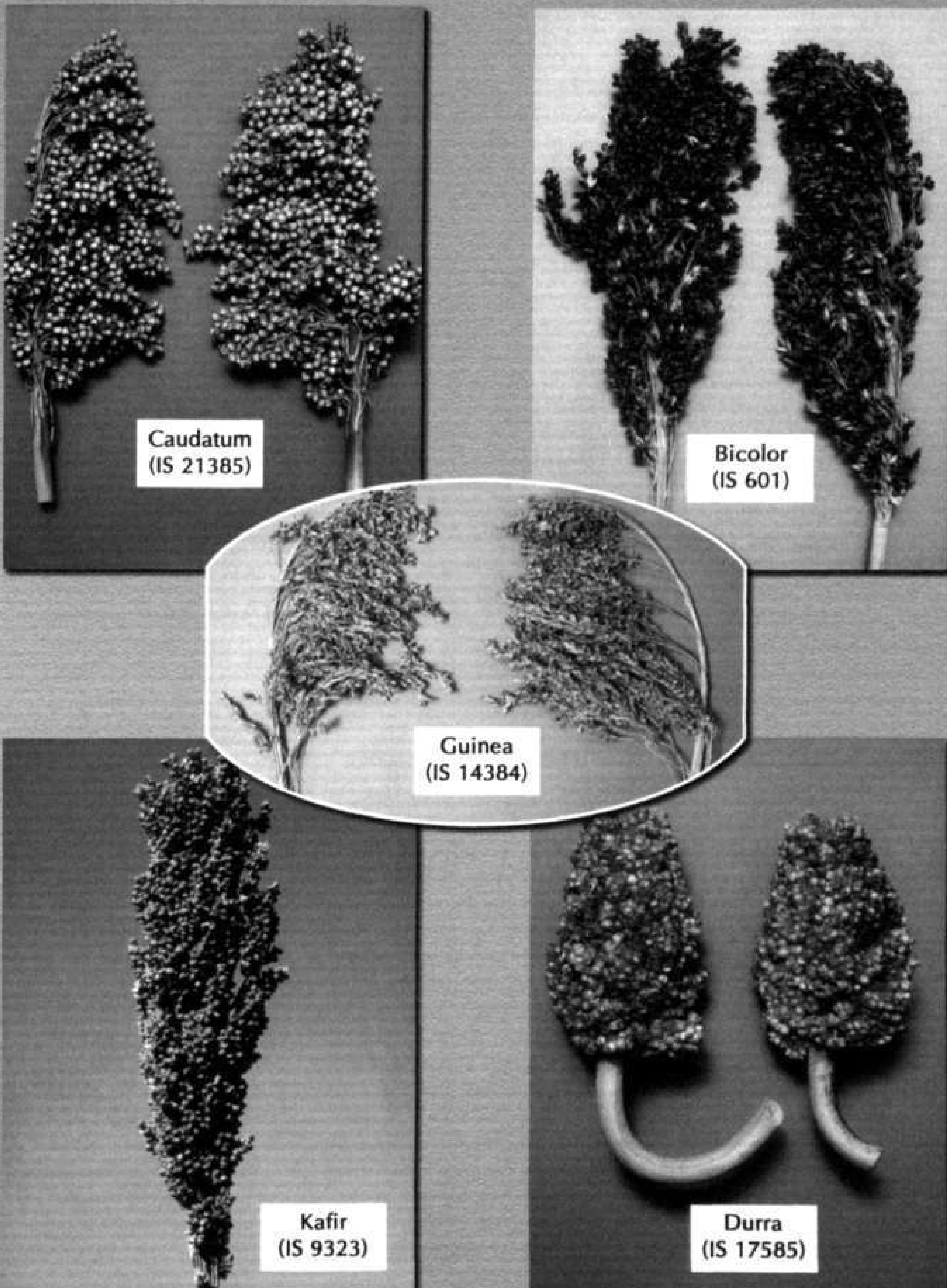


Figure 1.1. The five basic races of sorghum.

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 20th 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 (1982).

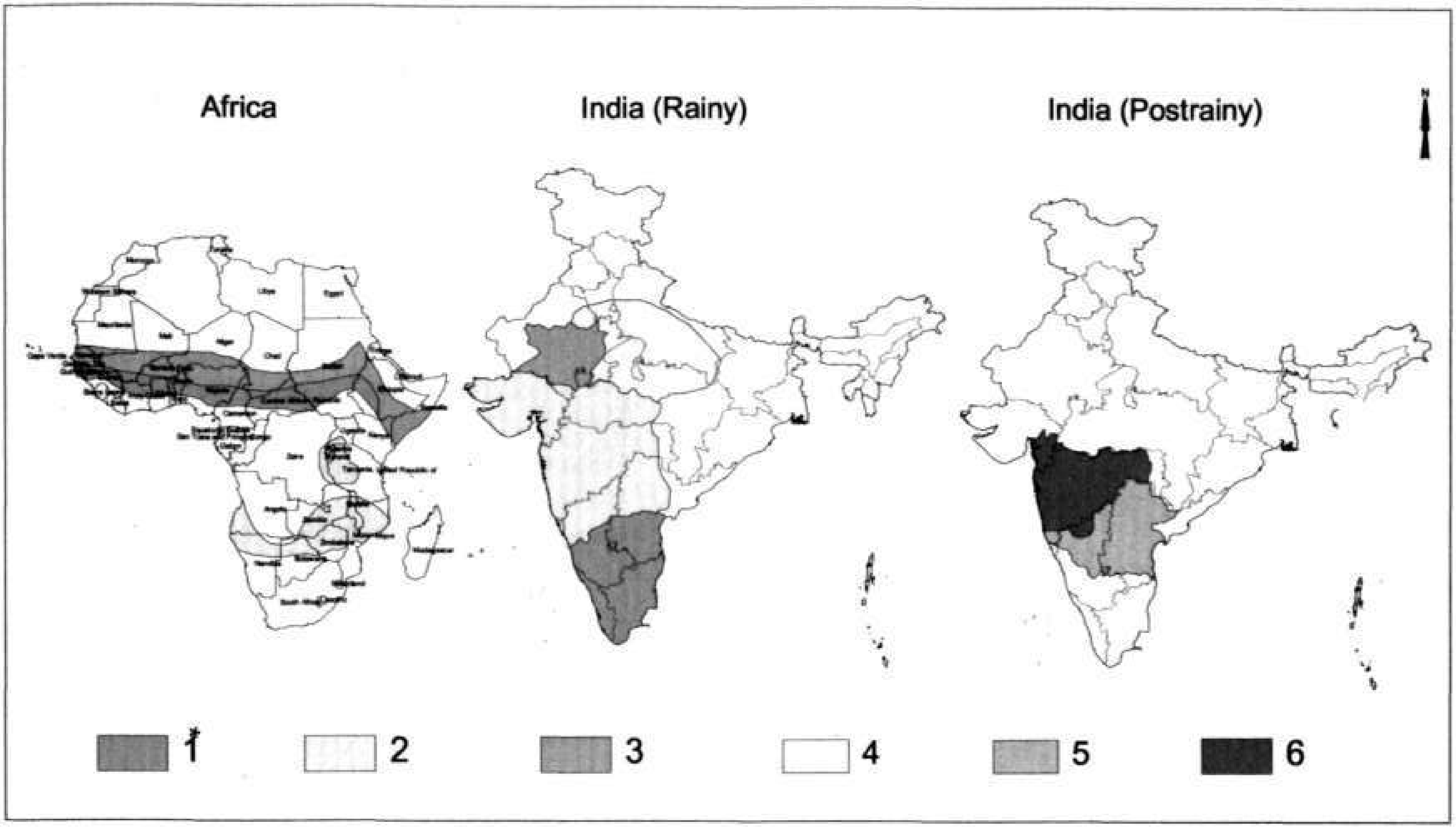


Figure 1.2. Sorghum research domains in Africa and India.

* 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.

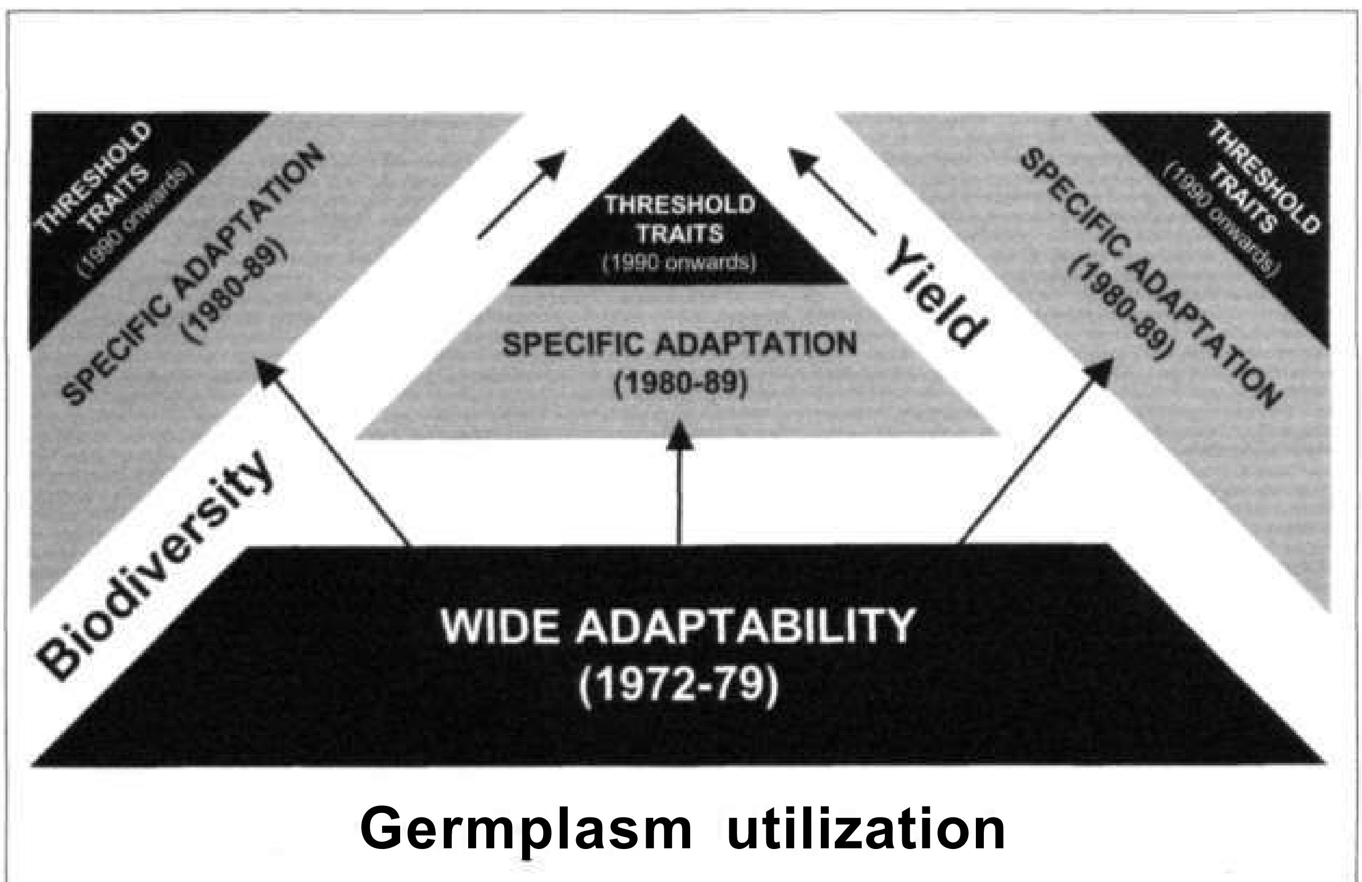


Figure 1.3. ICRISAT's *sorghum breeding strategy from 1972 onwards.*

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	**1986**	**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	**1996**	**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

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.

1.7. References

Conner AB and Karper RF. 1927. Hybrid vigour in sorghum. Texas Agricultural Experiment Station Bulletin No. 359. Texas, USA: Texas A&M University, College Station.

Doggett H. 1965. The development of cultivated sorghum. Pages 50-69 *in* Essays on crop plant evolutions (Hutchinson JB, et al., eds.). London, UK: Cambridge University Press.

Doggett H. 1988. Sorghum. Second edition. UK: Tropical Agricultural Series, Longman Scientific and Technical Publishers; and Ottawa, Canada: International Development Research Centre. 512 pp.

Doggett H and Prasada Rao KE. 1995. Sorghum. Pages 173-180 *in* Evolution of crop plants (Smartt J and Simmonds NW, eds.). UK: Longman, Harlow.

Harlan JR. 1972. Genetic resources in sorghum. Pages 1-13 *in* Sorghum in the seventies: proceedings of the International Symposium on Sorghum, 27-30 Oct (Ganga Prasad Rao N and House LR, eds.). New Delhi, India: Oxford and IBM.

Harlan JR and de Wet JMJ. 1972. A simplified classification of cultivated sorghum. Crop Science 12:172.

House LR. 1985. A guide to sorghum breeding. Vol. II. Patancheru, A.P., 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 206 pp.

ICRISAT 1992. ICRISAT Medium-term plan 1994-1998. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Rosenow DT, Dahlberg J A, Peterson GC, Clark LE, Hamburger AJ, Madera-Torres P and Woodfin CA. 1998. Release of 30 partially converted sorghum lines. International Sorghum and Millets Newsletter 39:82-84.

Sanders JH, Bezuneh T and Schroeder A C. 1994. Impact assessment of the SAFGRAD commodity networks. Mimeo.

Stephens JC and Holland RF. 1954. Cytoplasmic male sterility for hybrid sorghum production. Agronomy Journal 46:20-23.

Schertz KF and Pring DR. 1982. Cytoplasmic sterility systems in sorghum. Pages 373-383 *in* Sorghum in the eighties: proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT, India. Patancheru, A P 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Global Sorghum Production Scenario

2

UK Deb, MCS Bantilan, AD Roy and P Parthasarathy Rao

Global Sorghum Production Scenario

UK Deb[1], MCS Bantilan[2], AD Roy[3] and P Parthasarathy Rao[2]

2.1. Introduction

Sorghum is an important cereal crop which is grown globally for food and feed purposes. It is most widely grown in the semi-arid tropics where water availability is limited and frequently subjected to drought. About 100 countries grow sorghum, of which 66 cultivate it over more than 1000 ha or produce more than 1000 t. India has the largest sorghum area with 10.06 million ha (Table 2.1). The second largest sorghum cultivating country is Nigeria, followed by Sudan, USA and Niger. More than 90% of the world's sorghum area lies in the developing countries, mainly in Africa and Asia. In terms of annual production, USA tops the list with 13.38 million t during 1999-2001, followed by India (8.23 million t), Nigeria (7.65 million t), Mexico (6.09 million t) and Argentina (3.16 million t). However, none of these countries recorded the highest global yields. The highest sorghum yields during 1999-2001 were recorded by Israel (12 664 kg ha^{-1}), followed by Jordan (11 711 kg ha^{-1}), Italy (6458 kg ha^{-1}), Algeria (6400 kg ha^{-1}) and France (6094 kg ha^{-1}). Thus while Asian and African countries like India and Nigeria had the largest area devoted to sorghum cultivation, those in West Asia (like Israel and Jordan) and Europe (Italy and France) reaped the highest yields. It may be noted that Israel and Jordan are not major sorghum-growing countries. The average area under the crop during 1999-2001 was 1006 ha and production 13 400 t in Israel, and 30 ha and 300 t in Jordan. This chapter presents the global sorghum production situation and trends. It updates the trends and outlook given in FAO and ICRISAT (1996). It also analyzes changes in sorghum production and sources of changes during the last three decades.

2.2. Spatial Distribution of Sorghum

Sorghum cultivation is distributed throughout the world (Figures 2.1 and 2.2). 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, Eritrea, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Somalia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. In West and Central Africa, the crop is grown in Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Egypt, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Mali, Mauritania, Morocco, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Sudan, Togo, Tunisia and Uganda. 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.

[1] Centre for Policy Dialogue, House 40/C, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.
[2] International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
[3] Formerly of the International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Deb UK, Bantilan MCS, Roy AD and Parthasarathy Rao P. 2004. Global sorghum production scenario. Pages 21-38 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Table 2.1. Area, production and yield of sorghum in different sorghum-producing countries, 1999-2001.

				Global rank based on		
Country	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})	Area	Production	Yield
India	10 055.7	8231.7		1	2	72
Nigeria	6816.0	7647.3	1122.0	2	3	54
Sudan	4306.5	2441.0	566.8	3	7	89
USA	3352.7	13 379.8	3990.7	4	1	12
Niger	2286.2	500.9	219.1	5	16	98
Mexico	1992.4	6092.0	3057.6	6	4	19
Burkina Faso	1301.9	1130.6	868.4	7	10	68
Ethiopia	1189.8	1377.6	1157.9	8	9	53
China	941.5	2947.7	3130.9	9	6	16
Chad	879.4	529.6	602.2	10	15	85
Mali	718.5	649.5	903.8	11	14	67
Argentina	690.5	3159.1	4575.3	12	5	8
Tanzania	638.9	653.6	1023.0	13	13	57
Australia	601.8	1810.0	3007.8	14	8	20
Brazil	452.8	742.9	1640.4	15	12	38
Yemen	362.3	383.1	1057.5	16	19	56
Mozambique	360.8	297.5	824.6	17	22	71
Pakistan	353.7	224.6	635.2	18	25	83
Cameroon	317.4	380.7	1199.5	19	20	52
Ghana	296.4	287.2	969.1	20	24	61
Uganda	279.0	399.0	1430.1	21	18	42
Somalia	270.0	87.3	323.5	22	42	96
Senegal	186.9	145.0	775.3	23	33	75
Mauritania	183.3	90.1	491.2	24	41	91
Venezuela	181.5	457.7	2522.0	25	17	24
Togo	180.1	150.5	835.2	26	30	70
Eritrea	179.0	117.0	653.9	27	36	80
Benin	170.7	138.2	809.7	28	34	73
Zimbabwe	166.8	97.4	584.0	29	38	88
Egypt	162.7	945.1	5810.3	30	11	6
Rwanda	155.8	145.9	936.3	31	31	63
Saudi Arabia	155.4	204.0	1312.7	32	28	46
Kenya	136.7	125.3	917.1	33	35	66
Haiti	132.7	92.7	698.5	34	40	78
South Africa	110.5	293.6	2657.8	35	23	23
El Salvador	99.3	145.8	1468.6	36	32	40
Botswana	90.3	11.9	131.5	37	63	99
Thailand	87.7	163.3	1862.4	38	29	35
Congo	77.0	50.0	649.4	39	48	81
Honduras	72.3	70.2	971.6	40	45	60
Colombia	66.2	212.2	3203.0	41	27	15
France	59.8	364.2	6094.3	42	21	5
Malawi	56.4	38.7	686.2	43	52	79
Ivory Coast	53.3	28.2	529.4	44	54	90
Bolivia	51.8	115.7	2233.8	45	37	29
Burundi	51.7	63.3	1226.1	46	46	49
USSR (former)	47.3	86.8	1834.4	47	44	36
Nicaragua	45.5	87.3	1918.8	48	43	33
Lesotho	45.1	41.6	920.8	49	51	65
Guatemala	42.3	51.0	1205.4	50	47	51

...continued

Table 2.1. *Continued*

Country	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})	Global rank based on		
				Area	Production	Yield
Zambia	37.0	26.4	713.1	51	55	77
Central African Republic	35.0	47.6	1361.0	52	49	44
Italy	33.5	216.6	6457.8	53	26	3
Uruguay	26.8	95.0	3539.1	54	39	13
Paraguay	22.9	30.5	1331.5	55	53	45
Morocco	21.3	12.8	602.0	56	61	86
Namibia	20.7	7.0	338.7	57	70	94
Gambia	19.6	24.0	1221.9	58	56	50
Guinea-Bissau	16.1	13.7	850.4	59	59	69
Albania	15.7	14.6	930.1	60	58	64
Ukraine	11.7	12.7	1085.7	61	62	55
Sierra Leone	11.6	11.1	958.1	62	64	62
Korea DPR	10.0	10.0	1000.0	63	65	58
Spain	8.5	44.1	5164.1	64	50	7
Guinea	7.0	5.1	730.4	65	72	76
Uzbekistan	6.0	18.5	3083.3	66	57	18
Ecuador	5.5	8.2	1479.0	67	69	39
Hungary	4.5	9.1	2010.6	68	66	30
Dominican Republic	4.2	8.4	1995.8	69	68	32
Syria	3.7	2.3	630.5	70	77	84
Tunisia	3.0	1.0	333.3	71	80	95
Iraq	2.6	0.7	265.8	72	84	97
Panama	2.6	6.5	2493.5	73	71	26
Romania	2.2	3.2	1441.3	74	74	41
Yugoslavia, Fed. Republic of	2.2	9.1	4102.7	75	67	11
Madagascar	2.0	0.9	466.7	76	83	92
Korea, Republic of	1.5	2.9	1888.4	77	76	34
Papua New Guinea	1.1	3.4	3121.2	78	73	17
Israel	1.1	13.4	12 663.5	79	60	1
Lebanon	1.0	1.7	1666.7	80	79	37
Cuba	1.0	1.0	1000.0	81	81	59
Greece	1.0	2.0	2000.0	82	78	31
Swaziland	1.0	0.6	600.0	83	85	87
Oman	0.9	2.9	2983.1	84	75	22
Tajikistan	0.6	0.4	635.3	85	88	82
Bangladesh	0.4	1.0	2489.6	86	82	27
Moldova	0.2	0.2	1267.3	87	92	48
Sri Lanka	0.2	0.1	800.0	88	93	74
Croatia	0.1	0.5	4115.4	89	86	10
Peru	0.1	0.3	3268.9	90	90	14
New Caledonia	0.1	0.1	1366.7	91	95	43
Algeria	0.1	0.4	6400.0	92	87	4
Kazakhstan	0.1	0.2	4392.6	93	91	9
Macedonia	0.1	0.1	1300.0	94	96	47
Azerbaijan	0.1	0.0	104.2	95	100	100
Slovakia	negligible	0.1	2310.1	96	94	28
Kyrgyzstan	negligible	0.0	433.6	97	98	93
Jordan	negligible	0.3	11 710.5	98	89	2
Fiji	negligible	0.0	3000.0	99	97	21
Micronesia, Fed. States of	negligible	0.0	2500.0	100	99	25
World	41 859.3	58 556.5	1398.9			

Source: FAO website (www.fao.org).

2.3. Trends in Area, Production and Yield

The area under sorghum in countries across the world has recorded a mixed trend over the last three decades (Table 2.2). Trends in sorghum area in Africa are presented in Figure 2.3, where sorghum area is consistently increasing in Eastern and Western Africa and remains the most important cereal in these regions (Bantilan 2003). Area declined in many major sorghum-growing countries like Argentina, Australia, Burkina Faso, China, India, Mali, Mexico, Pakistan, Somalia, South Africa, USA, Yemen and Zimbabwe. However, some important sorghum-growing countries like Brazil, Burundi, Chad, Mauritania, Mozambique, Senegal, Sudan and Tanzania experienced notable increases in area at the end of the 20th century compared to the early 1970s, and this increase has been consistent over the last three decades. Though Nigeria experienced a decline in area under sorghum in the early 1980s, it increased in the early 1990s and, at the end of the 20th century, was 42% higher than in the early 1970s.

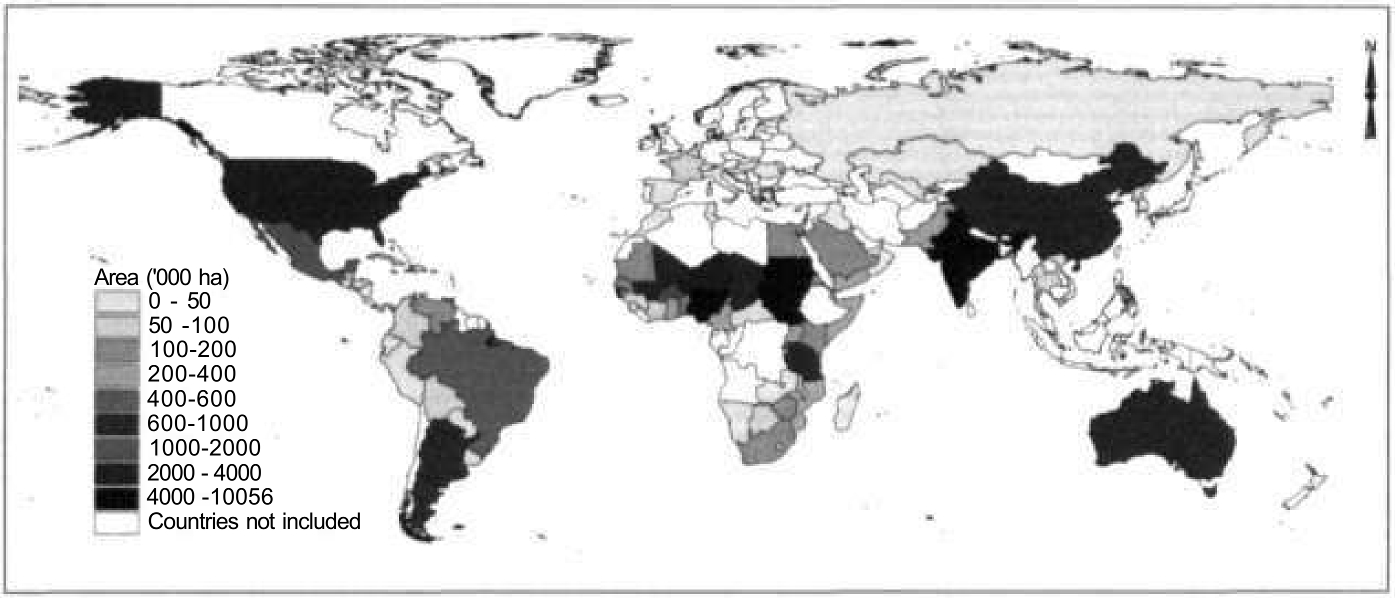


Figure 2.1. Distribution of sorghum area, 1999-2001.

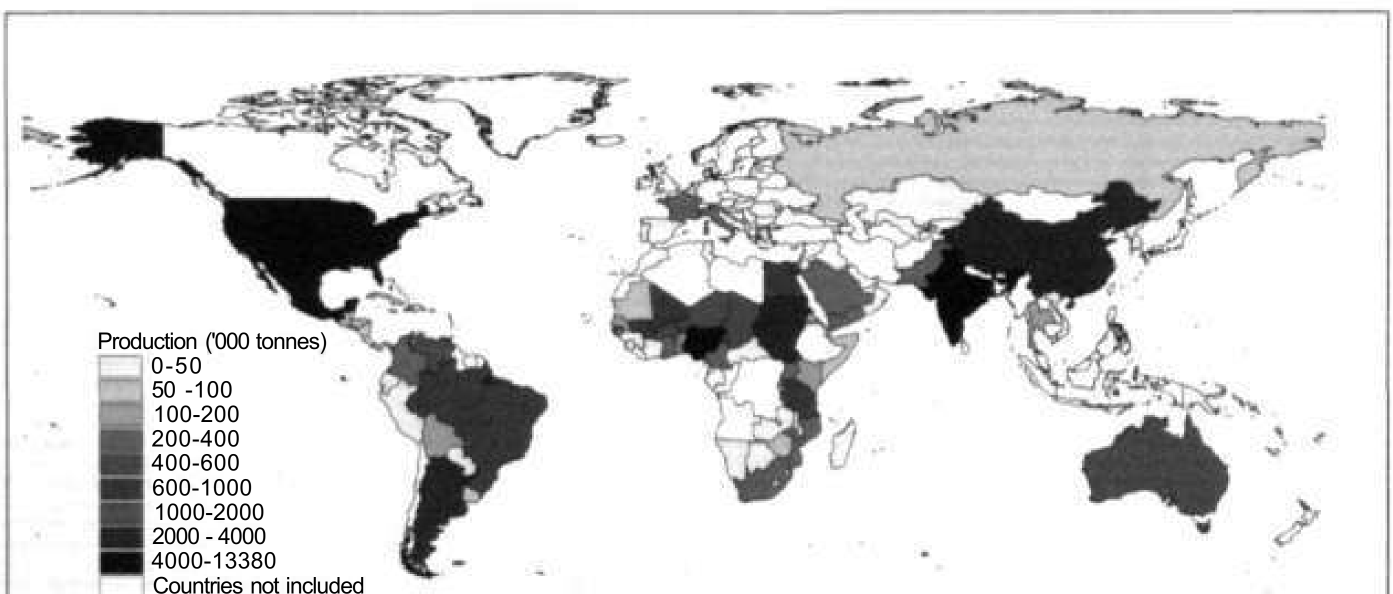


Figure 2.2. Distribution of sorghum production, 1999-2001.

Table 2.2. Area, production and yield of sorghum in different countries, 1971-2001.

	Average area ('000 ha)				Average production ('000 t)				Yield (kg ha^{-1})			
Country	1971-73	1981-83	1991-93	1999-2001	1971-73	1981-83	1991-93	1999-2001	1971-73	1981-83	1991-93	1999-2001
Albania	20	26	11	16	20	32	11	15	994	1232	992	930
Argentina	2074	2411	721	690	4140	7935	2626	3159	1953	3306	3635	4585
Australia	629	671	460	602	1181	1160	915	1810	1912	1738	1931	3003
Benin	90	98	143	171	59	58	110	138	653	594	773	810
Botswana	97	65	80	90	50	12	29	12	557	160	341	137
Brazil	50	117	159	453	85	224	274	743	2231	1953	1739	1639
Burkina Faso	1038	1073	1417	1302	489	626	1280	1131	471	583	903	867
Burundi	21	53	58	52	20	53	66	63	951	1000	1138	1225
Cameroon	343	404	510	317	243	266	390	381	710	659	765	1191
Central African Republic	47	54	27	35	38	43	24	48	809	820	903	1361
Chad	486	273	516	879	259	166	326	530	531	624	632	611
China	5072	2704	1368	941	8680	7343	5151	2948	1711	2716	3765	3124
Colombia	104	265	235	66	243	565	708	212	2394	2147	3025	3207
Ivory Coast	31	34	48	53	15	18	29	28	495	539	597	528
Cuba	2	1	1	1	2	1	1	1	1000	1000	1000	1000
Dominican Republic	4	9	7	4	16	26	16	8	3717	2913	2367	2107
Egypt	205	166	144	163	846	623	740	945	4120	3747	5149	5811
El Salvador	125	115	135	99	153	128	194	146	1224	1111	1430	1475
Eritrea	85	88	87	179	75	79	77	117	882	898	855	610
France	68	59	85	60	258	276	489	364	3857	4642	5725	6109
Gambia	7	7	11	20	7	7	11	24	1000	1056	990	1213
Ghana	218	211	293	296	164	91	276	287	753	438	939	969
Greece	5	1	1	1	7	2	2	2	1433	1333	2333	2000
Guatemala	41	40	67	42	41	82	80	51	1033	2097	1188	1205
Guinea	20	20	13	7	25	24	12	5	1250	1180	843	730
Guinea-Bissau	6	35	13	16	4	23	13	14	638	658	950	851
Haiti	198	157	120	133	187	114	97	93	936	730	807	698
Honduras	43	56	73	72	46	54	77	70	1098	963	1063	980
Hungary	1	6	14	5	3	20	33	9	2000	3272	2299	2006
India	16 335	16 469	12 574	10 056	7929	11 578	10 588	8232	485	703	839	819
Iraq	6	5	2	3	7	6	1	1	1063	1083	667	265
Italy	3	21	32	34	10	105	185	217	3667	5017	5772	6460
Kenya	204	97	146	137	227	62	114	125	1111	685	822	915
Korea, DPR	23	12	10	10	27	18	11	10	1157	1432	1133	1000

...continued

Table 2.2. *Continued*

Country	Average area ('000 ha)				Average production ('000 t)				Yield (kg ha^{-1})			
	1971-73	1981-83	1991-93	1999-2001	1971-73	1981-83	1991-93	1999-2001	1971-73	1981-83	1991-93	1999-2001
Korea, Republic of	8	3	1	2	6	4	1	3	738	1194	1000	2100
Lesotho	77	52	32	45	56	35	26	42	726	667	773	949
Madagascar	4	3	2	2	2	1	1	1	533	444	500	467
Malawi	120	28	34	56	96	16	15	39	797	546	419	686
Mali	373	534	875	719	284	452	716	649	765	848	833	902
Mauritania	171	111	128	183	35	31	67	90	203	272	513	489
Mexico	1077	1520	1305	1992	2799	5286	4582	6092	2601	3485	3513	3056
Morocco	68	35	31	21	77	22	18	13	1105	606	589	597
Mozambique	250	333	402	361	209	197	121	298	836	594	305	875
Namibia	10	15	14	21	5	7	6	7	467	444	398	333
Nicaragua	45	47	51	45	45	92	88	87	1010	1971	1724	1911
Niger	531	1075	2315	2286	200	345	424	501	370	322	185	217
Nigeria	4792	2216	4535	6816	3072	3589	4832	7647	637	1620	1064	1122
Pakistan	532	391	384	354	331	223	225	225	620	570	586	635
Paraguay	5	8	14	23	6	10	19	30	1200	1241	1349	1342
Romania	2	16	6	2	3	20	6	3	2000	1276	1042	1449
Rwanda	130	179	143	156	142	199	156	146	1092	1113	1085	930
Saudi Arabia	160	109	137	155	68	66	152	204	439	653	1097	1313
Senegal	122	113	119	187	88	123	98	145	716	1040	820	793
Sierra Leone	5	9	37	12	6	13	22	11	1200	1468	586	1123
Somalia	380	464	310	270	133	192	106	87	349	407	336	321
South Africa	305	183	196	110	428	337	292	294	1357	1827	1371	2544
Spain	43	27	11	9	172	112	58	44	3993	4138	5106	5173
Sudan	1974	3682	5345	4307	1527	2300	3323	2441	775	619	616	568
Tanzania	338	500	642	639	172	493	619	654	509	1134	965	1027
Thailand	70	251	171	88	129	279	236	163	1872	1111	1388	1857
Tunisia	14	14	5	3	8	5	2	1	607	325	311	333
USA	6077	5101	4160	3353	21 951	18 614	16 839	13 380	3625	3596	4001	3986
Uganda	304	192	250	279	385	332	374	399	1269	1733	1495	1430
Uruguay	70	62	45	27	118	143	134	95	1561	2253	3020	3105
Venezuela	4	215	220	182	6	363	498	458	1300	1692	2276	2522
Yemen	866	575	424	362	626	460	393	383	722	808	915	1057
Zambia	74	20	40	37	47	14	23	26	629	689	575	713
Zimbabwe	220	235	112	167	112	81	62	97	487	367	531	583

Source: Three-year average of data based on FAO website (www.fao.org).

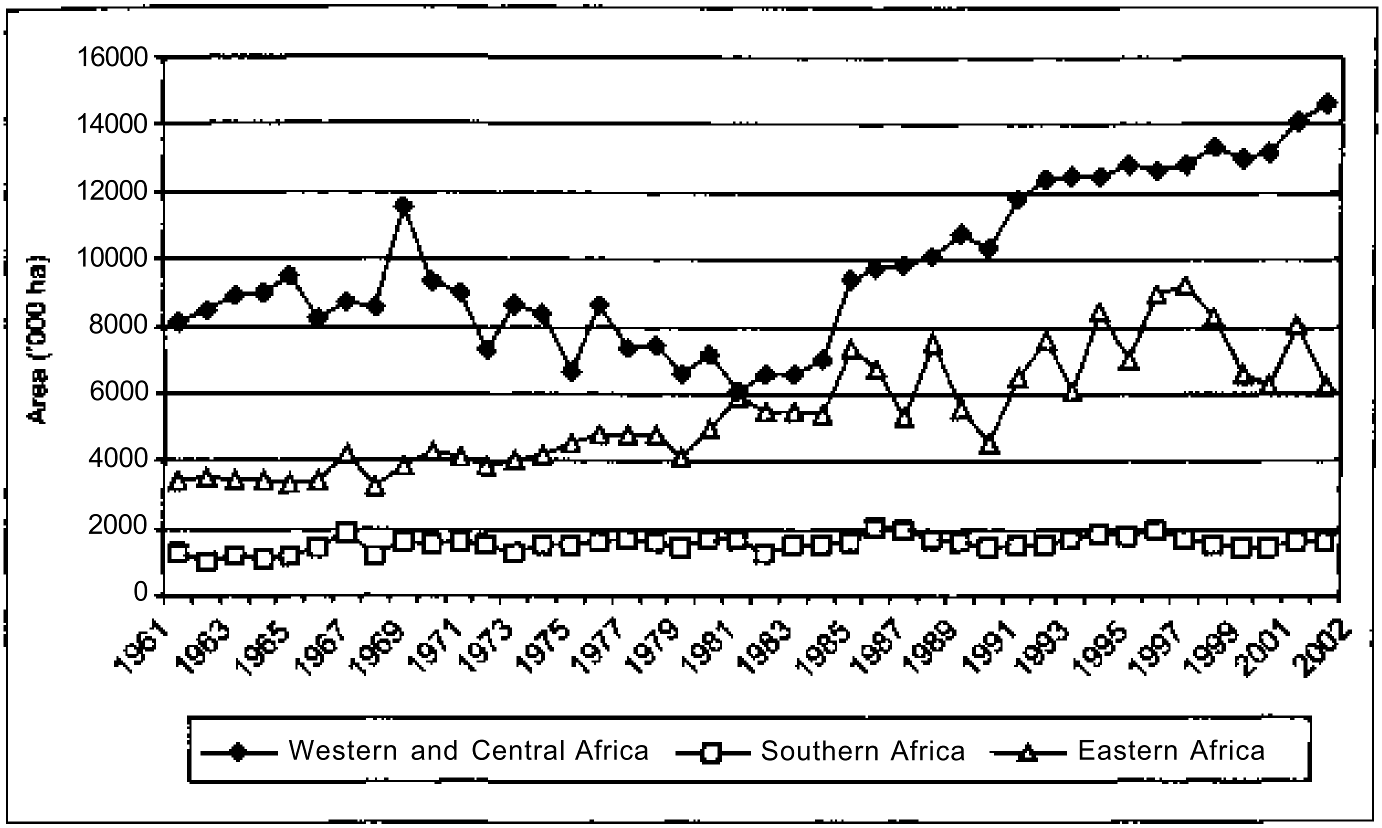


Figure 2.3. Trends in sorghum area in Africa, 1961-2002.

The data on area, production and yield contained in Table 2.2 facilitate the identification of countries with increasing, decreasing or fluctuating trends. For example, average annual production increased in Thailand in 1999-2001, mainly because the country exports sorghum to Japan, for which producers cut the plants at the 'dough stage'. Since FAO data do not record this type of information nor changes in commodity use, a decline in the grain area of sorghum was recorded in Thailand.

Although yields have increased in most of the sorghum-growing countries in Asia, Africa and Latin America, some countries like Brazil, Honduras, Iraq, Morocco, Romania and Rwanda experienced a decline, and Gambia, Guatemala, Guinea, Sierra Leone and Thailand experienced a fluctuating trend. Such declines and fluctuations deserve investigation. The decline in yield may be due to changes in sorghum use, eg, as livestock feed, harvesting for silage, or shifting of sorghum production to more marginal lands.

The trends in the area, production and yield of sorghum in major sorghum-growing states in India are presented in Table 2.3. The area under sorghum in the late 1990s (1998-2002) declined by 1 to 60% in major sorghum-growing states (Andhra Pradesh, Gujarat, Madhya Pradesh, Rajasthan and Tamil Nadu) compared to the early 1970s, early 1980s and early 1990s. In fact, the niche of sorghum production primarily remains in the two states of Maharashtra and Karnataka, where area under sorghum production stands at a total of 7 million ha (Figure 2.4). Average annual area under sorghum in India declined from 16 million ha in the early 1970s to 10 million ha in the late 1990s. Sorghum production was increasing until the early 1980s but declined after that. Yield of sorghum has increased over time. Average sorghum yield in the late 1990s was 826 kg ha^{1} against 543 kg ha^{-1} in the early 1970s. Decrease in sorghum production was primarily due to the decrease in area under sorghum.

Table 2.3. Area, production and yield of sorghum in different states of India.

State	1972-75	1981-84	1991-94	1998-2002
	Area ('000 ha)			
Andhra Pradesh	2709.9	2102.2	1057.2	721.6
Gujarat	970.6	956.6	444.6	206.1
Karnataka	2037.3	2205.7	2159.2	1885.0
Madhya Pradesh	2122.7	2138.0	1363.9	690.6
Maharashtra	5718	6588.7	5857.0	5019.8
Rajasthan	971.7	968.3	714.6	588.4
Tamil Nadu	665.3	688.7	500.8	402.6
India	16139.3	16469.0	12703.5	10012.3
	Production ('000 t)			
Andhra Pradesh	1363.9	1326.4	815.6	559.2
Gujarat	321.4	544.7	267.6	190
Karnataka	1578	1726.3	1842.7	1707.7
Madhya Pradesh	1598	1747.7	1277.3	575.9
Maharashtra	2577.7	4740.7	5351.3	4388
Rajasthan	337.3	451.7	243.1	153.8
Tamil Nadu	504	492	508.3	403.9
India	8826.3	11578.0	10773.3	8272.0
	Yield (kg ha^{-1})			
Andhra Pradesh	506.7	630.0	770.0	779.3
Gujarat	333.3	570.0	616.7	896.7
Karnataka	763.3	783.3	856.7	906.0
Madhya Pradesh	750.0	816.7	936.7	828.7
Maharashtra	436.7	720.0	906.7	875.3
Rajasthan	350.0	463.3	330.0	363.6
Tamil Nadu	760.0	710.0	1013.3	1001.7
India	543.3	706.7	846.7	826.0

Source: Authors' calculations are based on data obtained from CMIE (2002).

2.4. Growth Rates of Area, Production and Yield

The annual compound rates of growth of area, production and yield of sorghum were estimated for the periods 1971-80 (the 1970s), 1981-90 (the 1980s) and 1991-2001 (the 1990s). The following equation was used for estimating growth rates in area, production and yield:

$\ln Y = a + bt$

where

a is the intercept term;

ln Y is the area (ha)/production (metric t)/yield (kg ha^{-1}) expressed in natural log form;

t is the time trend denoting years; and

b is the annual compound rate of growth of area/production/yield.

The annual compound rates of growth of sorghum production, area and yield for different countries are estimated. We see a four-level hierarchy: (1) high growth (5% or more); (2) moderate growth (>1% to <5%); (3) slow growth (up to 1.0%) and (4) negative growth. The temporal changes in sorghum production under these four growth levels are given in Table 2.4.

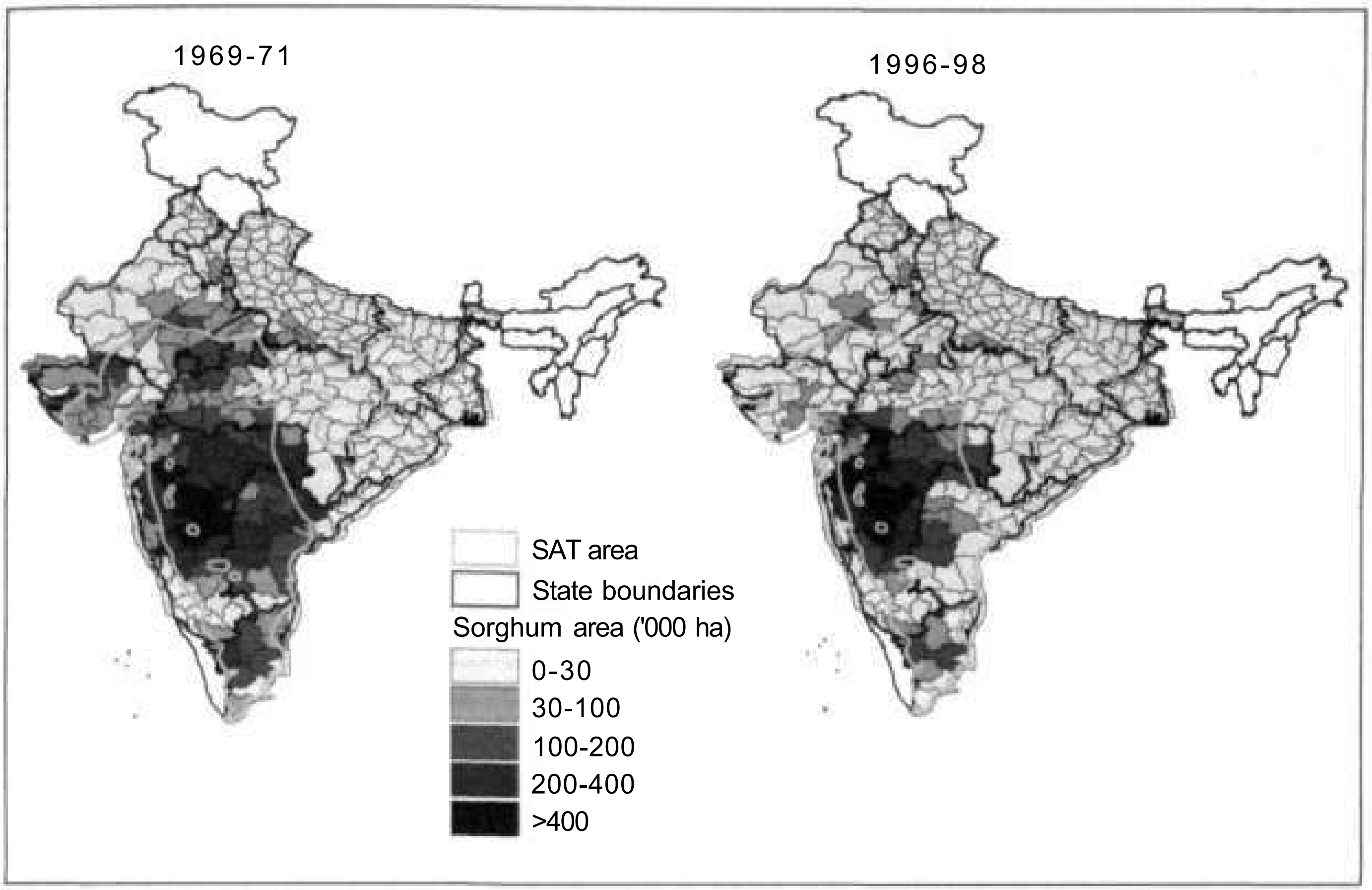


Figure 2.4. Change in sorghum area in India by district, 1970s-1990s.

The rates of growth of sorghum area, production and yield in India are given in Table 2.5. The area under sorghum has declined over time. During the last three decades (1972/73-2000/01), all the major sorghum-growing states except two (Maharashtra and Karnataka) experienced a measurable decline in area under sorghum. The rate of decline in sorghum area in India in the 1990s (3.08% per year) was much faster than in the 1980s (1.57% per year). Decline in sorghum production in India during 1972/73-2000/01 was 0.42% per year. The yield of sorghum in all these states has increased during the same period. During 1972/73-2000/01, annual growth in sorghum yield in India was 1.44% while the highest growth in yield was observed in Gujarat (2.44%) and Maharashtra (2.24%). During the 1990s, the highest growth in yield was observed in Gujarat (5.87% per year), followed by Rajasthan (3.43% per year). For the two sorghum niche states of Maharashtra and Karnataka, production increased from 4 to 6 million t during the period.

2.5. Sources of Changes in Average Sorghum Production

Results presented in the previous sections clearly depict three distinct situations where countries have experienced: (1) consistent increase in production; (2) persistent decrease in production and (3) fluctuations in production. Therefore, it is useful to analyze the average production in the 1990s compared to the 1970s and 1980s (Table 2.6). An analysis of the sources of these trends is important. A model developed by Hazell (1982) was used to analyze the changes in average

Table 2.4. Temporal changes in sorghum production in the 1970s, 1980s and 1990s.

	High growth			Moderate growth		
Region	1970s	1980s	1990s	1970s	1980s	1990s
Asia	Thailand	Saudi Arabia	Korea, Saudi Arabia	India, Saudi Arabia	Yemen	
Southern and Eastern Africa	Lesotho, Somalia, Tanzania	Botswana, Kenya, Zambia	Eritrea, Lesotho Malawi, Mozambique, Zimbabwe	Namibia, South Africa	Lesotho, Malawi, Namibia, Somalia, South Africa, Zimbabwe	Kenya, Namibia, South Africa, Tanzania, Zambia
West and Central Africa	Burundi, Guinea-Bissau, Ivory Coast, Niger, Senegal, Togo	Benin, Burkina Faso, Chad, Ghana, Guinea, Mali, Mauritania, Togo	Central African Republic, Chad, Gambia, Nigeria, Senegal	Benin, Burkina Faso, Cameroon, Mali, Rwanda, Sierra Leone, Sudan	Burundi, Cameroon, Gambia, Ivory Coast, Niger, Nigeria, Senegal, Uganda	Benin, Egypt, Ghana, Guinea-Bissau Mauritania, Niger, Togo
South America	Brazil, Colombia, Guatemala, Mexico, Nicaragua, Peru, Venezuela	Mexico, Venezuela	Brazil, Mexico	Argentina	Brazil, Colombia, Guatemala, Honduras	Argentina, Honduras
Others	Albania, Hungary, Italy, Romania	Hungary	Albania, Australia, Romania	France, Spain		

	Slow growth			Negative growth		
	1970s	1980s	1990s	1970s	1980s	1990s
Asia		India, Pakistan		China, Korea DPR, Korean Republic, Pakistan, Yemen	China, Korea * DPR, Korean Republic, Thailand	China, India, Korea DPR, Pakistan, Thailand
Southern and Eastern Africa	Eritrea			Botswana, Kenya Madagascar, Malawi, Mozambique, Swaziland, Zambia, Zimbabwe	Eritrea, Madagascar, Mozambique, Swaziland,	Botswana, Madagascar, Somalia, Swaziland Tanzania
West and Central Africa			Burundi, Cameroon, Uganda	Central African Republic, Chad, Egypt, Ghana, Gambia, Guinea, Mauritania, Morocco, Nigeria Tunisia, Uganda	Central African Republic, Egypt, Guinea-Bissau, Morocco, Rwanda, Sierra Leone, Sudan, Tunisia	Burkina Faso, Guinea, Ivory Coast, Mali, Morocco, Rwanda, Sierra Leone, Sudan, Tunisia
South America	El Salvador		El Salvador, Haiti	Haiti, Honduras, Uruguay	Argentina, El Salvador, Haiti, Nicaragua, Peru, Uruguay	Colombia, Guatemala, Nicaragua, Peru, Uruguay, Venezuela
Others		Italy		Australia, USA	Albania, Australia, France, Romania, Spain, USA	France, Hungary, Italy, Spain, USA

Source: Authors' calculations are based on data from FAO.

Table 2.5. Annual compound rates of growth (%) in sorghum area, production and yield in India.

State	1972/73-1980/81	1981/82-1990/91	1990/91-2000/01	1972/73-2000/01
		Area		
Andhra Pradesh	-3.17	-6.84	-5.37	-5.24
Gujarat	-0.68	-2.55	-11.00	-5.99
Karnataka	-1.37	0.23	-2.01	0.04
Madhya Pradesh	0.20	-2.68	-9.94	-4.04
Maharashtra	2.63	-0.52	-1.67	-0.63
Rajasthan	-1.19	-0.34	-2.63	-1.65
Tamil Nadu	-1.02	-2.12	-2.79	-2.55
India	0.13	-1.57	-3.08	-1.86
		Production		
Andhra Pradesh	0.62	-6.71	-4.61	-3.64
Gujarat	9.96	-6.37	-5.15	-3.54
Kamataka	1.16	-1.89	-1.28	0.29
Madhya Pradesh	-1.17	-0.63	-10.40	-3.19
Maharashtra	13.40	2.55	-1.60	1.60
Rajasthan	-3.24	-0.80	-4.25	-1.99
Tamil Nadu	0.64	2.35	-3.28	-1.58
India	4.64	0.18	-3.06	-0.42
		Yield		
Andhra Pradesh	3.81	0.21	0.81	1.60
Gujarat	10.60	-3.85	5.87	244
Kamataka	2.58	-2.06	0.69	0.27
Madhya Pradesh	-1.32	1.96	-1.01	0.84
Maharashtra	10.80	3.06	0.05	2.24
Rajasthan	-2.01	-0.36	3.43	025
Tamil Nadu	1.59	4.49	-0.47	0.97
India	4.57	1.66	-0.01	1.44

Source: Authors' calculations are based on data obtained from CMIE (2002).

production in the 1990s compared to the 1970s and 1980s in all major sorghum-growing countries in the world and states in India. Details of the analytical procedure are given in Appendix 2.1.

The temporal changes in average sorghum production in India are reported in Table 2.7. In the 1990s (1991/92-2000/01) compared to the 1970s (1972/73-1980/81), production increased in Kamataka by 7.3% and in Maharashtra by 23.1%. Average sorghum production in all other major sorghum-growing states (Andhra Pradesh, Gujarat, Madhya Pradesh, Rajasthan and Tamil Nadu) declined. Sorghum production declined in India in the 1990s by 8.2%. Sorghum production decreased by about 50% in Andhra Pradesh and Gujarat, 41% in Madhya Pradesh and by less than 30% in Rajasthan and Tamil Nadu.

An analysis of the sources of the trends in average production in the 1990s compared to the 1970s and the 1980s showed that there were four sources of change in average production. Two of these originated from the changes in mean yield and mean area, which are pure effects that would arise even if there were no other sources of change. The third source was an interaction effect, arising from simultaneous changes in the mean yield and mean area. This term will obviously be

Table 2.6. Trends in changes in average production of sorghum, 1971-2001.

Country	Average annual production ('000 t)			Change compared to 1971-80 (%)	
	1971-80	1981-90	1991-2001	1981-90	1991-2001
Albania	26	33	14	2672	-45.56
Argentina	5200	5082	2686	-2.28	-48.35
Australia	1035	1339	1315	29.42	27.07
Benin	64	82	121	29.09	90.85
Bolivia	5	43	92	754.00	1747.87
Botswana	40	28	27	-28.61	-30.60
Brazil	194	283	456	46.01	135.02
Burkina Faso	584	788	1207	34.88	106.64
Burundi	27	59	64	117.04	135.88
Cameroon	272	321	406	17.78	49.00
Central African Rep	35	42	31	18.13	-12.10
Chad	277	232	454	-16.23	63.77
China	8201	6255	4452	-23.73	-45.71
Colombia	369	627	448	70.07	21.53
Ivory Coast	24	22	26	-9.09	6.84
Dominican Rep	17	36	15	120.61	-7.54
Egypt	751	594	793	-20.90	5.69
El Salvador	153	129	181	-15.66	18.25
Eritrea	78	80	105	2.32	35.24
France	305	250	386	-18.00	26.51
Gambia	5	8	15	55.56	173.33
Ghana	154	144	313	-6.45	104.15
Greece	5	2	2	-70.59	-59.00
Guatemala	57	91	60	60.67	6.11
Guinea-Bissau	9	18	16	110.47	80.92
Haiti	142	120	94	-15.48	-34.02
Honduras	47	51	75	7.61	59.07
Hungary	13	29	17	132.00	33.01
India	9981	11 246	9437	12.68	-5.44
Italy	28	98	200	253.79	620.90
Kenya	217	103	120	-52.54	-44.86
Korea DPR	23	16	9	-32.19	-62.93
Korea Rep	5	3	2	-46.00	-60.71
Lesotho	59	38	33	-35.93	-44.75
Malawi	77	17	33	-77.59	-57.77
Mali	326	511	673	56.60	106.15
Mauritania	32	63	95	95.03	196.25
Mexico	3693	5650	5354	52.99	44.97
Mozambique	205	201	227	-1.71	10.77
Namibia	5	7	7	37.74	23.43
Nicaragua	56	108	86	92.02	51.79
Niger	279	359	422	28.54	50.98
Nigeria	3203	4537	6482	41.62	102.36
Pakistan	282	228	231	-18.86	-17.81
Panama	4	21	17	475.68	347.25
Paraguay	8	19	24	141.56	212.83
Rwanda	154	186	128	21.11	-16.32
Saudi Arabia	117	86	191	-26.05	63.59

...continued

Table 2.6. *Continued*

Country	Average annual production ('000 t)			Change compared to 1971-80 (%)	
	1971-80	1981-90	1991-2001	1981-90	1991-2001
Senegal	105	128	123	21.37	16.56
Sierra Leone	9	18	18	108.14	111.31
Somalia	134	232	120	73.78	-10.45
South Africa	479	452	354	-5.74	-26.08
Spain	185	101	53	-45.30	-71.57
Sudan	1801	2330	3228	29.35	79.20
Tanzania	327	518	645	58.45	97.44
Thailand	180	270	198	50.47	10.07
Togo	25	107	139	324.51	450.43
USA	19252	19 356	15 300	0.54	-20.53
Uganda	367	320	374	-12.76	2.09
Uruguay	123	115	109	-5.87	-10.74
Venezuela	162	537	466	232.20	188.34
Yemen	663	433	403	-34.68	-39.15
Zambia	36	24	27	-34.17	-23.85
Zimbabwe	100	97	83	-3.39	-16.98

Source: Authors' calculations are based on data from FAO.

Table 2.7. Trends in average annual sorghum production in some states in India.

State	Average production ('000 t)			Change compared to 1972-81 (%)	
	1972/73-1980/81	1981/82-1990/91	1991/92-2000/01	1981/82-1990/91	1991/92-2000/01
Andhra Pradesh	1307	1086	656	-16.91	-49.84
Bihar	5	4	2	-7.19	-51.97
Gujarat	486	410	234	-15.64	-51.87
Haryana	38	34	29	-11.31	-23.34
Karnataka	1598	1659	1716	3.82	7.34
Madhya Pradesh	1454	1663	859	14.35	40.94
Maharashtra	3976	4885	4897	22.88	23.17
Orissa	18	26	12	40.84	-36.60
Rajasthan	296	398	216	34.49	-26.98
Tamil Nadu	606	578	430	-4.56	-29.11
Uttar Pradesh	440	494	364	12.25	-17.20
India	10 232	11 246	9389	9.92	-8.24

Source: Authors' calculations are based on data obtained from CMIE (2002).

zero if either the mean yield or the mean area remain unchanged. The last source arose from changes in variability in area and yields.

As shown in Table 2.6, average annual sorghum production has increased in many countries but decreased in some. The sources of change in production are shown in Table 2.8. Yield improvement made a positive contribution to increase in sorghum production. It explained 98% of the increase in sorghum production in Uganda; about 90% in Egypt, Guatemala, Ivory Coast and Thailand; more than 80% in Colombia, El Salvador and Senegal; 70% or more in Australia, France, Hungary, Mozambique and Namibia; about 60% or more in Cameroon, Chad, Guinea-Bissau, Honduras and Nicaragua and more than 50% in Benin, Burkina Faso, Ghana, Mali, Nigeria, Sudan

Table 2.8. Contribution of different sources of change to the increase in average sorghum production in the 1990s (1991 to 2001) compared to the 1970s (1971 to 1980).

	Contribution of different sources of change (%)				
Country	Change in yield	Change in area	Interaction between changes in area and yield	Change in area yield covariance	Total
Australia	79	5	14	2	100
Benin	55	38	6	1	100
Bolivia	4	104	3	-11	100
Brazil	37	72	-8	0	100
Burkina Faso	53	17	30	0	100
Burundi	46	44	10	0	100
Cameroon	69	26	9	-4	100
Chad	64	23	13	0	too
Colombia	80	-8	28	0	100
Egypt	89	-19	30	0	100
El Salvador	83	*4*	23	0	100
Eritrea	69	41	-12	3	100
France	74	-13	39	1	100
Gambia	41	45	13	2	100
Ghana	54	24	22	1	100
Guatemala	90	25	-16	2	100
Guinea-Bissau	59	16	24	0	100
Honduras	66	22	9	3	100
Hungary	74	23	-6	8	100
Italy	17	76	7	-1	100
Ivory Coast	90	27	-13	-3	100
Mali	52	42	7	-1	100
Mauritania	42	23	28	7	100
Mexico	70	24	7	-1	100
Mozambique	79	46	-22	-3	100
Namibia	71	52	-17	-7	100
Nicaragua	64	-5	42	-1	100
Niger	36	84	-20	0	100
Nigeria	54	27	16	2	100
Panama	22	53	125	-100	100
Paraguay	34	63	4	-1	100
Saudi Arabia	45	-17	71	1	100
Senegal	84	23	-5	-2	100
Sierra Leone	29	92	-12	-9	100
Sudan	50	57	-9	1	100
Tanzania	54	12	36	-2	100
Thailand	91	-7	12	4	100
Togo	18	81	45	-44	100
Uganda	98	-6	5	3	100
Venezuela	40	44	21	-5	100

Source: Authors' calculations are based on data from FAO.

and Tanzania. In other countries such as Brazil, Burundi, Gambia, Italy, Mauritania, Niger, Panama, Paraguay, Saudi Arabia, Sierra Leone, Togo and Venezuela, yield increase contributed less than 50% of the total increase in production. Change in area made a positive contribution to increase in production except in Colombia, Egypt, El Salvador, France, Saudi Arabia, Thailand and Uganda, implying that had there been no decline in sorghum area, production would have increased further in these countries. The contribution of the area-yield interaction was positive in these countries, indicating that areas less suitable for sorghum were shifted to other crops in Colombia, Egypt, El Salvador, France, Saudi Arabia and Thailand. In Panama, increase in yield contributed 22% of the total production increase while increase in area accounted for 53%. The area-yield interaction accounted for 125% of the change, indicating the expansion in sorghum cultivation. However, both the area and yield were fluctuating in Panama; therefore, changes in variability in area and yield contributed negatively to sorghum production. The research and policy implication of this finding for Panama is that the country should encourage a stable average area under sorghum for a further increase in production, and sorghum researchers should give priority to reducing variability in sorghum yield.

The factors that led to a decrease in sorghum production are reported in Table 2.9. Yield decline was an important factor in all the countries that suffered a decrease in production. Expansion of area contributed negatively to the decrease. In other words, had the area under sorghum not increased, production would have been much lower. The interaction between area and yield contributed positively to the decrease in sorghum production in Argentina, Central African Republic, China, Greece, India, Korean Republic, South Africa, Spain, Uruguay, USA, Yemen and Zambia. This indicates that sorghum production in these countries has shifted to the more marginal environments. In other words, a shift to less suitable land reduced the yield of sorghum and thereby production. The interaction between area and yield had a negative contribution to the decrease in sorghum production in Albania, Botswana, Dominican Republic, Haiti, Kenya, Korea DPR and Lesotho. This means that cultivation of sorghum in these countries has shifted towards relatively suitable areas. Variability in area and yield made no noteworthy contribution to the decrease in sorghum production in these countries.

The sources of change in sorghum production in different Indian states are reported in Table 2.10. Average sorghum production in India decreased in the 1990s (1991/92-2000/01) compared to the 1970s (1972/73-1980/81). Karnataka and Maharashtra experienced increases in average sorghum production in the 1990s while all other major sorghum-growing states experienced decreases in production in the 1990s. Increases in sorghum production in Karnataka and Maharashtra were mainly due to increase in yield. There was no substantial effect of "changes in area-yield covariance" and "interaction between change in area and yield". Sorghum production in Gujarat declined due to the decrease in area while yield made a negative contribution to the decrease in production, indicating that if yield had not increased in Gujarat, the decrease in production would have been greater. Production decreased in Andhra Pradesh, Madhya Pradesh, Rajasthan and Tamil Nadu due to significant decline in area.

2.6. Conclusions

Though the global sorghum area at the end of the 20th century was 42% higher than in the early 1970s, the area under the crop declined in many major sorghum-growing countries including China, India and USA. High growth in sorghum area in the 1990s was attained by Eritrea,

Table 2.9. Contribution of different sources of change to the decrease in average sorghum production in the 1990s (1991 to 2001) compared to the 1970s (1971 to 1980).

	Contribution of different sources of change (%)				
Country	Change in yield	Change in area	Interaction between changes in area and yield	Change in area yield covariance	Total
Albania	201	-76	-24	-1	100
Argentina	107	-73	67	-1	100
Botswana	130	22	-57	5	100
Central African Rep	97	-37	38	1	100
China	87	-62	72	3	100
Dominican Rep	99	29	-29	1	100
Greece	155	-108	48	5	100
Haiti	159	-38	-20	-1	100
India	95	-29	33	0	100
Kenya	198	-70	-27	-2	100
Korea DPR	337	-195	-46	4	100
Korea Rep	103	-79	76	0	100
Lesotho	192	-81	-19	8	100
Malawi	360	-141	-109	-10	100
Pakistan	121	-24	3	0	100
Rwanda	120	-15	-3	-2	100
Somalia	112	-15	0	3	100
South Africa	122	-47	26	-1	100
Spain	278	-206	30	-2	100
USA	115	-40	24	1	100
Uruguay	77	-39	63	-1	100
Yemen	140	-70	29	2	100
Zambia	120	-43	26	-3	100
Zimbabwe	121	-21	-3	2	100

Table 2.10. Sources of change in average sorghum production in India.

		Contribution of different sources of change (%)				
States	Nature of production change	Change in yield	Change in area	Interaction between changes in area and yield	Change in area yield covariance	Total
Maharashtra	Increase	123.71	-15.22	-6.57	-1.92	100.00
Karnataka	Increase	96.68	3.92	0.17	-0.77	100.00
Andhra Pradesh	Decrease	722.86	458.42	-167.67	3.23	100.00
Gujarat	Decrease	-1743.57	1173.99	630.86	38.71	100.00
Madhya Pradesh	Decrease	263.13	-136.15	-28.52	1.54	100.00
Rajasthan	Decrease	139.59	-37.96	-2.87	1.24	100.00
Tamil Nadu	Decrease	185.85	-72.74	-12.28	-0.84	100.00
India	Decrease	163.47	-48.77	-14.95	0.26	100.00

Malawi, Namibia and Zimbabwe in Southern and Eastern Africa; by Chad, Guinea-Bissau, Nigeria and Sierra Leone in Western and Central Africa and by Brazil and Mexico in South America. Among the developed countries, high growth was experienced by Albania and Australia in the 1990s. None of the Asian countries experienced high growth in sorghum area in the 1990s. In the 1990s, high growth in sorghum production was experienced by Saudi Arabia in Asia; Eritrea, Lesotho, Malawi, Mozambique and Zimbabwe in Southern and Eastern Africa; Chad, Central African Republic, Gambia, Nigeria and Senegal in Western and Central Africa and Brazil and Mexico in South America. Among the developed countries, Australia experienced high growth in sorghum production in the 1990s. Significant growth in sorghum yield in the 1990s was attained by the Korean Republic in Asia; by Malawi, Mozambique, South Africa and Swaziland in Southern and Eastern Africa and by the Central African Republic and Mauritania in Western and Central Africa. None of the South American countries experienced high growth in sorghum yield in the 1990s.

There has been a sixfold increase in sorghum production in the 1990s (compared to the 1970s) in Bolivia and Italy and between two to five times in Panama, Paraguay and Togo. On the other hand, many countries like Albania, Argentina, Botswana, Central African Republic, China, Greece, Haiti, Kenya, Korea DPR, Korean Republic, Lesotho, Malawi, Pakistan, Rwanda, Somalia, South Africa, Spain, Uruguay, USA, Yemen, Zambia and Zimbabwe experienced decreases in average sorghum production in the 1990s (compared to the 1970s). Yield made a positive contribution to increase in sorghum production in most of the countries. The main reason for the fall in production in most of the countries was the decrease in area under sorghum. However, some countries also experienced decrease in production due to decrease in average yield. The reasons behind the decrease in average production need to be studied for appropriate policy actions.

2.7. References

Bantilan MCS. 2003. AEZs, productivity, poverty and research targets: Application for international agricultural research systems. Paper presented at a workshop on Green Revolution in Asia and its transferability to Africa, 15-16 Aug 2003, Durban, South Africa. 60 pp.

CMIE (Centre for Monitoring Indian Economy). 2002. Agriculture. Mumbai, India: Centre for Monitoring Indian Economy. 373 pp.

FAO/ICRISAT (Food and Agriculture Organization of the United Nations/International Crops Research Institute for the Semi-Arid Tropics. 1996. The world sorghum and millet economies: facts, trends and outlook. Viale delle Termi di Caracalla 00100 Rome, Italy: Food and Agriculture Organization of the United Nations; and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 68 pp.

Hazell PBR. 1982. Instability in Indian foodgrain production. Research Report No. 30. Washington DC, USA: International Food Policy Research Institute. 60 pp.

Appendix 2.1.

Analytical Procedure to Measure Changes in Average Production and Sources of Change

Changes in average annual sorghum production in different countries of the world and in different states of India were computed for the 1970s, 1980s and 1990s. The model used in this study was developed by Hazell (1982] and adapted for the purpose of this study in the following manner:

$$Q=\sum A_j Y_j \qquad ...(2.1)$$

where, A = area, Y = yield, and j = the country.

The average production of a selected crop in the first period is:

$$E(Q_I) = \sum[\bar{A}_{Ij} * \bar{Y}_{Ij} + COV(A_{Ij} Y_{Ij})] \qquad ...(2.2)$$

The average production in the second period is:

$$E(Q_{II}) = \sum[\bar{A}_{IIj} \cdot \bar{Y}_{IIj} + COV(A_{IIj} Y_{IIj})] \qquad ...(2.3)$$

Each variable in the second period can be expressed as its counterpart in the first period plus the change in the variable between the two time periods. Thus the change in average production, ΔE (Q), can be decomposed in the following way:

$$\Delta E(Q) = \sum[\bar{A}_{Ij} \Delta\bar{Y}_{Ij} + \bar{Y}_{i} \; \bar{A} \; .+\Delta\bar{A}_{j} \Delta\bar{Y}_{I} + \Delta\, COV(A_i, Y_j)] \qquad ...(2.4)$$

Different sources of change are shown in the following Table. There are two methods of decomposition: method I uses the first period as the base and method II uses the second period as the base. Both the methods are mathematically correct, but since method II combines pure and interaction effects, it is less useful for this type of analysis. Thus method I has been used in this study.

There are four sources of change in average production ΔE (Q). Two parts, $Aj\Delta Y$ and $Y_I\Delta A$, arise from changes in the mean yield and the mean area. These are "pure effects"; they arise even if there are no other sources of change. The term $\Delta\bar{A}\,\Delta\bar{Y}$ is an interaction effect, which arises from the simultaneous occurrence of changes in mean yield and mean area. Obviously, this term will be zero if either the mean yield or the mean area remains unchanged. The last term Δ COV (A, Y) arises from the changes in the variability of area and yields. Since COV (A, Y)= $r[V(A), V(Y)]^{1/2}$, where r is the correlation coefficient, it can be seen that Δ COV (A, Y) arises from the changes in the variances of areas and yields and from changes in the correlation between areas and yields.

Components of change in average sorghum production.

Sources of change	Symbols	Components of change	
		Method 1	Method II
Change in mean yield	$\Delta\bar{Y}$	$\bar{A}_I\Delta\bar{Y}$	$\bar{A}_{II}\Delta\bar{Y}$
Change in mean area	$\Delta\bar{A}$	$\bar{Y}_I\Delta\bar{A}$	$\bar{Y}_{II}\Delta\bar{A}$
Interaction between changes in mean area and mean yield	$\Delta\bar{A}, \Delta\bar{Y}$	$\Delta\bar{A}\Delta\bar{Y}$	$-\Delta\bar{A}\Delta\bar{Y}$
Change in area-yield covariance	Δ COV(A,Y)	Δ COV(A,Y)	Δ COV(A,Y)

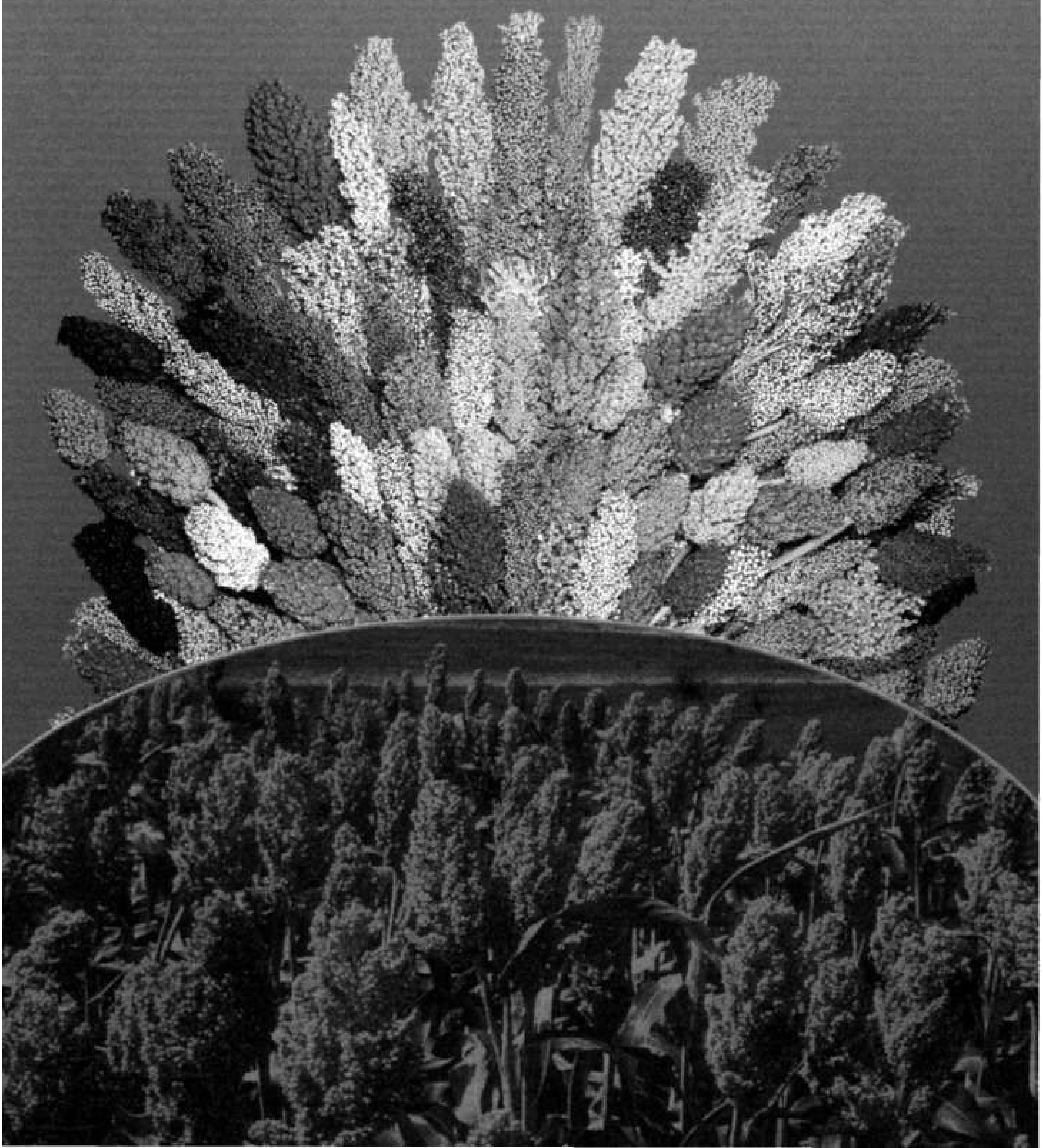
Note: Method 1 uses the first period as base while method II uses the second period as base.

PART II: Sorghum Genetic Enhancement Process

Conservation, Utilization and Distribution of Sorghum Germplasm

3

N Kameswara Rao, PJ Bramel, V Gopal Reddy and UK Deb



Conservation, Utilization and Distribution of Sorghum Germplasm

N Kameswara Rao[1], PJ Bramel[1], V Gopal Reddy[2] and UK Deb[3]

3.1. Introduction

Collection, characterization and maintenance of plant genetic resources are essential for crop improvement. ICRISAT has given high priority to this. The need to collect and conserve genetic diversity in sorghum was realized some 35 years ago as traditional landraces became vulnerable to loss due to several factors: increasing adoption of modern varieties and hybrids; substitution of sorghum by more remunerative crops, especially with extension of irrigation facilities as in India and frequent and prolonged droughts in Africa. Thus, several landraces once abundant in parts of Africa and Asia are reported to be extinct now. The landraces *Hegari, Zera-zera* and *Kurgis* once present in the Gezira, Kasala and Blue Nile provinces of Sudan, are on the verge of extinction or are no longer cultivated (Prasada Rao and Mengesha 1981 a).

3.2. Germplasm Collection and Assembly

The first major attempt toward assembling a world collection of sorghum was made by the Indian Agricultural Program of the Rockefeller Foundation (Murty et al. 1967; Rockefeller Foundation 1970), and 16, 138 accessions were assembled from the major sorghum growing areas. This collection was acquired by ICRISAT in 1974 through the All India Coordinated Sorghum Improvement Project (AICSIP), Rajendranagar (Mengesha and Prasada Rao 1982). However, only 8961 of the accessions were viable; the remainder had lost viability due to lack of proper storage facilities before they were transferred. ICRISAT later obtained some 3000 of the missing accessions from the duplicate sets maintained in the USA (Purdue and Fort Collins) and Puerto Rico (Mayaguez) (Mengesha and Prasada Rao 1982). In 1974, in accordance with the recommendations of the Advisory Committee on Sorghum and Millets Germplasm sponsored by the International Board for Plant Genetic Resources (IBPGR, now International Plant Genetic Resources Institute, IPGRI), ICRISAT assumed the responsibility to maintain sorghum germplasm and to enlarge the world collection. Special efforts were made to collect or assemble landraces and wild relatives from areas threatened by genetic erosion. Between 1975 and 1997, ICRISAT launched 32 collection missions in major sorghum growing areas and collected 8898 accessions (Table 3.1). Apart from ICRISAT's own efforts, donations from several international and national organizations such as IPGRI, Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM), the Ethiopian Sorghum Improvement Program, Gezira Agricultural

1 Formerly of the International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
2 International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
3. Centre for Policy Dialogue, House 40/C, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.

Kameswara Rao N, Bramel PJ, Gopal Reddy V and Deb UK. 2004. Conservation, utilization and distribution of sorghum germplasm. Pages 43-62 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Table 3.1. Sorghum germplasm collected from various countries by ICRISAT expeditions undertaken from 1975 to 1996.

Country	1975-79	1980-84	1985-89	1990-96[1]	Total
Botswana	-	133	29	-	162
Burundi	-	72	-	-	72
Cameroon	-	96	547	-	643
Central African Republic	-	-	210	-	210
Ethiopia	-	131	-	-	131
Gambia	-	56	-	-	56
Ghana	-	83	-	-	83
India	652	267	947	734	2600
Kenya	2	-	-	-	2
Lesotho	-	-	249	-	249
Malawi	288	6	-	-	294
Mali	-	-	-	20	20
Mozambique	-	48	-	-	48
Myanmar	-	4	-	-	4
Namibia	-	-		181	181
Nigeria	-	200	-	184	384
Pakistan	-	-	46	-	46
Russia (former)	-	-	-	41	41
Rwanda	-	73	-	-	73
Sierra Leone	-	104	-	-	104
Somalia	120	-	271	-	391
South Africa	-	63	-	-	63
Sri Lanka	-	23	-	-	23
Sudan	130	30	-	-	160
Swaziland	-	-	182	-	182
Tanzania	107	44	267	-	418
Togo	-	-	34	-	34
Uganda	-	-	-	448	448
Yemen	-	163	-	-	163
Zambia	-	204	-	-	204
Zimbabwe	-	228	1131	-	1359
Total	1299	2028	3913	1658	8898

1. There was no collection expedition in 1995.

Research Station (Sudan), AICSIP, several Indian agricultural universities and individuals contributed to the collection (Prasada Rao et al. 1989). With 36, 774 accessions conserved from 91 countries (Table 3.2), the ICRISAT Gene Bank now serves as a major repository of sorghum germplasm. More than half of this collection is from five countries: India, Ethiopia, Sudan, Cameroon and Yemen. Although diversity from many countries has been adequately sampled, some remain poorly represented and are therefore high priority for future collection efforts. These countries include Angola, Chad, China, Eritrea, Ivory Coast, Mozambique, Thailand, Turkey and Zaire. Ethiopia, Indonesia, Myanmar, the Philippines and parts of West Africa are high-priority countries for collection of wild relatives (Stenhouse et al. 1997).

Table 3.2. Source of the sorghum germplasm assembled at the ICRISAT Gene Bank, 2002.

Country/institution	Number of accessions	Country/institution	Number of accessions
Asia		**Africa**	
Afghanistan	5	Senegal	**241**
Bangladesh	9	Sierra Leone	**108**
China	646	Somalia	**446**
ICRISAT	548	South Africa	**937**
India	6202	Sudan	**2505**
Indonesia	36	Swaziland	**203**
Iran	17	Tanzania	**716**
Iraq	3	Togo	**294**
Israel	22	Uganda	**1763**
Japan	108	Zaire	**52**
Korea, Republic of	78	Zambia	**362**
Lebanon	360	Zimbabwe	**1576**
Maldives	10		
Myanmar	20	**Americas**	
Nepal	8	Argentina	**16**
Pakistan	88	Colombia	**4**
Philippines	61	Cuba	**2**
Russia (former)	405	Dominican Republic	**2**
Saudi Arabia	22	El Salvador	**2**
Sri Lanka	25	Guatemala	**7**
Syrian Arab Republic	4	Haiti	**1**
Taiwan	6	Honduras	**65**
Thailand	9	Jamaica	**3**
Turkey	51	Mexico	**63**
Yemen, Republic of	2164	Nicaragua	**2**
		USA	**2128**
Africa		Uruguay	***t***
Algeria	23	Venezuela	**173**
Angola	44		
Benin	199	**Europe**	
Botswana	219	Belgium	**1**
Burkina Faso	548	Cyprus	**1**
Burundi	140	France	**5**
Cameroon	2485	Germany	**7**
Cape Verde	1	Greece	**1**
Central African Republic	249	Hungary	**87**
Chad	193	Italy	**9**
Congo	1	Portugal	**6**
Egypt	35	Romania	**7**
Ethiopia	4400	Spain	**3**
Ghana	147	United Kingdom	**3**
Gambia	57		
Ivory Coast	7	**Oceania**	
Kenya	990	Australia	**63**
Lesotho	271	Papua New Guinea	**1**
Madagascar	14		
Malawi	423	**Unknown**	170
Mali	694	Total number of accessions	36, 774
Mauritania	16	Total number of countries	91
Morocco	27		
Mozambique	48		
Namibia	189		
Niger	413		
Nigeria	1683		
Rwanda	291		

3.3. Conservation and Maintenance

Sorghum seeds show orthodox storage behavior (ie, desiccation tolerant); hence, the germplasm is conserved *ex situ* as seeds in the gene bank under controlled conditions. *Ex situ* conservation is cost efficient, and also makes it easier for scientists to access, study, distribute and use plant genetic resources. At ICRISAT, all the germplasm is stored as active collection under medium-term storage conditions (4°C and 20% RH). For each accession, about 300-400 g of seed is harvested at optimum maturity, usually 6-7 weeks after anthesis, from postrainy-season multiplication plots. The seeds are dried in the shade to about 8% moisture content, threshed by hand, cleaned and stored in screw-capped aluminium containers. The germplasm is also conserved as base collection at -20°C for long-term storage. For this purpose, about 125 g of seed is cleaned and dried to 5-6% moisture content by equilibration with air at 20°C and 15% RH for approximately 3 weeks. The dried grain is vacuum-sealed in aluminum foil bags and stored after confirming that initial viability is more than 95%. Seeds stored under medium-term conditions (active collection) are used for distribution and research, while those stored under long-term conditions [base collection) are used only for regenerating active collections. Viability is monitored by germination tests at 5-year intervals in medium-term storage and 10-year intervals in long-term storage. Any sample having less than 75% viability is identified for rejuvenation.

The medium- and long-term storage rooms are constructed on a modular principle with fabricated panels. Each room has a capacity of 125 m^3, capable of accommodating over 30,000 germplasm accessions. The storage rooms have mobile shelving systems, and are equipped with standby refrigeration and dehumidification systems. The temperature and relative humidity inside the storage rooms are monitored regularly with thermohygrographs. Audible and visual electronic alarm systems have been installed to safeguard the seeds from any rise in temperature and relative humidity and to help maintain the desired conditions. The Gene Bank has a power generator to cope with long periods of power failure.

Chapter 14G of Agenda 21 of the United Nations Conference on the Environment and Diversity (UNCED) recommends that all gene banks duplicate their collections of germplasm for safety under long-term conditions. ICRISAT's agreement with the Food and Agriculture Organization of the United Nations (FAO) also requires safety duplication. ICRISAT has a memorandum of understanding for the duplication of sorghum germplasm with the Southern African Development Community (SADC), Regional Gene Bank (SRGB), Zambia, and recently transferred 4527 accessions of African origin. Efforts are being made to identify sites for the safe duplication of the complete collection. Once the sites are identified, agreements will be made to facilitate transfer and safe storage of the duplicate collection. Other options for duplication are also being explored. For example, the sorghum germplasm collections at ICRISAT and at the National Plant Germplasm System (NPGS), USA, overlap considerably and cross-referencing the two databases revealed that over 21,985 accessions (approximately 60% of ICRISAT holdings) are duplicated. Obtaining unique accessions from NPGS to add to the world collection at ICRISAT and duplication of those not available at NPGS are being considered.

Sorghum is a partially outbreeding and self-pollinated species. Therefore, germplasm accessions are maintained by selfing. During collection and initial multiplication at ICRISAT, variant types were separated so that each accession is a true-breeding single type. To prevent contamination by foreign pollen, individual panicles are covered with selfing bags as soon as they emerge from the boot prior to anthesis. They are kept covered for at least 3 weeks, after which the bags are removed to assist in seed drying and maturity. Seed from at least 30 selfed plants is bulked to maintain an accession. Wild relatives are also maintained by selfing. However, a number of species do not set seeds and are maintained as live plants in a field gene bank (Stenhouse et al. 1997).

Diversification, genetic studies and germplasm enhancement through conversion and introgression resulted in the development of trait-specific germplasm pools over the years at ICRISAT. These, along with the germplasm accessions possessing some valuable traits, are maintained as subsets or working collections for ready access and use. In addition to the active collections, the following working collections were established and maintained at ICRISAT on the recommendation of various sorghum workers (Prasada Rao et al. 1989).

Spontaneous collection. This includes 542 wild and weed races from 33 taxa (Table 3.3).

Named cultivar collection. This includes 237 named cultivars released by private and public institutions in different countries. About 2 kg seed samples are maintained to meet seed requests.

Table 3.3. Wild relatives of sorghum assembled at ICRISAT until December 1999.

Genus/section/species/subspecies	Race	Number of accessions
Genus: Sorghum	*arundinaceum*	33
Section: Sorghum	*aethiopicum*	16
S. *bicolor/arundinaceum*	*lanceolatum*	7
	macrochaeta	3
	rhizomatous	2
	usumbaranse	3
	verticilliflorum	87
	virgatum	18
S. *bicolor/drummondii*	*drummondii*	153
	hewisonii	2
S. *halepense*	*halepense*	22
	controversum	4
	miliaceum	5
	almum	8
S. propinquum		3
Section: Chaetosorghum *S.macrospermum*		1
Section: Heterosorghum S. *laxiflorum*		1
Section: Parasorghum S. *australiense*		3
S. brevicallosum		1
S. matarankense		2
S. *purpureosenceum*		2
	deccanense	4
	dimidiatum	2
S. *versicolor*		6
Section: Stiposorghum S. *affstipodeium*		2
S. Intrans		5
S. plumosum		1
S. stipoideum		5
Section: Unclassified *Para sorghum*		10
Others		2
Genus: Sorghastrum		6
Total		417

Genetic stock collection. This consists of genotypes resistant to diseases and pests, lines with identified genes and cytoplasmic-genetic male steriles. Seed samples of 1 kg are maintained by selfing, except in the case of male-sterile lines, which are maintained by hand pollination.

Conversion collection. To augment the use of tropical sorghum germplasm in breeding programs, and to broaden the genetic base, ICRISAT began a program to convert the tall, photoperiod-sensitive landraces into photoperiod-insensitive lines. Currently, the collection has 1 76 conversion lines obtained from USA and 348 lines developed at ICRISAT, mostly from the *Zera-zera* landraces (from Ethiopia and Sudan), which are highly prized for their superior agronomic characteristics but are of restricted utility because of their photoperiod sensitivity and plant height.

Core collection. A sorghum core collection consisting of 3,475 accessions was established after stratifying the total world collection geographically and taxonomically into subgroups followed by clustering into closely related groups on the basis of characterization data using principle component analysis. Representative accessions from each cluster were drawn in proportion to the total number of accessions in the subgroup (Prasada Rao and Ramanatha Rao 1995). This core collection represents the genetic spectrum of the whole collection for utilization in crop improvement.

3.4. Characterization and Evaluation

Characterization of germplasm facilitates its utilization for crop improvement. Much of the germplasm assembled at ICRISAT was characterized for important morpho-agronomic characters at Patancheru during both the rainy and postrainy seasons, using the crop descriptors co-published by IBPGR and ICRISAT (IBPGR/ICRISAT 1993). The range of variation observed in the collection for 21 important traits is summarized in Table 3.4. Substantial variation could be seen in days to flowering (very early 33 days to very late 199 days), plant height (less than 1 m to more than 6 m), panicle size (head length 2.5-90 cm and head width 1.0-80 cm), shape, plant pigmentation, grain color and grain mass.

Traditional landraces and wild relatives evolve through centuries of introgression, and natural and human selection and acquire resistance to specific pests, diseases and environmental stresses, which can be used as sources of resistance. Over the years, ICRISAT scientists have screened sorghum germplasm accessions for resistance to diseases and pests under natural as well as artificial conditions (Stenhouse et al. 1997). For example, screening of germplasm accessions resulted in the identification of 60 accessions resistant to shoot fly, 169 accessions tolerant to stem borer and 12 accessions resistant to midge. Stable resistance to both shoot fly and stem borer was found in IS 1082, IS 1855, IS 2122, IS 2134, IS 2205, IS 2312, IS 5470, IS 5480, IS 5604, IS 18554 and IS 18577. Similarly, sources of resistance to grain molds were identified in more than 156 accessions, resistance to anthracnose was found in 14 germplasm accessions and resistance to downy mildew in 89 accessions. Germplasm accessions that have resistance to more than one disease were also identified, eg, IS 18758 (anthracnose and rust); IS 3443, IS 18882 (downy mildew and rust); IS 17141 (grain mold and anthracnose) and IS 3547, IS 8283 (grain mold, downy mildew and rust).

The germplasm has also been screened for resistance to *Striga,* abiotic stresses (drought and temperature stress) and for capability of emergence at higher soil temperatures. Some germplasm accessions identified as resistant to *Striga* and used in breeding programs are IS 2221, IS 4202, IS 5106, IS 7471, IS 8741, IS 9830, IS 9951 and IS 18331. The results of screening conducted over the years at ICRISAT and the number of promising lines identified with 20 useful traits are summarized in Table 3.5.

Table 3.4. Range of variation in selected characteristics of sorghum germplasm.

Characteristics	Range of variation
Plant height (postrainy season)	50-580 cm
Plant height (rainy season)	65-655 cm
Plant pigmentation	Tan to pigmented
Number of basal tillers	1-20
Nodal tillering	Present to absent
Midrib color	White to brown
Days to flowering (postrainy season)	36-154
Days to flowering (rainy season)	33-199
Panicle exertion	0-72 cm
Panicle length	2.5-90 cm
Panicle width	1-80 cm
Panicle compactness and shape	Very loose, stiff branches to compact oval
Glume color	Straw to black
Glume covering	Fully covered to uncovered
Seed color	Straw to black
Seed lustre	Lustrous to nonlustrous
Seed subcoat	Present to absent
Seed size	0.8-8 mm
100-seed weight	0.29-8.92 g
Endosperm texture	Completely starchy to completely corneous
Threshability	Freely threshable to difficult to thresh

The morphological variation in some accessions was found to be associated with economically important traits. For example, the presence of a phenolic compound (flavan-4-ol) in the pericarp results in a red pigmentation that is associated with resistance to grain molds. Of the 7123 accessions screened for grain mold resistance, all but one of the 156 resistant lines identified have a colored pericarp (Bandyopadhyay et al. 1988). Similarly, tan plant color is associated with resistance to leaf diseases and grain weathering. A brown midrib appears to be associated with low lignin content and high digestibility of plant parts. The dull green midrib color is used to identify sweet-stalk sorghums for chewing in South Africa (Stenhouse et al. 1997).

In addition to resistance to biotic and abiotic stresses, other important genes have also been obtained from the germplasm. For example, Singh and Axtel (1973) reported a high-lysine gene from two Ethiopian sorghums (IS 11167 and IS 11758), associated with relatively high levels of protein. Prasada Rao and Murthy (1979) reported the collection of *basmati* (scented) sorghums in India.

Multilocational evaluation of germplasm by ICRISAT scientists in collaboration with scientists of national programs in India, Kenya, Nigeria, Somalia and Thailand led to the identification of locally-adapted varieties and thus broadened the sorghum genetic base in these countries. Table 3.6 shows the list of collaborators, locations, number of accessions and the type of germplasm evaluated during different years. For instance, in a collaborative effort with the National Bureau of Plant Genetic Resources/Indian Council of Agricultural Research (NBPGR/ICAR), India, accessions originating from 35 countries, but predominantly from Ethiopia, India and Uganda, were evaluated for 26 characters at 3 locations to identify useful and adapted lines. The results were published as a catalog (Mathur et al. 1992).

Table 3. 5. Source of useful traits[1] identified from the sorghum germplasm maintained at ICRISAT Center.

Country	Traits A	Traits B	Traits C	Characteristics D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Total
Algeria			1																		1
Angola															1			1			2
Argentina			4																		4
Australia			9								6										15
Benin										1											1
Botswana	2		20					1		1											24
Burkina Faso	1		6									1				1	5				14
Cameroon			10			1		3	1				8		10	4	7	66		1	111
Central African Republic												1									1
Chad			3													2	4				9
China			15					5									1	1		15	37
Dominican Republic			1																		1
Egypt	4		5							1											10
Ethiopia	16		10	3	1			8	1				3		5	4	2	3			56
France										1											1
Germany					1																1
Ghana			11				3	14									5				33
Hungary								1													1
India	195	348	200	41	42	1		6	1	1	11	11	426	36	5	137	58	10		17	1546
Indonesia			1																		1
Iran								1										1			2
Israel			1																	8	9
Italy			1																		1
Jamaica			2																		2
Japan			6								1					3			1		11
Kenya	1		7					3		1	5		1		10	1	2	1			32
Korea, Republic of								1													1
Lebanon	1		54					15									1		3		74
Lesotho			56																		56
Malawi			5					4			1							2			12
Mali			8							1						1					10
Mexico			8					1			1								3		13

...continued

Table 3. 5. *Continued*

Country	Traits			Characteristics																	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Total
Myanmar								1											1		2
Nepal			1																		1
Niger			3														2				5
Nigeria			17	1	10	1		3	1	1	15	1	34		1	4	10	5		7	111
Pakistan	1		6		1																8
Portugal																			2		2
Senegal	1		2								1					1					5
Somalia			6															1			7
South Africa			158	1				24		2		1	2					3			191
Sri Lanka			1																		1
Sudan	1		316	8	5	5	2	19	3	7	10	2	13		37	4	3	13		11	459
Swaziland			27					2													29
Syrian Arab Republic			1																		1
Taiwan								1													1
Tanzania			2			1					1							2		9	15
Thailand			2					1													3
Turkey			5															1	16		22
USSR (former)			4															1	1		6
Uganda	5		8	2	2		1.00	4	2	3	23	1	3		3		8			20	85
United Kingdom	1																				1
USA	7		305	3	5	3		25	5	11	12	2	20		2		9	6	23	62	500
Yemen, Republic of			8		1													71			80
Zaire								1													1
Zambia			1					5										9			15
Zimbabwe			90		1			7			2				1			3			104
Unknown			6	1									2		1			1	1	124	136
Total	236	348	1413	60	69	12	6	156	14	31	89	20	512	36	76	162	117	201	51	274	3883

1. A = named cultivars; B = ICRISAT conversion lines; C = rainy-season basic collection; D = shoot fly resistant; E = stem borer; F= midge; G = head bug; H = grain mold; I = anthracnose; J = rust; K = downy mildew; L = *Striga* resistant; M = glossy; N = pop sorghum; O = sweet stalk; P = twin seeded; Q = large glume; R = bloomless; S = broomcorn and T = cytoplasmic male-sterile.

Table 3.6. Collaborators[1], locations, number of accessions and type of sorghum germplasm material characterized/evaluated by ICRISAT in different years.

Year	Collaborator	Location	Number of accessions	Type of material
1986	NBPGR, India	Hisar	2000	Photoperiod sensitive
	NBPGR, India	Trichur	2000	Photoperiod sensitive
	NBPGR, India	Issapur	1500	Forage sorghums
	NBPGR, India	Hisar	1500	Forage sorghums
	NBPGR, India	Jhansi	1500	Forage sorghums
	NBPGR, India	Akola	1500	Forage sorghums
1987	NBPGR, India	Trichur	2000	Photoperiod sensitive
	NBPGR, India	Akola	99	Evaluation for midseason drought resistance
	NBPGR, India	Issapur	4577	Entire Indian collection and promising forage types
1988	NBPGR, India	Issapur	2993	Selected germplasm
	AICSIP, India	Akola	1305	Rainy-season basic collection
	AICSIP, India	Coimbatore	1305	Rainy-season basic collection
	AICSIP, India	Indore	1305	Rainy-season basic collection
	AICSIP, India	Rajendranagar	1305	Rainy-season basic collection
	AICSIP, India	Surat	1305	Rainy-season basic collection
	Ministry of Agriculture, Somalia	Bonka, Baidoa	2066	Rainy-season short-duration sorghums
1989	NBPGR, India	Issapur	1200	Selected germplasm for forage
	IGFRI, India	Jhansi	1200	Selected germplasm for forage
	NRCS, India	Rajendranagar	1200	Selected germplasm for forage
	NBPGR, India	Akola	1000	Selected germplasm for grain
	TNAU, India	Coimbatore	1000	Selected germplasm for grain
	NRCS, India	Rajendranagar	1000	Selected germplasm for grain
	UAS, India	Bijapur	1002	Selected germplasm for postrainy-season program
	MPKV, India	Mohol	1002	Selected germplasm for postrainy-season program
	NRCS, India	Rajendranagar	1002	Selected germplasm for postrainy-season program
	WASIP, Nigeria	Bagauda	2010	Early-maturing germplasm
1990	NBPGR, India	Issapur	500	Selected germplasm for forage
	IGFRI, India	Jhansi	500	Selected germplasm for forage
	NRCS, India	Rajendranagar	500	Selected germplasm for forage
	NBPGR, India	Akola	500	Selected germplasm for grain
	TNAU, India	Coimbatore	500	Selected germplasm for grain
	NRCS, India	Rajendranagar	500	Selected germplasm for grain
	MPKV, India	Rahuri	200	Selected germplasm for postrainy-season program
	UAS, India	Bijapur	200	Selected germplasm for postrainy-season program
	ICRISAT, India	Patancheru	200	Selected germplasm for postrainy-season program
	WASIP, Nigeria	Bougouda	70	Selected early-maturing germplasm for grain
	EARCAL, Kenya	Kiboko	69	Selected germplasm for grain
1991	NBPGR, India	Issapur	200	Forage sorghums
	IGFRI, India	Jhansi	200	Forage sorghums
	NRCS, India	Rajendranagar	200	Forage sorghums
	NBPGR, India	Akola	200	Forage sorghums
	AICSIP, India	Surat	200	Forage sorghums
	NRCS, India	Rajendranagar	200	Forage sorghums
	NBPGR, India	Patancheru	200	Forage sorghums
	NRCS, India	Rahuri	1200	Selected germplasm for postrainy-season program
	NRCS, India	Sholapur	1200	Selected germplasm for postrainy-season program

...continued

Table 3.6. *Continued*

Year	Collaborator	Location	Number of accessions	Type of material
	NRCS, India	Bijapur	1200	Selected germplasm for postrainy-season program
	NRCS, India	Rajendranagar	1200	Selected germplasm for postrainy-season program
	NRCS, India	Patancheru	200	Selected germplasm for postrainy-season program
	INTSORMIL/Purdue University	Wad Medani (Sudan)	2340	Sorghum germplasm of Sudanese origin
1992	NBPGR, India	Issapur	200	Forage sorghums
	IGFRI, India	Jhansi	200	Forage sorghums
	NRCS, India	Rajendranagar	200	Forage sorghums
	ICRISAT, India	Patancheru	200	Forage sorghums
	NBPGR, India	Akola	200	Forage sorghums
	AICSIP, India	Surat	200	Forage sorghums
	AICSIP, India	Udaipur	200	Forage sorghums
	NRCS, India	Rajendranagar	200	Forage sorghums
	ICRISAT, India	Patancheru	200	Forage sorghums
	NRCS, India	Rajendranagar	1200	Selected germplasm for rainy-season program
	NRCS, India	Sholapur	1200	Selected germplasm for rainy-season program
	NRCS, India	Bijapur	1200	Selected germplasm for rainy-season program
	NRCS, India	Rajendranagar	1200	Selected germplasm for rainy-season program
1993	NBPGR, India	Issapur	200	Forage sorghums
	GAU, India	Anand	200	Forage sorghums
	NRCS, India	Rajendranagar	200	Forage sorghums
	ICRISAT, India	Patancheru	200	Forage sorghums
	NBPGR, India	Akola	200	Forage sorghums
	AICSIP, India	Surat	200	Forage sorghums
	AICSIP, India	Udaipur	200	Forage sorghums
	RAU, India	Durgapura	200	Forage sorghums
	ICRISAT, India	Patancheru	200	Forage sorghums
	FCRI, Thailand	Suphan Buri	500	Forage, grain, dual purpose
1994	NBPGR, India	Issapur	200	Forage sorghums
	ICRISAT, India	Patancheru	200	Forage sorghums
	NBPGR, India	Akola	200	Forage sorghums
	AICSIP, India	Surat	200	Forage sorghums
	AICSIP, India	Indore	200	Forage sorghums
	NRCS, India	Rajendranagar	200	Forage sorghums
	TNAU, India	Coimbatore	200	Forage sorghums
	ICRISAT, India	Patancheru	200	Forage sorghums

1. NBPGR = National Bureau of Plant Genetic Resources; AICSIP = All India Coordinated Sorghum Improvement Project; IGFRI = Indian Grassland and Fodder Research Institute; NRCS = National Research Centre for Sorghum; TNAU = Tamil Nadu Agricultural University; UAS = University of Agricultural Sciences; MPKV = Mahatma Phule Krishi Vidyapeeth, ICRISAT = International Crops Research Institute for the Semi-Arid Tropics; WASIP = West African Sorghum Improvement Program; EARCAL = Eastern Africa Regional Cereals and Legumes Network; INTSORMIL = International Sorghum/Millet Collaborative Research Support Program; GAU = Gujarat Agricultural University; RAU = Rajasthan Agricultural University and FCRI = Field Crops Research Institute.

3.5. Distribution

ICRISAT's gene bank has become a major source of diversity available to sorghum plant breeders. So far, ICRISAT has distributed sorghum germplasm samples to users in 105 countries (Tables 3.7 and 3.8). About 92% of the germplasm was distributed to national and international programs and universities, while 8% was provided to the private sector. The year-wise distribution of sorghum germplasm (246,901 samples) to different regions is given in Table 3.8.

Table 3.7. Distribution of sorghum lines from ICRISAT's Gene Bank.

Country	73-74	75-79	80-84	85-89	90-94	95-99	2000	2001	2002	Total
Argentina	0	83	213	110	5	0				411
Australia	3	86	425	132	25	5	2	3	9	690
Austria	0	0	98	0	0	0				98
Burundi	0	48	25	217	0	0				290
Belgium	0	22	0	1251	224	56				1553
Benin	0	7	0	17	0	0				24
Burkina Faso	0	359	2219	3640	0	0				6218
Bangladesh	0	414	143	42	0	34				633
Bolivia	0	24	0	50	0	0				74
Brazil	352	131	159	1864	79	0		9		2594
Barbados	0	0	91	0	0	0				91
Botswana	0	75	1240	472	0	0			70	1857
Cambodia	0	0	0	0	0	5				5
Central African Republic	0	0	0	0	3	0				3
Canada	2	52	0	14	350	106				524
China	0	70	108	602	33	32			10	855
Cameroon	0	0	2777	85	16	0				2878
Chad	0	0	0	141	0	0				141
Colombia	0	10	0	573	0	0				583
Cape Verde	0	0	125	0	0	0				125
Costa Rica	0	0	0	49	0	0				49
Czechoslovakia	0	0	30	0	0	0				30
Djibouti	0	0	0	50	0	0				50
Denmark	0	0	10	0	0	0	3			13
Dominican Republic	0	0	2	0	0	0				2
Ecuador	0	0	0	42	8	0				50
Egypt	0	782	0	147	1075	239				2243
El Salvador	0	36	49	0	0	0				85
Ethiopia	0	1751	651	656	31	0		452		3541
Fiji	0	0	0	0	20	0		1		21
France	0	33	649	342	189	290	7	6	10	1526
Ghana	0	19	182	5	0	92		2		300
Gambia	0	0	0	55	0	0				55
Germany	0	4	2	419	38	1	6			470
Guatemala	0	0	608	285	0	0				893
Guyana	0	0	0	99	0	0				99
Honduras	0	0	0	88	0	0	36			124
Haiti	0	0	0	0	0	0	28			28
Hungary	0	78	0	15	0	0				93
Indonesia	0	0	2	0	78	98				178
India	3	12145	10047	59352	27915	11648	638	2265	1626	125639
Ireland	0	12	0	0	0	0				12
Iran	0	0	0	620	425	12	16			1073
Iraq	0	0	0	28	0	0				28
Israel	0	0	20	100	0	0				120
Italy	0	55	166	777	239	10	10			1257
Jamaica	0	0	0	0	426	0			426	
Jordan	0	0	0	0	0	5			5	

...continued

Table 3.7. *Continued*

Country	73-74	75-79	80-84	85-89	90-94	95-99	2000	2001	2002	Total
Japan	0	0	668	244	73	9			3	997
Kenya	0	1132	2426	1471	5945	68				11042
Korea, Republic of	0	170	0	932	0	0	81			1183
Kuwait	0	0	0	0	0	0	2			**2**
Lebanon	0	105	0	0	0	0				**105**
Liberia	0	0	0	50	0	0				**50**
Libyan Arab Jamahiriya	0	20	0	0	70	0				**90**
Morocco	0	0	231	0	0	0				**231**
Mexico	0	1040	329	3244	105	0				**4713**
Mali	0	189	1279	424	559	1273	314			**4038**
Mozambique	0	0	0	248	0	0			6	254
Mauritania	0	0	33	0	0	0				33
Malawi	0	57	1244	509	0	0				**1810**
Myanmar	0	0	0	8	0	0				**8**
Malaysia	0	101	0	0	0	0				**101**
Niger	0	28	369	3	1838	15	1			**2254**
Nigeria	0	366	101	2075	415	20				**2877**
Nicaragua	0	0	0	46	0	0				**46**
Netherlands	0	41	99	6	2	0				**148**
Nepal	0	5	0	0	20	0				**25**
New Zealand	0	0	2	0	0	0				**2**
Pakistan	0	49	276	37	2	15	17			**396**
Peru	0	45	0	0	16	0				**61**
Philippines	0	7	131	207	26	0				**371**
Papua New Guinea	0	49	83	6	0	0				**136**
Qatar	0	126	30	202	0	0				**358**
Romania	0	0	114	0	20	0				134
Russia (former)	0	422	442	35	549	0		2		1450
Rwanda	0	81	161	1052	99	0				**1393**
Saudi Arabia	0	57	0	71	78	0				**206**
Sudan	0	1184	1049	0	2794	181				5208
Senegal	0	19	29	183	0	0				231
Solomon Islands	0	0	0	0	0	0			25	25
Sierra Leone	0	0	35	118	30	0	50			233
Somalia	0	59	839	2159	0	0				3057
South Africa	0	0	23	0	132	29				**184**
Sri Lanka	4	36	21	2	0	35				**96**
Surinam	0	37	8	0	0	0				**45**
Switzerland	0	0	0	67	1	0				**68**
Syrian Arab Republic	0	0	98	0	21	2				**121**
Thailand	0	0	158	10	820	214				**1262**
Trinidad and Tobago	0	0	0	0	0	15				**1S**
Turkey	0	0	0	99	0	50				**146**
Taiwan	0	25	41	17	0	0				**68**
Tanzania	0	329	1290	0	0	0		40		1659
United Arab Emirates	0	0	0	0	0	0	168	87		255
United Kingdom	1	123	702	47	155	36			3	1067
Uganda	0	0	903	46	1369	0				2318

...continued

Table 3.7. *Continued*

Country	73-74	75-79	80-84	85-89	90-94	95-99	2000	2001	2002	Total
Uruguay	0	0	126	0	30	0				156
USA	0	316	11228	3041	4046	178	7	990	17	19823
Venezuela	0	40	13	23	256	11	5			348
Vietnam	0	0	0	0	4	0				4
Yemen, Republic of	0	134	237	2104	178	29	132			2814
Yugoslavia (former)	0	0	52	0	0	154				206
Zaire	0	10	0	2149	0	0				2159
Zambia	0	60	1240	383	3431	0				5114
Zimbabwe	0	0	2659	4790	99	29			4	7581
Total	**365**	**22758**	**48810**	**98447**	**54362**	**14996**	**1523**	**3857**	**1783**	**246,901**

Table 3.8. Year-wise distribution of sorghum germplasm to different regions (as on December 2002).

Year	Africa	America	Asia	Europe	Oceania	Total
1973					3	3
1974		354	7	1		362
1975	148	750	2255	15		3168
1976	1682	146	2363	89		4280
1977	2097	503	3126	61	135	5922
1978	473	72	2164	27		2736
1979	2175	343	3958	176		6652
1980	268	461	2129	207	390	3455
1981	2616	1343	3755	38	16	7768
1982	3326	4839	2483	128		10,776
1983	9476	284	2922	802	21	13,505
1984	5444	5899	1133	747	83	13,306
1985	7474	573	3731	1382	18	13,178
1986	2715	3780	15427	1075	20	23,017
1987	4489	519	13456	300		18,764
1988	5625	1406	20630	29	99	27,789
1989	842	3250	11369	237	1	15,699
1990	4051	325	7419	133	40	11,968
1991	2553	47	7124	397		10,121
1992	878	4067	5475	222	5	10,647
1993	6772	7	7468	26		14,273
1994	3652	875	2736	90		7353
1995	682	187	1992	20	5	2886
1996	92	34	2903	15		3044
1997	822	3	3023	52		3900
1998	110	86	3486	340		4022
1999	245		729	170		1144
2000	365	76	1054	26	2	1523
2001	495		2355	1005	3	3857
2002	80	17	1639	22	5	1783
Total	**69,646**	**30,246**	**138,311**	**7832**	**866**	**246,901**

ICRISAT has responded positively to requests from national programs for the restoration of lost or damaged germplasm. The germplasm lost during the civil wars in Ethiopia and Rwanda was restored from the sorghum collections maintained in ICRISAT's Gene Bank. Similarly, sorghum collections from Botswana, Cameroon, Kenya, Nigeria and Somalia were repatriated to those countries for conservation and utilization (ICRISAT 1991).

As part of the FAO International Network of Ex Situ Collections, ICRISAT designated over 80% of the sorghum collection to the auspices of FAO/CGIAR. The agreement covers collections held by ICRISAT prior to December 1993, when the Convention on Biological Diversity (CBD) which affirmed sovereign rights of national governments over their natural resources came into effect. Though the designated germplasm will continue to be readily available to all, ICRISAT will have to ensure that recipients do not apply for intellectual property rights to it. For this, ICRISAT requires every recipient of germplasm to sign a Material Transfer Agreement (MTA). The availability of germplasm acquired after December 1993 is subject to conditions imposed by the source country.

3.6. Documentation

The morphological and agronomic data along with the passport information were until recently documented and stored on a VAX-based computer program called ICRISAT Data Management and Retrieval System (IDMRS) written in BASIC language. However, since information retrieval was slow, it was first replaced with System 1032 of 'CompuServe Technology' and now with Microsoft Access, a Relational Database Management System (RDBMS). MS Access facilitates a more efficient management of large databases and quicker retrieval of information in full or in part and in combinations of desirable traits to suit specific requirements. ICRISAT has supplied many copies of the passport and characterization database to scientists in India, Cameroon, Chad, China, Ethiopia, Germany, Mexico, UK and the USA (Prasada Rao et al. 1989).

Access to information on collections facilitates greater utilization of genetic diversity. ICRISAT is involved in the System-wide Information Network for Genetic Resources (SINGER) by which information on collections of genetic resources maintained at CGIAR centers can be accessed and searched collectively- SINGER provides ready access on the identity, origin and characteristics of the accessions in ICRISAT's Gene Bank to users worldwide through a website on the Internet.

3.7. Utilization

As with most crops, the earliest phase of sorghum improvement in Africa and Asia utilized pure line selections from among and within indigenous landraces, exploiting variations that arose from mutations and natural hybridization between different plant types. The second phase involved deliberate hybridization between landraces (Stenhouse et al. 1997). Some of the important derivatives of landraces include Maldandi in India, which still occupies millions of hectares in the postrainy-season sorghum belt; Naga White (IS 17632) in Ghana, notable for its exceptional seedling vigor; Segaolane (IS 18535) in Botswana; Framida (IS 8744), selected in South Africa from a variety from Chad and notable for its excellent resistance to *Striga asiatica;* Serena (IS 18520) in Tanzania and Uganda, subsequently shown to have some resistance to *Striga* and shoot fly, and found to be resistant to bird damage because of its high-tannin brown grain (Stenhouse et al. 1997).

The *Zera-zera* landraces from Ethiopia and Sudan have proved to be useful sources of many traits such as excellent grain quality, high grain yield potential, tan plant, straw glume color, resistance to leaf diseases, tolerance to grain weathering and desirable plant type (Prasada Rao and Mengesha 1979, 1981b). So extensive was their use in sorghum breeding programs at ICRISAT and national sorghum breeding programs, that they dominate the germplasm base of the elite materials. Other groups of germplasm have also been used as sources of specific traits. Indian landraces *(Durra)* have provided sources of resistance to drought, shoot fly, stem borer and midge. The *Kafir* race of sorghum in combination with *Durra* sorghums from eastern Africa provided the basis of the nuclear cytoplasmic male-sterility system that is the basis of all commercial hybrid sorghum breeding. The *Guinea* race from West Africa has provided resistance to grain mold and *Bicolor* sorghums, which have contributed to the breeding of forage sorghums. In some cases, germplasm accessions were directly released as improved cultivars. For example, E 35-1 (a selection from a *Zera-zera* landrace from Ethiopia) was recommended for release in Burkina Faso , and IS 9302 and IS 9323 *(Kafir* landraces from South Africa) were released for intermediate altitude areas of Ethiopia (Prasada Rao et al. 1989). Table 3.9 lists the number of sorghum germplasm accessions or selections released to date as superior varieties in different countries.

Alternative uses of sorghum. Normally, sorghum grain is ground or pounded after removing the pigmented pericarp. The flour is used to make porridge, bread or beer. Alternative uses of sorghum are becoming increasingly important and its use as food is slowly declining. For example, there is an increasing demand for forage-sorghum genotypes. Breeders of such genotypes in India have screened the world collection and identified many promising plant types with desirable attributes like plant height, profuse leafiness and dry matter digestibility. In a joint evaluation with NBPGR in India, 165 promising germplasm lines were identified for forage improvement (Mathur et al. 1991, 1992).

Sorghum grain and stalk too have vast potential for industrial utilization. Technology is now available to produce sugar, alcohol, starch, semolina and malt products from sorghum grain. Large-scale urbanization in Africa has resulted in the transformation of sorghum beer production from a community affair to an industrialized process (opaque beer brewing). Most reddish-brown sorghums from the Greater Horn of Africa and Southern Africa (Rwanda, Zimbabwe, Burundi and Ethiopia) are used for making beer. In West Africa, 75-90% of the sorghum grown (white grained) is used to make thin and thick porridges. In China, sorghum is mainly used to prepare a popular alcoholic drink (sorghum wine), vinegar and as poultry feed.

Sorghum grain is a major component of cattle, pig and chicken feeds in the USA, Central and South America, Australia and China. The grain is usually processed by grinding, rolling, flaking or steaming to improve digestibility. Dried sorghum stems that remain standing in the field after harvest are often grazed or cut and fed to livestock (Stenhouse et al. 1997). The fibrous stem is also used to manufacture fibre boards for construction purposes.

Sorghum landraces with sweet stalks are sparingly distributed across sorghum growing areas in Africa and India. The green and tender stalks are chewed like sugarcane. In Ethiopia, sweet-stalk sorghums are also used to make confectionery and to produce alcohol, adopting the sugarcane technology. Screening part of the world collection of sorghum germplasm for stalk sugar content revealed that 78 promising lines had sugar content ranging from 16.2-38.1% (on dry weight basis) (Subramaniam et al. 1987).

Table 3.9. 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 8965	Kenya	Myanmar	Shwe-ni 1	1980	
IS 2940	USA	Myanmar	Shwe-ni 2	1981	
IS 18758	Ethiopia	Burkina Faso	E 35-1	1983	
IS 23520	Ethiopia	Zambia	Sima	1989	
IS18758	Ethiopia	Burundi	Gambella 1107	1990	
IS 18484	India	Honduras	Tortillerio 1	1984	
IS 302	China	Myanmar	Shwe-ni 10	1980	
IS 5424	India	Myanmar	Shwe-ni 8	1980	
IS 8571	Tanzania	Mozambique	Mamonhe	1989	
IS 4776	India	India	UP Chari-1	1983	Forage sorghum
IS 3923	Zimbabwe	Botswana	Mahube	1994	
IS 23496	Ethiopia	Tanzania	Pato	1995	
IS 8193	Uganda	Rwanda		2001	
IS 8193	Uganda	Kenya	Kari Matama 1	2001	
IS 13444	Zimbabwe	Sudan	Arous el Rima	2001	Drought tolerant
IS 29415	Lesotho	Eritrea	Shiketi	2000	
IS 15401	Cameroon	Mali	Soumalemba	2001	
IS 21219	Kenya	Rwanda		2001	
IS 25395	Kenya	Rwanda		2001	
IS 33844	India	India	Parbhani Moti	2002	
IS 9302	South Africa	Ethiopia	ESIP 11	1980	
IS 9323	South Africa	Ethiopia	ESIP 12	1984	
IS 30468	Ethiopia	India	NTJ 2	1980	
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	
IS 2391	South Africa	Swaziland	MRS 13	1989	
IS 3693	USA	Swaziland	MRS 94	1989	
IS 9830	Sudan	Sudan	Mugawim Buda-2	1991	
IS 3924	Nigeria	India	Swarna		
IS 3541	Sudan	India	CS 3541		Converted *Zera-zera*
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 6928	Sudan	India	Moti	1978	Induced mutant
IS 18484 x IS 3924	India, USA	India	SPV 297	1985	
IS 4283 x IS 18478	India, India	India	CO-25	1985	

Popped sorghum grains are consumed as snack food in parts of India. A screening of 3682 selected germplasm accessions resulted in the identification of 36 cultivars with good popping quality (Prasada Rao et al. 1989).

Singh R and Axtel JD. 1973. High lysine mutant gene (hl) that improves protein quality and biological value of grain sorghum. Crop Science 13:535-539.

Stenhouse JW, Prasada Rao KE, Gopal Reddy V and Appa Rao S. 1997. Sorghum. Pages 292-308 *in* Biodiversity in trust (Fuccillo D, Sears L and Stapleton P, eds.). Cambridge, UK: Cambridge University Press.

Subramaniam V, Prasada Rao KE, Mengesha MH and Jambunathan R. 1987. Total sugar content in sorghum stalks and grains of selected cultivars from the world germplasm collection. Journal of Science, Food and Agriculture 39: 289-295.

Weibel DE. 1970. Broomcorn. Pages 441-468 *in* Sorghum production and utilization (Wall JS, and Ross WM, (eds.). Westport, Connecticut, USA: Avi Publishing.

Global Sorghum Genetic Enhancement Processes at ICRISAT

4

BVS Reddy, Prakasha Rao, UK Deb, JW Stenhouse, B Ramaiah and R Ortiz

Global Sorghum Genetic Enhancement Processes at ICRISAT

BVS Reddy[1], Prakasha Rao[2], UK Deb[3], J W Stenhouse[2], B Ramaiah[2] and R Ortiz[2]

4.1. Introduction

The global production of sorghum in 2003 is about 59 million t with an average productivity of 1.34 t ha^{-1} (FAO http://www.fao.org). Despite advances in breeding improved cultivars, productivity has increased only marginally. Productivity recorded at research stations in African countries and in India, Myanmar, Pakistan and Thailand in Asia was 3.5-4.0 t ha^{-1} in the rainy season. In China, it is about 12 t ha^{-1} at research stations but only 0.8-2.5 t ha^{1} in farmers' fields. This productivity gap of about 9-11 t ha^{-1} remains a challenge for agricultural scientists and extension specialists to bridge. Several biotic and abiotic stresses account for this gap.

The NARS need more research support in developing countries where sorghum productivity is much lower (about 1 t ha^{-1}) than in developed countries (3.5 t ha^{-1}) (Doggett 1988). The genetic enhancement efforts at ICRISAT are aimed at meeting this need. ICRISAT scientists located in Asia (at Patancheru, Andhra Pradesh, India); West Africa (at Bamako, Mali and Kano, Nigeria); Eastern Africa (Nairobi, Kenya); Southern Africa (Bulawayo, Zimbabwe) and Latin America (El Batan, Mexico) have been conducting sorghum improvement research in collaboration with NARS scientists.

This chapter briefly describes the global sorghum breeding processes followed over the years at ICRISAT, Patancheru. It also discusses the status of various germplasm sources identified and utilized in developing male-sterile lines and pure-line materials, exploitation of the male-sterility system, screening techniques and breeding concepts, the genetics and mechanisms of resistance, the materials tested in international trials and the cultivars released from ICRISAT-developed materials.

4.2. Evolution of Sorghum Breeding at ICRISAT

ICRISAT has been engaged in sorghum improvement since 1972. Its breeding program has seen several results: segregating families, populations with specific traits, intermediate products such as restorers or varieties, male-sterile lines, etc, with resistance to various biotic and abiotic factors. Improved sorghum cultivars (varieties and hybrids) developed by NARS in collaboration with ICRISAT have been released in several countries. Since its establishment in 1972, ICRISAT has made deliberate attempts to diversify the germplasm base to enhance yield levels and to identify sources of resistance to pests and diseases and use them to develop varieties and seed parents.

---

[1] International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
[2] Formerly of the International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
[3] Centre for Policy Dialogue, House 40/c, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.

Reddy BVS, Rao Prakasha, Deb UK, Stenhouse JW, Ramaiah B and Ortiz R. 2004. Global sorghum genetic enhancement processes at ICRISAT. Pages 65-102 in Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy RVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India; International Crops Research Institute for the Semi-Arid Tropics.

Incorporating diverse germplasm into elite breeding materials widens the gene base but requires time, effort and resources. The transfer of undesirable traits appears to be an unavoidable consequence of the introgression process. ICRISAT's role has been to emphasize the long-term goals of developing diverse source materials and intermediate products that are essential for future gains. In utilizing genetic resources, ICRISAT pursues three broad approaches: (1) transfer of genes for specific traits such as disease or pest resistance from the germplasm source into an agronomically desirable background; (2) formation of gene pools for specific traits, which results in diversity of the 'genetic background' as well as for the target trait; and (3) development of new methods for effective utilization of genetic resources such as application of molecular marker-assisted selection.

Breeding concepts and objectives and the mode of research involving partners have undergone several changes since the initiation of sorghum improvement at ICRISAT. The external environment, the perceptions of development investors, NARS capacities and ICRISAT's research agenda have influenced the evolution of the global breeding program. For the sake of convenience, we discuss this evolution - which is continuing - in six major phases:

1. Wide adaptability and high grain yield (1972-1975)
2. Wide adaptability and screening techniques (1976-1979)
3. Regional adaptation and resistance breeding (1980-1984)
4. Specific adaptation and resistance breeding (1985-1989)
5. Trait-based breeding and sustainable productivity (1990-1994)
6. Upstream research and intermediate products (1995 onwards)

4.2.1. Wide Adaptability and High Grain Yield (1972-1975)

This period was characterized by the generous support of development investors and an immediate need to develop varieties with wide adaptability and higher grain yield. The emphasis was on wide adaptability with the premise that the materials developed at ICRISAT-Patancheru would be adapted in various SAT regions of the world. Higher grain yield, primarily in the red grain background, was the major breeding objective. Population improvement through recurrent selection was carried out in 33 populations collected from the USA (from the universities of Nebraska, Purdue and Kansas) and Australia, and from the programs in West Africa (Nigeria) and East Africa (Tanzania). Nine populations such as the Indian diallel population (white grain), the tropical conversion population (Puerto Rico), high-altitude population, etc, were also improved. Multi-environment testing for grain yield was carried out initially at Patancheru in varied soils and seasons (ICRISAT 1975). Resistance to shoot fly, grain mold and *Striga* was considered important later on and programs to identify resistant sources were initiated. Studies on grain characters that contribute to food and nutritive traits such as high lysine content were also begun. NARS involvement during this phase was confined to providing information on constraints to sorghum production and final testing of advanced breeding lines for adoption.

4.2.2 Wide Adaptability and Screening Techniques (1976-1979)

The major research thrusts during this period were (a) identifying high-yielding genotypes; (b) developing efficient screening techniques for yield constraints; and (c) identifying sources of resistance. New variability was generated by crossing male-sterile plants in populations with select germplasm lines or named cultivars to select for high grain yield. Population breeding approaches

-source populations, backup populations, advanced populations and fast-lane populations - were improved for high grain yield and wide adaptability through wider testing of S_1/S_2 progenies. International trials were initiated in Africa, Asia and South America (ICRISAT 1976a) to identify materials with high grain yield potential and wide adaptability. Greater emphasis was laid on breeding photoperiod-insensitive varieties with earliness. Screening techniques to identify sources of resistance to major pests and diseases (including *Striga)* were given major emphasis during this phase. Thus, in addition to breeding for high grain yield, research was initiated to develop materials with resistance. While retaining the emphasis on population improvement, programs for wide adaptability, high grain yield and specific pedigree breeding were also initiated for (a) drought resistance; (b) stalk rot resistance and postrainy season adaptability; (c) downy mildew resistance; and (d) grain mold resistance in cream colored grain genotypes. The sorghum program allocated 50% of its resources to population improvement, and 50% to work on specific adaptability, including grain nutritional quality. A major shift in selection from red-grained to white-grained genotypes occurred during this phase. Research on foodgrain quality was pursued with greater vigor. The target materials were expanded to include seed parents and hybrids in addition to varieties. A regional program based in Burkina Faso in West Africa started working on regional adaptability towards the end of 1978 (ICRISAT 1978b), the details of which can be found in Chapter 5 of this book.

4.2.3. Regional Adaptation and Resistance Breeding (1980-1984)

This phase was characterized by (a) intensive testing of varieties in international trials for high grain yield in various regions and in international nurseries for resistance to various pests and diseases; (b) initiation of work on regional adaptability including tolerance to early-, mid- and late-season drought; (c) breeding for high grain yield and resistance to various pests and diseases to ensure sustainability of production; (d) large-scale production and testing of hybrids; and (e) further refinement of various screening techniques. Collaborative research was initiated at various locations in India (Anantapur, Bhavanisagar, Bijapur and Dharwad), West Africa (Burkina Faso), East Africa (Nairobi) and Latin America (Mexico) to serve regional needs. Thus, three regional programs were established in addition to the global program at Patancheru. The scope of the West Africa program was expanded to include breeding for *Striga* resistance in Africa in addition to regional adaptation. Materials bred at Patancheru were introduced and evaluated in all the regional programs. This enabled ICRISAT to identify several promising lines adapted to various regions. Screening techniques for resistance to grain mold, downy mildew, rust, anthracnose, leaf blight, charcoal rot, shoot fly, stem borer, midge and *Striga* were refined. Similarly, techniques to screen materials for emergence under high temperatures and crusting, and for tolerance to early-, mid- or late-season drought were also developed. Both population improvement (with recurrent selection) and pedigree breeding programs were given equal emphasis. White-grain types that are useful in preparing various foods (ICRISAT 1985) were preferred, and, as a result, grain color variability in the breeding materials was lost. Thus, by the end of this project the initial program of breeding for wide adaptability was diversified into regional programs by taking advantage of various ICRISAT sites in Africa and Latin America.

4.2.4. Specific Adaptation and Resistance Breeding (1985-1989)

This period was characterized by regional network trials and development of high-yielding and pest/disease-resistant pure lines. In addition to the International Sorghum Varieties and Hybrids

Adaptation Trials (ISVHAT), the Asian Regional Sorghum Hybrids Adaptation Trial (ARSHAT), the Asian Regional Sorghum Varietal Adaptation Trial (ARSVAT), the Eastern Africa Co-operative Sorghum Screening Nursery (EACSSN), and the West Africa Sorghum Hybrid Adaptation Trials (WASHAT) were conducted. For the first time, networking gave member countries greater participation in planning these trials, including the opportunity to test their own materials in other countries. In addition to the sites in West Africa, East Africa and Latin America, ICRISAT established another research location at Bulawayo, Zimbabwe, for Southern Africa. Concerted efforts were made to identify the major abiotic and biotic constraints in each region and a breeding program was initiated to develop multifactor-resistant (MFR) populations and targeted populations (Table 4.1) As a result, there was a shift from developing high-yielding populations to MFR populations. Later, R/MFR, B/MFR and BR/MFR populations were merged to form ICSP IBR/MFR and ICSP 2BR/MFR populations for rainy-season adaptation (Africa and Asia), and the BR/MFR population was continued as ICSP 3BR/MFR population for the postrainy season. In addition, a pedigree-breeding program for specific adaptability was carried out to develop high-yielding varieties with resistance to appropriate insect pests and diseases at each of the locations. Thus, season and location specificity were factored within, combining high grain yield and a set of resistant factors. At least seven geographic areas - Latin America (low altitude and high altitude), West Africa, East Africa, Southern Africa and Asia (rainy and postrainy seasons) - were addressed during this phase.

Table 4.1. Multifactor-resistant (MFR) populations developed at ICRISAT.

Population	Important traits incorporated	Traits monitored
ICSP 1R/MFR and ICSP 2B/MFR	Resistance to grain mold, stem borer or shoot fly and midge	Improved grain yield, charcoal rot, stand establishment, *Striga* and food quality
ICSP 3R/MFR and ICSP 4B/MFR	Stand establishment and resistance to grain mold and *Striga*	Improved grain yield, charcoal rot, stem borer or shoot fly, midge and food quality
ICSP 5BR/MFR	Improved grain yield and resistance to stem borer or shoot fly and *Striga* and food quality	Charcoal rot, grain mold, midge and stand establishment

4.2.5. Trait-based Breeding and Sustainable Productivity (1990-1994)

By the late 1980s, many NARS had enhanced their crop improvement programs, and were involved in planning the crop improvement programs of International Agricultural Research Centers (IARCs) aimed at specific adaptability. Therefore, during 1989/90, a major review of the efficiency of various breeding programs was undertaken at ICRISAT and the following decisions were taken:

- Population improvement would be scaled down to gene pool development as it was not found to be as efficient as pedigree breeding in meeting short-term goals.
- Combining several resistance traits at one time is less efficient. Hence, a trait-based breeding approach was suggested.
- Intermediate products such as seed parents, restorers and gene pools were suggested as the target materials for the ICRISAT-Patancheru program, and finished products (varieties and hybrids) for the Africa-based programs.
- A participatory mode of research planning and execution would be followed, involving the NARS on the basis of their needs.

- Since A/B-lines were susceptible to most of the diseases and pests, major emphasis would be placed on incorporating resistance into high-yielding seed parents at ICRISAT-Patancheru.
- Materials would be tailored to production systems in specific areas within the region. On the basis of the amount and duration of rainfall, growth period of the crop, temperature and soils, a total of 29 production systems (PSs) in the semi-arid tropics were identified.

Thus, the global sorghum improvement program was reoriented to develop materials suitable to 12 PSs in Asia, 6 in West Africa, 6 in East and Southern Africa and 5 in Latin America. The severity of the constraints to sorghum productivity in each PS was prioritized and formed the main focus of research in sorghum breeding (Table 4.2).

Table 4.2. Drought and biotic constraints and their severity affecting sorghum productivity in the SAT.

		Low rainfall			Medium rainfall							High rainfall		Post-rainy	Low temp, high elev.	
		Asia PS[1]	WA PS[2]	E&SA PS[3]	Asia PS			WA PS		E&SA PS		WA PS	E&SA PS	Asia PS	E&SA PS	LA PS[4]
Themes/ constraints[5]	Rank[6]	1	13	19	4	7	9	14	15	20	21	16	22	8	23	26
Striga	18			4		3		5	5	5	5	5				
Grain/stover	22	3	4	3	3	5	5	5	5	5	5	4			5	4
Stem borer	34		4	3	4	3	3	5	5	5	3	5		4		
Grain mold	35		3			3	4	3	4		4	5	5		3	
Low temperature	44														5	
Head bugs	46		3			3	4	4	5	3		5				
Anthracnose	48				3			4	5	3	5	5			4	
Midge	49											4			4	
Acidic soil	61															
Drought	65	3	5	5			3	5	4	5	3			4		
Leaf blight	66									3	5				4	3
Foliar diseases	72								3			3				4
Shoot fly	76						4		3			4		5		
Forage	86		3					4								3
Sooty stripe	100							4	4		4	4				
Long smut	101		5	3				5	4			3				
Storage pests	102		4	3				4	3	4	4	3			3	
Ergot	104								4		3	4				

1. Asia PS = Asian production systems.
2. WA PS = West African production systems.
3. E&SA PS = East and Southern African production systems.
4. LA PS = Latin American production systems.
5. Severity was measured on a scale of 1 to 5, where 1 = least severe and 5 = most severe. The analysis is based on ICRISAT project planning exercise, 1994.
6. Ranking of constraints across crops at ICRISAT; Source: ICRISAT (1992a).

Dynamic crop improvement programs were conducted by ICRISAT at Patancheru (India), Bamako (Mali), Kano (Nigeria), Nairobi (Kenya) and Bulawayo (Zimbabwe). At Patancheru, the emphasis during these years was on strategic research-development of techniques and intermediate products for utilization by the NARS programs in Asia. Accordingly, an extensive program of diversifying and breeding new milo cytoplasmic male-sterile lines for earliness, introgression with *Durra* and *Guinea* races, incorporating bold and lustrous grain characters, and resistance to *Striga,* shoot fly, stem borer, midge, head bug, grain molds, downy mildew, anthracnose, leaf blight and rust was carried out (ICRISAT 1993a). The usefulness of single-cross male-sterile F_1s in developing three-way-cross forage hybrids was also examined (ICRISAT 1995). Strategic research was carried out to gain knowledge on stability of alternative cytoplasms, identification of differential minimum testers for various male-sterile cytoplasms, conversion of improved resistance sources into male-steriles using alternative cytoplasms, development of isonuclear lines, genetic methods of rectifying low temperature-induced female sterility in 296A and development of restorer lines for alternative cytoplasms (ICRISAT 1995). Information was generated on the role of early seedling vigor and growth rate in biomass accumulation. A restorer breeding program was undertaken to develop high-yielding lines with resistance to shoot fly, stem borer, midge and grain mold, and significant gains were realized in combining midge resistance and high grain yield in restorers or varieties.

Novel populations or trait-specific gene pools for bold grain and high productive tillering were developed. Test crosses involving progenies of postrainy-season landraces as pollinators were examined for their fertility restoration ability under cool nights and for productivity in the postrainy season. Variability for restoration was quite significant, indicating the possibility of selection within and among landraces. The frequency of hybrids with productivity was higher in landrace hybrids than in bred restorer hybrids (Reddy and Stenhouse 1994). Unlike other released cultivars, landrace hybrids mimic landraces in the postrainy season and, therefore, would have better acceptance. Progress in improving cultivars by introducing desirable resistance or earliness for adaptation to specific regions was reported at other ICRISAT locations (ICRISAT 1991; ICRISAT 1992b; ICRISAT 1992c; ICRISAT 1993b and ICRISAT 1993c). Chapters 5 and 6 provide further details of sorghum research in Africa and Latin America, respectively.

4.2.6. Upstream Research and Intermediate Products (1995 Onwards)

The sorghum improvement program was further reviewed in 1994, and emphasis was laid on upstream research including biotechnology tools. The partnership mode of conducting research to develop improved intermediate products at ICRISAT-Patancheru and finished products (varieties and hybrids) at other ICRISAT locations in Africa was emphasized.

The current emphasis is to produce parental lines (seed parents and pollen parents) and gene pools. Accordingly, the objectives of the program are to breed resistant seed parents and restorer lines, to develop specific new gene pools and novel plant types and to identify and use molecular markers. The breeding programs in Africa will continue to develop high-yielding cultivars (varieties and hybrids) with resistance to *Striga* and head bug which are endemic to the region.

ICRISAT's Medium Term Plan (1994-98) (ICRISAT 1992a) reassessed various constraints to sorghum production in the SAT on a global basis, giving less emphasis to minor local factors. It prioritized further the importance of these constraints to provide a rational basis for the allocation of resources and time. Eighteen research themes (see Table 4.2) were thus reduced to 13 (Table 4.3). All the 13 major themes are being addressed through global research projects. Many of these constraints are common to some production systems. ICRISAT's global sorghum projects take into account these common features as well as the individual requirements of different regions. Table 4.4 lists the main constraints to sorghum production in Asia and Africa, as identified in the MTP 1994-98, and the strategies adopted by breeders working in the regional programs to address them. In general, the occurrence of a constraint, the comparative advantage of a location or region and research need (Table 4.3) provide the basis for emphasis on a type of research in any region. In Asia, the NARS have considerable strength in terms of scientific manpower and research infrastructure, and the private seed industry is well established. So, ICRISAT mainly develops suitable intermediate products such as hybrid parents and random-mating gene pools with specific traits for Asia. In Africa, the NARS in general are still developing their research infrastructure, the private seed industry is still in its infancy and public seed services are not yet strong. So, in that region, ICRISAT develops finished products such as varieties and hybrids.

Diversification of the genetic base of breeding lines is an important objective, which is achieved by intercrossing resistant sources of diverse origin - often of different races - with agronomically elite lines. At ICRISAT-Patancheru, recurrent selection is practised in broad-based, random-mating

Table 4.3. Ranking of 13 constraints or themes relevant to sorghum in 10 production systems of the SAT[1].

	Production Systems (PS)									
	Asia				West and Central Africa			East and Southern Africa		
Constraint/theme[2]	PS 4	PS 7	PS 8	PS 9	PS 14	PS 15	PS 16	PS 19	PS 20	PS 21
Drought			4	3	5	4		5	5	3
Low temperature										
Grain molds		3		4	3	4	5			4
Anthracnose	4				4	5	5		3	4
Leaf blight						3	3		3	5
Foliar diseases						3	4			
Stem borer	4	3	4	3	5	5	5	3	5	3
Midge		5		4	5	4	4			
Head bug		3		4	4	5	5		3	5
Shoot fly			5	4						
Striga		3			5	5	5	4	5	5
Grain and stover yield	3	5	3	5	5	5	4	3	5	5
Forage sorghum		3			4					

1. Source: Medium Term Plan, ICRISAT 1994-98 (ICRISAT 1992a).
2. Severity measured on a scale of 1 to 5, where 1 = least severe and 5 = most severe. Analysis based on ICRISAT project planning exercise, 1994.

Table 4.4. Important constraints to sorghum production targeted for genetic improvement in Asia and Africa.

Constraint/theme	Asia	West and Central Africa	Eastern Africa	Southern Africa
Drought	++[1]	+[2]	+	++
Low temperature	3	-	++	-
Grain molds	++	+	-	-
Anthracnose	++	++	-	-
Leaf blight				
Foliar diseases	+	++	-	-
Shoot fly	++	-	+	-
Striga	+	++	+	++
Stem borer	++	++	+	+
Midge	++	+	+	-
Head bug	+	++	-	-
Grain and stover yield	++	++	++	++

1. ++ = Basic, strategic and applied research.
2. + = Applied and adaptive research,
3. _ = No emphasis.

populations or gene pools for specific traits [such as maintainer (B), restorer (R), high tillering (HT), large grain (LG)], and resistance to shoot pests, grain molds and head pests. In West and Central Africa (WCA), the development of random-mating populations of *Guinea* and *Caudatum* races has been completed and another *Guinea* x *Caudatum* type population is under development. Random-mating populations for early maturity have been developed in Southern Africa. These populations will have good agronomic backgrounds and adaptability while preserving their broad genetic variability. Another important goal is to broaden the cytoplasmic-genetic diversity of hybrid parents. Grain yield improvement of several female parents of non-milo origin ($A_2/A_3/A_4$) and incorporation of resistance factors in A, cytoplasmic male-sterile lines is being pursued using backcrossing procedures.

Farmers are involved in ICRISAT's selection processes through visits to germplasm and preliminary cultivar nurseries on station. Groups of farmers are invited to the station through extension agencies and nongovernmental organizations (NGOs). They are asked to evaluate the entries on a simple scale of 1 to 5 (1 = excellent, 5 = very poor) on an overall basis or for individual agronomic traits, depending upon the targets of the trial. Their scores are compared with agronomic data collected independently to help identify their preferences. Thus, the farmers' impressions and visual scores of preliminary or advanced entries in comparison with their own local checks are integral to participatory selection of cultivars. Conclusions from such exercises help retarget breeding and selection procedures on the basis of farmer-preferred traits. The best cultivars emanating from advanced trials are tested in on-farm trials managed by the farmers themselves. On-farm trials are organized in collaboration with NARS and NGOs, and are monitored by multidisciplinary teams (socioeconomists, breeders, crop protectionists and agronomists) from ICRISAT and NARS.

4.3. Germplasm Utilization

Successful development of new varieties and hybrids depends largely on the availability of source germplasm with desirable traits such as disease and pest resistance, drought tolerance and improved grain quality. The identification and incorporation of desirable traits into a wide range of germplasm is important to expand the gene pool. ICRISAT's screening program identified additional germplasm lines with desirable traits.

4.3.1. Grain Yield and Agronomic Desirability

The major germplasm sources utilized in varietal improvement so far include temperate lines from the USA, *Zera-zera* lines from Ethiopia and Sudan and some lines of Indian origin. The male-sterile gene sources used were mainly CK 60, 172, 2219, 3675, 3667 and 2947. These were further diversified by using parents such as CS 3541, BTX 623, population derivatives (Bulk-Y, Indian Synthetic, FLR, US/R, US/B, Serere, Diallel and WAE), IS 517, IS 1037, IS 2225, IS 3443, IS 6248, IS 10927, IS 12611, IS 12645, IS 19614, E 12-5, E 35-1, ET 2039, Lulu 5, M 35-1 and Safra. The basic germplasm sources used in the development of restorer parents and varieties were IS 84, IS 1151, IS 3687, IS 3691, IS 3922, IS 3924, IS 3941, IS 6928, IS 12622, IS 18961, IS 19652, ET 2039, Safra, E 12-5, E 35-1, E 36-1 and GPR 168.

Although germplasm from different regions of the world was used, the number of lines involved was very few. This has led to a yield plateau in rainy-season genotypes and only marginal yield increases in postrainy-season genotypes. To break this plateau, efforts are being made to involve accessions recently collected from Ethiopia, Yemen, Cameroon, Nigeria, Russia and China.

4.3.2. Resistance to Biotic and Abiotic Stresses

The main strategy adopted to reduce losses due to insect pests and diseases including *Striga* has been the incorporation of resistance to these pests and diseases. Systematic screening of germplasm accessions was initiated in 1974/75 to identify sources of resistance to important pests and diseases. This was intensified during the past decade in collaboration with NARS. So far, the bulk of the germplasm and breeding material has been screened for most of the important pests and diseases. This has facilitated the identification of several sources of resistance.

The most exhaustive germplasm screening was carried out for resistance to shoot fly and stem borer. Many of the sources of resistance were found to exhibit low infestation under high pest pressure. The sources identified are predominantly of Indian origin, while a few are from Ethiopia, Nigeria, Sudan and USA. The stable sources of resistance (Table 4.5) for shoot fly and stem borer were IS 1082, IS 2205, IS 5470, IS 5480, IS 5604 (India), IS 18554, IS 18577 (Nigeria), IS 2312 (Sudan), IS 18551 (Ethiopia), IS 2122, IS 2134 and IS 2146 (USA). Besides, other Indian germplasm lines such as M 35-1 (IS 1054), BP 53 (IS 18432), Karad Local (IS 18417) and Aispuri (IS 18425) were used as resistance sources.

Extensive screening of germplasm was also carried out for midge and many resistant sources were identified. Notable among these are DJ 6514 (IS 18700), IS 18961, S-GIRL-MR 1 (IS 18699), TAM 2566 (IS 18697), IS 3443, IS 12573C and AF 28 (IS 18698). The lines DJ 6514 and IS 3443 were used at ICRISAT to develop ICSV 197 (SPV 694), an improved midge-resistant variety.

Success was also achieved in the identification and utilization of disease resistance sources. Highly stable resistance sources (Table 4.5) were identified for all foliar diseases. The tan-pigmented plant type was found to be associated with resistance to foliar diseases. Grain mold resistance was found to be moderate in the white-grain background. E 36-1, QL 102 and QL 104 have been identified as the most stable resistant sources for charcoal rot disease.

Multiple disease resistances are available in some lines. Based on multilocational evaluation over the years, the following lines were found to have multiple disease resistance: ICSV 1, ICSV 120, ICSV 138, IS 18758 and SPV 387 (anthracnose and rust); IS 3547 (grain molds, downy mildew, anthracnose and rust); IS 14332 (grain molds, downy mildew and rust); IS 17141 (grain molds and anthracnose); IS 2333 and IS 14387 (grain molds and downy mildew); and IS 3413, IS 14390 and IS 21454 (grain molds and rust). These lines are currently being used in the breeding programs.

Resistance to *Striga* has been reported in several indigenous sources. Based on extensive laboratory and field screening, many *Striga*-resistant lines were identified from the germplasm. However, many of these sources could not be used in the breeding programs because of their undesirable agronomic base. Some germplasm lines used in *Striga* resistance breeding were: IS 18331 (N 13), IS 87441 (Framida), IS 2221, IS 4202, IS 5016 and IS 9830. Some of the breeding lines like IS 555, IS 168, SPV 221 and SPV 103 proved to be useful resistant sources. The *Striga*-resistant variety SAR 1 developed at ICRISAT from the cross IS 555 X IS 168 was released for cultivation in *Striga*-endemic areas. Several other promising selections derived from these resistance sources, both from ICRISAT and Indian programs, have been identified.

Nearly 1300 germplasm lines and 332 breeding lines were screened for early- and mid-season drought stress. The most promising ones for various droughts are: E 36-1, DJ 1195, DKV 3, DKV 4, DKV 17, DKV 18, IS 12611 and IS 6928 for early-season and terminal drought, and DKV 1, DKV 3, DKV 7, DJ 1195, ICSV 272, ICSV 273, ICSV 295 and ICSV 572 for mid-season stress.

Table 4.5. Resistant germplasm sources and improved lines identified at ICRISAT.

Constraint	Resistance sources	Improved lines: R-lines	Improved lines: A-B lines
Drought			
Seedling emergence	IS 301, Naga White, D 71463, D 71464	IS 1045, IS 2877, D 38060, D 38061, D 38093, ICSV 88050, ICSV 88065, SPV 354	VZM1-B, 2077B
Early	IS 824, IS 1037, IS 3477, IS 8370, IS 10596, IS 10701, E 36-1, DJ 1195	ICSV 88056, ICSV 88057, ICSV 88059, ICSV 88063, IS 24025, SAR 35	ICSB3, ICSB6, ICSB 11, ICSB 37, ICSB 54, ICSB 88001, ICSB 22198
Midseason	IS 1347, IS 13441, DJ 1195	ICSV 213, ICSV 221, ICSV 210, ICSV 272, ICSV 273, ICSV 295, ICSV 572, D 71463, D 71464, DKV 1,DKV 3,DKV 7	ICSB58, ICSB 196B, ICSB 2077B
Terminal	DJ 1195, M 35-1, IS 6928, IS 12611, IS 22314, IS 22380, E 185-2	D 38001, D 71283, D 71464, IS13441,DKV3,DKV4,	ICSB 17, 296B
Acidic soils	Real-60, ICARAVAN, SBL 107 and other INTSORMIL products	DKV 17,18 A 2267-2, ICSR 102, ICSR 110, ICSR 143, ICSR 91020-1, ICSR 93033, ICSV 93042	ICSB 89002, SPMD 94006, SPA 2-94013, SPA 2-94021, SPA 2-94039, SPAN 94046, ICSB 38
Striga	IS 18331 (N 13), IS 87441 (Framida), IS 168, IS 555, IS 2221, IS 4202, IS 5016, IS 9830	SAR 1, SAR 29, SAR 36, ICSV 697, ICSV 760, ICSV 761, SPV 103, SPV 221	SRN 4882B, SPST 94001, SPST 94002, SPST 94006, SPST 94010, SPST 94018, SPST 94026, SPST 94030, SPST 94034
Insects			
Shoot fly	PS 19349, IS 1054, IS 1082, IS 2312, IS 2313, IS 2134, IS 2146, IS 2195, IS 2205, IS 5604, IS 18417, IS 18551	20-67 ICSV 702, ICSV 705, ICSV 708, PS 21318	ICSB 51, ICSB 101, ICSB 102, SPSFR 94006, SPSFR 94007, SPSFR 94022, SPSFR 94036, SPSFPR 94002, SPSFPR 94007, SPSFPR 94012, SPSFPR 94025
Stem borer	IS 1044, IS 1151, IS 2122, IS 2123, IS 2205, IS 2375, IS 5470, IS 5480, IS 5604, IS 18425, IS 18432, IS 18554, IS 18577	ICSV 112, ICSV 700, ICSV 702, ICSV 714, ICSR 7, ICSR 38, ICSR 63, ICSR 125, ICSR 89066, PB 14698-2, PB 15621	ICSB 25, ICSB 37, ICSB 67, ICSB 70, ICSB 101, ICSB 102, SPSBR 94005, SPSBR 94011, SPSBR 94013, SPSBR 94017, SPSBPR 94010, SPSBPR 94011, SPSBPR 94013
Midge	AF28, DJ6514, IS 12666C, TAM 2566, S-Girl-MR-1(IS 18699), IS 3443, IS 18961, IS 12573C,	ICSV 112, ICSV 197, ICSV 745, ICSV 743, ICSV 89057	ICSB 3, ICSB 24, ICSB 25, ICSB 82, ICSB 102, SPMD 94006, SPMD 94010, SPMD 94016, SPMD 94022, SPMD 94025, SPMD 94045, SPMD 94060
Head bug	Mali Sor 84-2, Mali Sor 84-7, IS 2573C	ICSV 92030, IS 2761, IS 9692, IS 17610, IS 17645	ICSB 13, ICSB26, ICSB 37, ICSB 38, ICSB 42, SPHB 94004, SPHB 94007, SPHB 94011, SPHB 94014

...continued

Table 4.5. *Continued*

Constraint	Improved lines		
	Resistance sources	R-lines	A-B lines
Diseases			
Grain mold	IS 2333, IS 2501, IS 2815, IS 3436, IS 9225, IS 9470, IS 10288, IS 14332, IS 14387, IS 14390, IS 15119, IS 17141, E 35-1, CS 3541, CS 3555, CS 3573, CS 9225, CS 12658	ICSV 96094, ICSV 96105, GM 950187, GM 950199	ICSB 11, ICSB 17. ICSB 37, ICSB 42, ICSB 51, ICSB 70, SPGM 94001, SPGM 94002, SPGM 94005, SPGM 94008, SPGM 94011, SPGM 94035,
Anthracnose	IS 2058, IS 3575, IS 3547, A 2267-2, IRAT 204, TRL74C-57	ICSV 112, ICSV 173, ICSV 91020, ICSV 91021, SPV 387, ICSR 91001, ICSR 91006, IS 6928, IS 8354	SPGM 94060, ICSB 38, ICSB 55, ICSB 101, ICSB 89004, ICSB 91001, 296B, PM7061A, SPAN 94010, SPAN 94021, SPAN 94029, SPAN 94033, SPAN 94035
Leaf blight	A 2267-2, IS 2906, IS 18417, IS 18425, IS 18758, IS 19667, IS 19669	ICSV 1, ICSV 120, ICSV 138, ICSR 91022, ICSR 91025	ICSB 26, ICSB 53, ICSB 88004, ICSB 91002, BTX 2755, SPLB 94004, SPLB 94007, SPLB 94010, SPLB 94023
Rust	A 2267-2, IS 3413, IS 2816C, IS 3574C, IS 13896, IS 18417, IS 21454, IS 29016	ICSV 91022, ICSV 91023, ICSV 197, ICSR 91027, ICSR 91029	ICSB 3, ICSB 11, ICSB 22, ICSB 70, ICSB 72, ICSB 101, SPRU 94001, SPRU 94005, SPRU 94009, SPRU 94011
Downy mildew	QL3(IS 18757), UChV2, SC 414-12, SP 36257, IS 3547, IS 20450	ICSR 113, ICSR 89008, ICSR 90003, ICSR 90012, ICSR 90016, ICSV 91019	ICSB 11, ICSB 37, ICSB 51, ICSB 88001, ICSB 90004, SPDM 94001, SPDM 94006, SPDM 94022, SPDM 94035, SPDM 94060
Ergot	ETS 2454, ETS 3135, ETS 3147	ICSR 64, ICSR 160, ICSR 89014, ICSR 89049, ICSR 89067	ICSB 12, ICSB 15, ICSB 18, ICSB 70, ICSB 84, ICSB 101, ICSB 88001, ICSB 88009, ICSB 88015
Charcoal rot	E 36-1, QL 101, QL 102, QL 104	SPV 504, SPV 86, CS 3541,	296B, ICSB 17 ICSB 37

4.3.3. Conversion

Tropical landraces do not flower in temperate countries such as the USA, when they are grown in the summer where the day length is more than 13 hours. Most sorghum breeders recognize the positive correlation between plant height and grain yield; so they develop tall sorghums to withstand hazards associated with production (Miller 1982). Generally, maximum productivity is achieved at about 1.75-1.80 m height and flowering at 68-70 days (Rao and Rana 1982). A conversion program was initiated jointly by the Texas Agricultural Experiment Station and the United States Department of Agriculture (USDA) in the early 1960s to change the tall and late or nonflowering sorghums from the tropics (in USA) into short, early forms. This involved substituting up to four to eight genes that control height and maturity to obtain the desired type. The scheme essentially involved backcrossing (at Mayaguez, Puerto Rico) early and dwarf F_3s selected from F_2s (grown at Texas, USA) to the landrace. This was repeated four times before final crosses were made at Mayaguez involving the landrace as female to capture the landrace cytoplasm as well. This program had nearly 1279 converted lines (Miller 1982), and contributed to breeding programs in USA and other countries. BTX622 and BTX623 are examples that contributed yield potential to various seed parent programs in several parts of the world. Reddy and Stenhouse (1994) elaborated on the Puerto Rican conversion program carried out at Mayaguez.

At ICRISAT-Patancheru, a program to convert tall, late-flowering *Zera-zera* landraces (from the Ethiopia-Sudan border) was initiated in 1979. Later, *Kauras* and *Guineanses* (from Nigeria) were also included for conversion. Several short- and early-flowering lines were selected. Early and dwarf plants have been selected in the rainy season and backcrossed in the postrainy season at ICRISAT-Patancheru. The converted *Zera-zeras* and yellow-endosperm *Kauras* contributed extensively to various programs (ICRISAT 1986). The converted (short) *Guineanses* were least productive and hence least preferred (ICRISAT 1988).

Tall, late-maturing and photoperiod-sensitive landraces were crossed with three dwarf, early-maturing, day-neutral genotypes (IS 10513, IS 18729 and IS 10927) to convert into dwarf and early types for use in breeding programs. The photoperiod-sensitive landraces involved were eight *Zera-zeras* (IS 24706, IS 24721, IS 24722, IS 24728, IS 24741, IS 24743, IS 24756 and IS 24759), three *Guineas* (IS 24885, IS 24886 and IS 27043), five *Kauras* (IS 24704, IS 24737, IS 24750, IS 24881 and IS 27044) from Nigeria, four *Durra-Caudatums* (IS 29017, IS 29018, IS 29027 and IS 29054) and two *Durras* (IS 29054 and IS 29102) from Yemen.

4.3.4. Populations for Multiple Resistances

Three populations are under development at ICRISAT-Patancheru. These are ICSP IBR/MFR (resistance to grain mold, stem borer, shoot fly and midge), ICSP 2BR/MFR (resistance to grain mold and *Striga,* and improved stand establishment), both with rainy-season adaptability, and ICSP 3BR/MFR (resistance to stem borer, shoot fly and rust, with improved grain quality) with postrainy-season adaptability. Several resistance sources from the germplasm were transferred to these populations:

- ICSP IBR/MFR and ICSP 2BR/MFR (rainy-season) populations
  - From India (8 lines), Ethiopia (3), Sudan (2), Nigeria (1), Zimbabwe (2), Egypt (1), USA (9) and Australia (2).
  - Resistance to shoot fly (3 lines), stem borer (6), midge (5), grain mold (1), leaf diseases (3) and *Striga* (1), good grain (3), stand establishment (3) and early and dwarf (13)
- ICSP 3BR/MFR (postrainy-season) populations
  - From India (13 lines), Ethiopia (27), Nigeria (12), Sudan (8), Botswana (8), Cameroon (8), Yemen (12), Malawi (1), South Africa (1), Egypt (1), USA (6), Mexico (1) and Australia (3).
  - Bold grain (20); with postrainy-season adaptability and resistance to terminal drought (29), photoperiod-sensitive (2), temperature-insensitive (28), resistant to shoot fly and stem borer (4), downy mildew (1), stay green (6), stand establishment (3) and early and dwarf (3).

4.3.5. Sorghums with Special Traits

High-lysine sorghums. The high-lysine sorghum lines IS 11167 and IS 11758 from Ethiopia were used in the breeding program for transferring the gene to a desirable agronomic background. Some promising high-lysine derivatives (with both shrivelled and plump grains) have been obtained.

Sweet sorghums. Several sweet-stalk lines were selected from the germplasm. Prominent among these were IS 2266, IS 3572, IS 8157, IS 9639, IS 9890, IS 14790, IS 15428, IS 15448, IS 20963 and IS 21100. These materials were screened across locations and were found to be very promising.

Forage sorghums. Forage sorghum germplasm was systematically evaluated over several years for various yield and quality traits, for which a wide range of variability has been noted. The lines identified with desirable forage attributes were IS 1044, IS 12308, IS 13200, IS 18577, IS 18578 and IS 18580. In respect of quality parameters, IS 1059, IS 2944, IS 3247, IS 4776 and IS 6090 were selected for low hydrocyanic acid (HCN), and IS 3247 and PJ 7R for low tannin content. The need for further critical evaluation of germplasm materials and their utilization in forage sorghum improvement is evident. This work is being strengthened and the National Research Centre for Sorghum (NRCS), Hyderabad (India), has a good program on forage sorghum improvement (Vidyabhushanam et al. 1989).

4.4. Recent Research Thrusts

Genetic enhancement research at ICRISAT has always maintained complementarity with its partners, especially the NARS of developing countries. The recent thrust in genetic enhancement research at ICRISAT has been on the development of breeding materials to augment resistance to different abiotic (drought, low temperature, acidic soil) and biotic constraints (*Striga,* diseases and insect pests) to increase grain yield and enhance genetic diversity to achieve sustainability in sorghum productivity.

4.4.1. Abiotic Constraints

Drought. Drought is one of the most important factors affecting sorghum production. It may affect growth in the early-, mid- or late-season after flowering. Research carried out at ICRISAT (during 1976-84) showed that globally adapted drought-resistant genotypes cannot be bred, and that it is possible to breed genotypes adapted to specific environments. Morphological traits associated with drought endurance and escape, such as good seedling emergence and vigor, earliness, stay-green, tillering, recovery from early- and mid-season stress, pollination gap, better seed set and grain filling, good panicle exertion and reduced stalk lodging are the components of drought resistance. Screening techniques for traits associated with various droughts were developed (ICRISAT 1982), and some germplasm lines and breeding lines tolerant to specific drought environments were identified (Table 4.5). The complex nature of stress, the wide array of physiological mechanisms and adaptation to diverse forms of drought require careful targeting of selections for specific production systems rather than for drought resistance *per se.*

Low temperature. In the tropical highlands of East Africa, sorghum is traditionally grown at 1500-2000 m above mean sea level where the minimum temperature during the crop season varies from 0°C to 12°C. This results in poor germination, retarded plant growth, poor pollen production and seed set. Screening and selection for low temperature has been carried out at Kabete and Muguga in Kenya. Several germplasm accessions collected from the high altitudes of Uganda, Kenya, Rwanda and Ethiopia were found to be promising and were used in the breeding program.

Acidic soils. Soil acidity due to high levels of Al^{3+} saturation is widespread in vast areas (*Illanos, savannas, cerredos)* in Colombia, Brazil, Bolivia and Venezuela. Some areas in Zambia and Zimbabwe are known to be highly acidic. During the late 1980s, the INTSORMIL program developed acid soil-tolerant varieties suitable for production systems in Latin America (Table 4.5). With funding from the Inter-American Development Bank (IDB), a large number of grain sorghum (378 male-sterile lines, 784 restorer lines, 94 forage sorghums) and pearl millet lines (61) were screened for four consecutive seasons (1995-98) in varied Al^{3+} concentrations in Colombia in collaboration with CIAT, Cali, Colombia, and NARS in the region. High-yielding male-sterile lines, restorer lines and forage sorghum lines tolerant to Al^{3+} soil (Table 4.5) were identified and distributed to various agencies in the region. It is planned to develop acid soil-tolerant sorghum hybrids and evaluate them in the production systems.

4.4.2. Biotic Stresses

Striga. This parasitic weed is most common in Asia and Africa. It proliferates when sorghum is grown under poor management. The biology and establishment of *Striga* has been investigated in detail. Some mechanisms of resistance such as low strigol production and mechanical resistance have been elucidated. Several field and laboratory screening techniques to evaluate sorghum resistance to *Striga* have been developed. Lines that are tolerant to different species of *Striga* are agronomically poor. More detailed information on the physiological and genetic basis of the host-parasite interaction is needed to distinguish the mechanisms of resistance operating in various *Striga*-resistant or -tolerant cultivars in the world collection and breeding stocks. In spite of this complexity, pedigree and backcross breeding techniques have been applied with moderate success in selecting for improved varieties such as SAR 1 to SAR 36 and seed parents such as SPST 94001, SPST 94018 and SPST 94034. At ICRISAT-Patancheru several *Striga*-resistant male-sterile lines have been developed (Table 4.5). In view of the cumbersome screening procedures required for the identification of *Striga*-resistant plants and the complex mechanisms involved, marker-assisted selection approaches are being explored. A collaborative project with the University of Hohenheim, Germany, to search for restriction fragment length polymorphism (RFLP) markers which can tag *Striga* resistance genes and assist breeders in transferring them to agronomically improved cultivars is in progress at ICRISAT

Diseases. Among the diseases, grain mold, anthracnose and foliar diseases such as leaf blight are considered to be the most important to various production systems (Table 4.3).

In all sorghum production systems, grain molds can reduce the yield and quality of short-duration cultivars if they mature in wet and humid weather, particularly when rains extend beyond their normal duration. Important parasitic fungi causing grain molds are generally the same in Asia and Africa. They include *Fusarium, Curvularia, Phoma* and *Colletotrichum* species, as well as a complex of saprophytic molds such as *Aspergillus* and *Cladosporium* species. The parasitic fungi invade and destroy the endosperm while the saprophytic fungi cause relatively less damage and affect only the pericarp. The problem of grain molds could be complicated and accentuated when associated with an attack of head bugs.

Artificial screening for grain mold resistance is carried out under supplementary sprinkler irrigation to increase humidity. Threshed grains are visually rated on a scale of 1 to 9 for percentage discoloration and mold attack. A high level of resistance to grain molds has been identified at ICRISAT-Patancheru as a result of screening the world collection. Most of the resistant accessions belong to the *Margaretiferum* subrace of the *Guinea* race, have a red or brown pericarp and are associated with tannins and/or phenolic compounds such as flavan-4-ols. However, among white grain types, a very hard endosperm and involute glumes that protect the developing grain from fungal invasion until physiological maturity are the two known mechanisms of grain mold resistance. Grain color, pericarp thickness, presence of tannins, polyphenols, flavan-4-ols and grain hardness are controlled by major genes but some polygenes also seem to be affecting the level of phenolic compounds and endosperm hardness.

Current breeding efforts include both pedigree selection and population improvement. Pedigree selection using artificial screening for grain mold resistance has resulted in improved high-yielding lines and hybrid parents with red grains. Progress has been less successful with white grain types. A random-mating population with white grains and *Guinea-type* panicle and glume traits is under improvement at ICRISAT-Patancheru. Male-sterile lines with white, red and brown grain color and resistance to grain molds were developed (Table 4.6). ICRISAT scientists and scientists at Texas A&M University, Texas, USA, are investigating the possible role of antifungal proteins that inhibit growth of molds.

Among the various fungal diseases that attack sorghum, anthracnose caused by *Colletotrichum graminicola* is a potentially serious disease in the production systems of India, WCA and East Africa. Hot and humid weather favors the fungus which causes lesions that spread and kill leaves, sheath, stem, peduncle and panicles depending upon the cultivar and the stage of the crop. Grain yield losses up to 50% or more can occur in severe epidemics. Variation in anthracnose races between the regions is known but more information on inter- and intraregional variability is needed. Resistance to anthracnose has been identified in some germplasm accessions and breeding lines (IS 9225, A 2267-2, IS 12658 and ICSB 38) (Table 4.5). Resistance to this fungus appears to be governed by major dominant genes. Some sources of resistance identified in India were susceptible in WCA, while others have proved to be resistant across locations. Often, introductions from other regions into WCA were susceptible to anthracnose. Some local landraces of WCA exhibit horizontal type of resistance. Further investigations were carried out to identify other sources and to develop broad-based and durable resistance.

Pedigree selection and backcrossing methods were practised in crosses involving resistant parents with the aid of visual scores (1-9 rating) and susceptible checks. Advanced progenies were evaluated in disease hot spot locations in each region in observation nurseries sown under natural conditions. Pathologists confirm the resistance status under artificial inoculation. Several male-sterile lines resistant to anthracnose were developed (Table 4.6) following this procedure at ICRISAT-Patancheru.

Other leaf diseases of sorghum [such as leaf blight *(Exserohilum turcicum),* sooty stripe (*Ramulispora sorghi*), gray leaf spot (*Cercospora sorghi*), oval leaf spot (*Ramulispora sorghicola)* and rust (*Puccinia purpurea*)] are of less importance globally but cause significant grain and forage yield losses individually or collectively in susceptible cultivars in specific production systems. For example, sooty stripe can be serious in PSs 14 and 15 in WCA, while leaf blight causes significant losses in PSs 20 and 21 and to a lesser extent in WCA. In India, rust can be a serious problem in postrainy-season sorghum in PS 8. Foliar leaf diseases are generally confined to the lower leaves of tall local landraces but can damage most of the leaf area when they occur on susceptible dwarf cultivars. Foliar leaf disease resistance assumes high importance when attempts are made to reduce the height and improve the harvest index of landraces. Several germplasm and breeding lines with resistance to a few or more leaf diseases (IS 3555, IS 3575, IS 9225, IS 12658, ICSB 38, BTX631, A 2267-2 and Tegemeo) have been identified.

Table 4.6. Male-sterile lines available with ICRISAT and their characteristics.

Type of A/B lines	ICSA numbers	No. of lines retained	Agronomic score: Plant height (m) at maturity – Rainy	Plant height (m) at maturity – Postrainy	Days to 50% flowering – Rainy	Days to 50% flowering – Postrainy	Yield parameters: Grain yield (t ha[1])	100-grain weight (gm)
High-yielding lines	1-102	71	1.0-2.6	0.9-1.4	60-74	65-92	0.5-5.4	1.9-4.5
	88001-88020	13	1.3-1.9	1.0-1.5	63-72	60-80	2.5-4.0	2.5-3.2
	89001-89004	4	1.3-1.5	1.0-1.2	66-72	76-80	3.2-3.6	2.6-3.2
	90001-90004	4	1.3-1.5	1.2-1.4	68-70	68-75	2.0-3.4	2.4-3.1
Downy mildew-resistant lines	201-259	59	1.1-2.0	1.0-1.7	65-87	70-86	1.7-6.3	1.5-3.9
Anthracnose-resistant lines	260-295	36	1.1-2.1	1.1-1.9	62-75	66-79	1.5-5.1	1.5-3.8
Leaf blight-resistant lines	296-328	33	1.4-2.1	1.0-1.9	65-83	69-89	1.1-6.5	2.3-4.3
Rust-resistant lines	329-350	22	1.1-2.1	1.0-1.9	63-82	66-80	1.7-6.1	2.1-3.7
Grain mold-resistant lines	351-408	58	1.6-2.2	1.0-2.0	58-72	64-78	0.8-5.0	1.7-4.1
Shoot fly (rainy)-resistant lines	409-436	28	1.5-2.0	1.0-2.0	68-76	66-84	1.9-6.2	2.0-3.5
Shoot fly (postrainy)-resistant lines	437-463	27	1.1-2.1	1.0-1.8	65-78	70-84	1.5-5.3	1.4-3.5
Stem borer (rainy)-resistant lines	464-474	11	1.3-2.1	1.3-2.1	65-76	66-78	1.9-4.5	2.2-3.9
Stem borer (postrainy)-resistant lines	475-487	13	1.7-2.8	1.5-2.0	61-75	69-81	2.2-4.4	1.8-3.1
Midge-resistant lines	488-545	58	1.2-2.0	1.0-1.8	59-81	67-87	2.1-5.8	2.2-4.1
Head bug-resistant lines	546-565	20	1.5-1.9	1.1-1.8	61-72	66-80	1.7-5.3	2.5-3.5
Striga-resistant lines	566-599	34	1.2-2.2	1.0-1.9	54-80	64-79	1.3-5.4	1.7-3.5
Acidic soil-tolerant lines	600-614	15			72-84			
Early-maturing lines	615-637	23	1.1-2.0	1.0-1.7	55-67	60-71	1.0-4.7	2.0-3.6
Durra (large grain) lines	638-670	33	1.2-2.2	1.1-2.0	50-76	66-90	1.2-4.7	2.0-4.1
Tillering lines	671-674	4	1.3-1.4	1.1-1.7	54-72	61-79	1.0-4.5	2.3-4.0
Stay-green lines	675-687	13	1.2-1.5	1.1-1.9	57-75	61-79	1.0-4.5	2.3-4.0
A_2 cytoplasmic lines	688-738	51	1.2-2.4	1.1-2.0	63-81	65-82	1.5-5.7	1.9-3.9
A_3 cytoplasmic lines	739-755	17	1.6-2.1	1.3-1.9	65-77	66-80	2.6-5.2	2.1-3.8
A_4 cytoplasmic lines	756-767	12	1.4-2.1	1.2-1.5	64-75	69-74	2.0-4.7	2.0-3.8

Major genes govern resistance to most of these leaf diseases. Breeding for multiple disease resistant cultivars with high grain yield has been generally successful with pedigree selection. Several hybrid parents with good levels of multiple leaf disease resistance are available. Breeders initially select, on an empirical basis, plants with clean leaves or higher proportion of green leaf area in the early segregating generations of crosses involving resistance sources. Further evaluation and selection in advanced generations in the presence of susceptible checks is carried out using a 1 to 9 rating scale (where 1 < 10% of leaf area diseased; 9 refers to > 80% of leaf area diseased). Advanced breeding lines are further evaluated in disease hot spot locations for specific leaf disease resistance in cooperation with pathologists. Although good progress is being made in breeding for leaf disease resistance, more detailed information on the genetics of resistance, variability of pathogen species and sources of horizontal resistance is required to develop improved cultivars with broad-based and durable resistance. Following this strategy, several male-sterile lines (Table 4.6) resistant to rust and leaf blight diseases were developed.

Insect pests. Stem borer, shoot fly, midge and head bug are known to cause considerable yield losses in various production systems. A different complex of stem borer species attacks sorghum in different parts of the SAT and causes damage at various stages of the crop ~ India: *Chilo partellus;* East Africa: *Busseola fusca* (higher altitudes) and C. *partellus* (intermediate altitudes); Southern Africa: C. *partellus, B. fusca, Sesamia calamistis* and *Eldana saccharine;* WCA: *B. fusca, S. calamistis* and *E. saccharine.* Overall, C. *partellus* is the most important species in Asia, East and Southern Africa while *B. fusca* is important in WCA. Consequently, ICRISAT sorghum breeding efforts on resistance to stem borer in India and WCA are focussed on C. *partellus* and *B. fusca,* respectively. Stem borer resistance is evaluated on the basis of the percentage of dead hearts, the extent of leaf damage, stem tunnelling, panicle damage and recovery. Screening is carried out under either natural infestation in staggered late sowings or artificial infestation with egg masses or early instar larvae of C. *partellus.* Techniques for artificially rearing *Busseola* have been developed together by ICRISAT and the Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement (CIRAD), France. Only a modest level of resistance to stem borer is known (IS 1044, IS 2205, IS 5613, IS 2123, IS 18551, PB 14698-2 and PB 15621) but immunity is absent. Resistance across species is limited (Seshu Reddy and Davies 1979) and needs confirmation through artificial intensive screening. Hitherto, stem borer resistance evaluations at ICRISAT-Patancheru relied heavily on low percentage of dead hearts. However in future other components of resistance such as recovery, extent of tillering and leaf damage may need to be considered. The threshold levels of resistance required in the target production systems also need to be determined. Stem borer-resistant sources are agronomically poor. A genetically broad-based random-mating population with shoot pest-resistant sources (98 accessions and 17 breeding lines) has been developed at ICRISAT-Patancheru and improved by S_1/S_2 testing procedures. Inheritance of stem borer resistance seems to be different under natural and artificial conditions and needs further study. In our experience, correlation between natural and artificial screening results has been generally low.

Breeding lines identified at ICRISAT-Patancheru are subjected to screening tests in hot-spot locations in East and Southern Africa and selections are made. Several borer-resistant male-sterile lines (Table 4.6) and pollinators and varieties were developed at ICRISAT-Patancheru. In WCA, a random-mating population with sources of resistance to *B. fusca* and adapted high-yielding lines are being developed and pursued through recurrent selection procedures. The International Institute of Tropical Agriculture (IITA), Nigeria, is working on screening techniques for resistance to *B. fusca* in maize, and ICRISAT cooperates and exchanges information on insect-rearing techniques.

Shoot fly (*Atherigona soccata)* causes widespread damage to sorghum in Asia and Africa. Research on shoot fly resistance has been going on since the 1970s at ICRISAT-Patancheru and at NRCS, India. Screening for resistance is carried out by late sowing of test materials between early-sown infester rows applied with a fly attractant, namely fishmeal.

Only low levels of primary resistance to shoot fly have been observed in some cultivars such as IS 1054, IS 2313 and IS 18551. Low levels of primary resistance have been incorporated into a few improved cultivars such as ICSV 702 and ICSV 705. By incorporating these improved varieties and restorers in backcrosses, several improved shoot fly-resistant male-sterile lines were developed (Table 4.6). However, hybrid parents with improved agronomic characters such as seed size coupled with shoot fly resistance are particularly needed to produce postrainy-season hybrids. Resistance to shoot fly has been observed to be polygenic and additive under modest levels of infestation, although susceptibility is dominant under severe infestation. Sorghum plants with 'glossy' leaves and trichomes under the leaf surface have been associated with shoot fly resistance and are used as markers in empirical selection. Hitherto, pedigree breeding and backcross breeding were used (supported by artificial screening) at ICRISAT-Patancheru to breed hybrid parents resistant to shoot fly and adapted to the rainy-season production systems. A broad-based shoot pest population has been developed from 78 germplasm accessions and several breeding lines. Use of wild sorghum S. *versicolor* and S. *arundinacium* to obtain qualitatively different sources of resistance is a future objective. Absolute resistance to shoot fly was noticed in wild sorghum relatives (*S. dimidiatum* and S. *australiense).* Efforts are underway to exploit and introgress these using molecular markers. G X E studies showed that trichome development is season (temperature)-dependent (Jayanti 1997).

Currently, improved shoot fly-resistant lines bred in Asia are being screened in Eastern and Southern Africa and WCA, and successful selection has been carried out since there is no variation in the insect pest. Selected lines are crossed to other pest-resistant sources such as head bug-resistant lines. In Eastern Africa, recovery resistance will receive more attention since it is adapted to the local production systems.

Sorghum grain midge *(Contarinia sorghicola)* is known to cause significant grain losses on late-maturing cultivars or late planted sorghum crops in Asia, Africa and America. Complete grain yield losses can be observed in severely affected susceptible cultivars.

Serious attacks of midge have been reported in Maharashtra state of India, northern Nigeria, Burkina Faso, Niger and many other countries. An infester row technique using staggered dates of sowing late in the season, and a 1 to 9 scale of damage rating was used in the identification of resistant sources (Sharma et al. 1992). Final screening for midge resistance in cages under no-choice conditions is done to confirm high degree of resistance. Short and tough glumes, faster development of fertilized ovaries and other antibiotic mechanisms are associated with midge resistance. Inheritance of midge resistance has been found to be mostly polygenic and additive although recessive behavior has been reported in some cultivars. Several improved varieties such as ICSV 197 and ICSV 745 and hybrid parents have been developed at ICRISAT-Patancheru using pedigree selection and backcrossing techniques. However, these are mostly based on a single source of resistance, DJ 6514, which does not hold up its resistance at high altitudes and in the low temperatures in Eastern Africa. Obviously, there is a need to identify more stable and diverse sources of resistance. Some agronomically poor landraces from Kenya and one from Ghana (Nunaba) were found to be resistant to midge. Further intensive screening of local germplasm and multilocational tests in India and Africa may enable researchers to find more stable and diverse sources of resistance. An immediate objective would be to incorporate midge resistance expressing even at low temperatures (PS 21) in Eastern Africa into agronomically improved cultivars. At Patancheru, the emphasis has been to diversify improved high-yielding and resistant cultivars and hybrid parents, and recombine multiple resistances to pests. Several improved midge-resistant seed parents (Table 4.6) and midge-resistant restorers or varieties were developed using pedigree and backcross breeding materials. A random-mating restorer (R) population with sources of resistance to midge and head bug and another maintainer (B) population with sources of resistance to midge and shoot fly have been developed (Appendix 4.1). Detailed studies on mechanisms of resistance and their inheritance were carried out at Patancheru. In WCA. advanced midge-resistant lines bred at Patancheru are being crossed to locally adapted elite materials to obtain improved resistant cultivars.

A number of head bug species *[Calocoris angustatus* in Asia, *Eurystylus oldi* in West and Central Africa) are known to feed and damage developing grains of sorghum. Guinea cultivars with lax panicles and involute glumes that cover the grain till physiological maturity were less damaged by head bugs than improved cultivars with exposed soft grains. Agronomically good cultivars such as Mali Sor 84-7 and some *margaretiferum* types are known to possess high levels of resistance to *E. oldi.* Resistance to *Calocoris* has also been observed in some brown grain types with lax panicles. Using Mali Sor 84-7 in crosses with the high yielding B-lines, several head bug-resistant male-sterile lines were developed at ICRISAT-Patancheru (Table 4.6).

Mechanisms of resistances to head bugs are only partially known. Rapid grain filling and maturity are supposed to be associated with resistance. Very hard grains, involute glumes and unspecified phenolic compounds also contribute to head bug resistance. Resistance in Mali Sor 84-7 to *Eurystylus* attack has been found to be recessive. The high levels of head bug infestation required for uniform screening are achieved by adjusting and staggered sowing in the crop season. Artificial infestation of individual panicles with *Eurystylus* using nylon or plastic bag cages is also practised. Pedigree and backcross breeding supported by artificial screening of advanced generations under cages is followed. Some promising head bug-resistant breeding lines are on advanced tests. Selection for free-threshing but extended glumes, which reduce damage due to *Eurystylus,* also appears promising. More detailed information is required on the resistance mechanisms to different head bug species important in Asia and West and Central Africa, particularly the genetics of these mechanisms.

4.4.3. Grain Yield, Stability and Adaptation

Improved grain yield and adaptation to the target or primary sorghum production system is the main objective, wherein breeding lines are improved for various biotic and abiotic stress factors combined with high yield potential adapted to a production system. Adaptation to different sorghum production systems requires cultivars with a specific maturity, grain type and a specific combination of resistance factors. For example, improved postrainy-season sorghums in India (PS 8) would require, in addition to higher grain and fodder yields, tolerance to drought, shoot fly and lodging and grain quality suitable for 'roti'. On the other hand, in the Northern Guinean Zone of WCA (PS 16), improved sorghum lines should have longer maturity and hard grains with suitable resistance to *Striga,* anthracnose, grain mold, stem borer, midge and head bug. In Southern Africa (PS 19), sorghum cultivars with early maturity, drought resistance (seedling, midseason and postflowering) and resistance to S. *hermonthica* need to be combined with high yield. Breeding lines and improved resistance sources are exchanged between the breeding programs at different ICRISAT locations. However, cross adaptation of breeding lines has been good only between Asia (PS 7 and 9) and Southern Africa (PS 19, 20 and 21) and to some extent Central America (PS 27). The soils and the biotic stress factors (stem borer, head bug and *Striga)* affecting sorghum in WCA are different from those in Asian production systems, and there seems to be poor cross-adaptation of cultivars. A certain degree of photosensitivity seems to confer advantages on sorghums adapted in the Sudano-Guinean Zone of Africa where the length of the rainy season is highly unpredictable.

The adaptability of highland sorghum in Eastern Africa is governed by tolerance to low temperatures. Therefore, breeding should be *in situ* to incorporate and select for local adaptability in certain production systems in Africa, although some stress factors are common to several production systems. Improved breeding lines and hybrid parents with resistance to shoot fly, midge, grain mold and foliar diseases and bred at ICRISAT-Patancheru are supplied to the African locations for incorporation in locally adapted germplasm or elite lines. The segregating progenies are normally grown in a set of diverse locations in each region to screen for important biotic and abiotic factors. Selections for appropriate maturity, panicle and grain type are made and further evaluated at the same set of locations in the following generations. Thus, we ensure local adaptation and improved yield by incorporating exotic materials into local germplasm.

4.4.4. Genetic Diversification

Diversification of the genetic base of breeding lines is another important objective and is achieved by intercrossing resistance sources of diverse origin, frequently of different races, with agronomically elite lines. At ICRISAT-Patancheru, recurrent selection (with mass selection S_1 and S_2 testing) in broad-based, random-mating populations or gene pools with specific traits such as maintainer (B), restorer (R), high-tillering, large grain, shoot pest resistance, grain mold resistance and head pest resistance is in progress. In WCA, the development of random-mating populations of *Guinea* and *Caudatum* races has been completed and another *Guinea xCaudatum* type population is also under development.

Random mating early-maturity populations have been developed in Southern Africa. These populations being developed or selected in different regions will assure long-term improvement of sources of resistance to different biotic factors in desirable agronomic backgrounds and adaptation, while preserving broad genetic variability. Another important goal is to broaden the cytoplasmic genetic diversity of hybrid parents. Grain yield improvement of several female parents of non-milo origin ($A_2/A_3/A_4$ cytoplasm) and incorporation of resistance factors in A, male-sterile lines are being pursued using backcrossing procedures. Details of various male-sterile lines available are given in Table 4.6.

4.5. Genetics and Mechanisms of Resistance

4.5.1. Diseases

In general, the genetics of resistance to various diseases caused by a given strain of fungi, bacteria and virus is simple. For example, three races are known for kernel smut, and resistance to each is controlled by an incomplete dominant genetic system, *Ss*$_1$, *Ss*$_2$ and *Ss*$_3$.The head smut resistance gene is dominant. A partially dominant gene controls milo disease resistance. Resistance to anthracnose is inherited as a dominant trait and is controlled by a single gene. Similarly, resistance to rust is also controlled by a single dominant gene. While resistance to leaf blight is controlled by a single recessive gene (House 1985), downy mildew resistance is controlled by more than two loci, possibly three with different interactions (Reddy et al. 1992b). Grain mold resistance is complex (House 1985). Stay green, a trait related to terminal drought tolerance, is inherited as a dominant trait in the F_1s of E 36-1 hybrids (Reddy and Stenhouse 1993). Among the diseases, grain mold and anthracnose are considered important in India. It was shown by Reddy et al. (1992a) that grain mold-resistant (red-grained) hybrids can be produced by crossing susceptible red-grained female parents and white-grained restorer lines. It was established that the presence of flavan-4-ols in moderate levels in red-grained females and the hardness found in white-grained restorers were not separately sufficient to cause resistance in the parental lines; but the traits were inherited by the F_1 hybrids and resulted in resistant hybrids. Reddy and Singh (1993) have shown that a single dominant gene controls resistance to anthracnose and that the effect of cytoplasm on resistance is not significant. More information on the genetics of disease resistance can be found in Thakur et al. (1997).

4.5.2. Insect Pests

The genetics of resistance to pests is more complex. Shoot fly (predominantly in Asia), stem borer (*Chilo* spp in Asia and Eastern and Southern Africa and *Busseola* spp in WCA), midge and head bug *(Calocoris* spp in India, Nigeria and Mali) are important pests. Nonpreference is the predominant mechanism, and it is quantitatively inherited mostly through additive gene action for resistance to shoot fly (Rao et al. 1974; Sharma et al. 1977). Rana et al. (1981) reported that F_1 is almost intermediate between the two parents for shoot fly resistance. Resistance was found to be partially dominant under low to moderate shoot fly pressure but not under heavy infestation. Most resistant varieties have glossy lines in the seedling stage (Maiti et al. 1980); most of them belong to the *Durra* group (Maiti et al. 1984). Also, the majority of shoot fly-resistant sorghum cultivars have a high density of leaf trichomes. Maiti and Bidinger (1979) noticed that trichomes on the abaxial surface of the leaf deterred egg-laying. In addition, Maiti et al. (1980) did not observe any differences in cuticle thickness or in the degree of lignification of leaves between trichomed and trichome-less lines. Omori et al. (1983) suggest that glossy expression in sorghum seedlings could be utilized as a simple and reliable selection criterion for shoot fly resistance. When shoot fly-resistant male-sterile lines and maintainers were evaluated, the male-steriles were more susceptible to shoot fly than the maintainers in both rainy and postrainy seasons at ICRISAT (Reddy 1998, unpublished data), indicating that male-sterile cytoplasm (A_1) is more susceptible to shoot fly than male-sterility maintainer cytoplasm.

Inheritance and gene action studies based on hybrid group means in relation to parental-line group means indicated dominance, intermediate or overdominance for susceptibility (as measured by egg count and dead heart percentage) in various hybrid and parent groups. Dominant gene action was observed for low seedling vigor and nonglossiness under low temperature conditions. Season specificity for trichome density was reflected in the hybrid groups depending upon the type of parents involved. Low density (associated with susceptibility) appeared to be additive. In the hybrids with postrainy-season-bred resistant (PRBR) female lines, trichome expression during the rainy season was lower than during the postrainy season. Similarly, hybrids with rainy-season-bred resistant (RBR) female lines supported low density in the postrainy season and high density in the rainy season. The same was observed in the parents *per se.* In respect of uniformity in recovery among the hybrid groups, those involving rainy season-bred females recovered well in the rainy season and postrainy season-bred female hybrid groups recovered well in the postrainy season. This again demonstrated the effectiveness of season-specific breeding that had been used in developing these resistant female groups. This might also have been due to the existence of different biotypes. This needs further confirmation, especially in no-choice experiments.

In general, only hybrids of resistant female lines x postrainy-season landraces or resistant female lines X resistant-bred lines were resistant to shoot fly in both rainy and postrainy seasons (Jayanti 1997).

Information on mechanisms of resistance to stem borer is limited. Both tolerance and antibiosis have been reported (Jotwani 1976). Rana and Murty (1971) reported that resistance to stem borer is polygenically inherited. The F_1 hybrids were intermediate for primary damage (leaf feeding), but better than mid-parent for secondary damage (stem tunnelling). While additive (A) and A X A interactions explained resistance to primary damage, secondary damage was controlled by additive and nonadditive gene interactions. Morphological traits such as shoot length, ligular hairs, leaf angle and seedling vigor have been reported to be associated with resistance to spotted stem borer. Reddy and Taneja (1993) studied the correlation of various traits with dead hearts and found that the length of the second internode, measured 45 days after emergence or at maturity, and the length of the seventh, measured at maturity were significantly and negatively correlated with dead heart formation in both rainy and postrainy seasons. By comparing the isogenic lines for plant height, they found that the dominant gene had no effect on dead hearts caused either by shoot fly or stem borer. Sharma (1993) found that shoot length measured at 40 days after emergence, ligular hair and leaf angle were significantly and negatively associated with dead heart formation. Widstrom et al. (1984) studied the gene effects governing resistance to midge. Most of the crosses expressed highly additive gene effects. Sharma et al. (1996) studied the combining ability of midge resistance and found that general combining ability was predominant. Information on the genetics of head bug resistance is scanty but it appears that both male and female parents should have resistance to produce resistant hybrids for insect pests.

4.5.3. *Striga*

Resistance to *Striga* may be due to the absence of chemical signals or stimulants from the host eliciting *Striga* germination, post-germination chemical and nonchemical barriers to growth through the host roots, mechanical barriers to the establishment of haustoria or due to antibiosis and avoidance. Considerable research was done at ICRISAT-Patancheru on screening for low stimulant (strigol) production during 1975-1980 (ICRISAT 1976b; ICRISAT 1981a), early thickening of root walls in resistant genotypes (Maiti et al. 1984) and the deep root system in resistant genotypes (ICRISAT 1983). Ramaiah (1987) reported that in three out of the five sorghum parents studied, susceptibility was dominant over resistance; resistance was dominant in one, and partially dominant in the other. Using pot studies, Hess and Ejeta (1992) established that resistance was inherited as a recessive trait controlled by one or two genes in SRN 39. A single gene check for *Striga* resistance was postulated based on specific components such as the absence of strigol tolerance. However, if levels of production of strigol were considered, quantitative inheritance *of Striga* resistance was reported in some genotypes (Ramaiah et al. 1990).

Based on an evaluation at two sites each in Mali and Kenya, Haussman et al. (2000) reported that the heritabilities (in a broad sense) were 0.84, 0.79 and 0.89 in nine parental lines and 0.70, 0.78 and 0.88 in 36 F_2s of nine parental lines-half diallel for number *of Striga* plants emerged at 85 days after sowing, area under *Striga* severity-progress curve and grain yield, respectively. General and specific combining ability mean squares were significant for all and their interaction with locations were significant for all traits studied.

4.6. Screening Techniques

Effective disease and insect pest screening techniques are crucial for identifying sources of resistance. Developing a screening technique requires an understanding of the biology or epidemiology of the insect and disease. Effective field screening techniques have been developed for downy mildew (Pande and Singh 1992), stalk rot (Mahalinga et al. 1989; Pande and Karunakar 1992), anthracnose (Pande et al. 1994), leaf blight (Sifuentes et al. 1993), sooty stripe (Thomas et al. 1993), ergot (Tegegne et al. 1994; Musabyimana et al. 1995) and grain mold (Bandyopadhyay and Mughogho 1988).

Effective screening techniques were also developed for screening for resistance to shoot fly. It involves creating uniform infestation and scoring for dead hearts through the stark's interlards and fish meal techniques (Agrawal and House 1982), glossiness (Maiti et al. 1980) and trichomes (Maiti and Bidinger 1979). Screening for resistance to stem borer involves conducting nurseries with natural infestation in hot-spot locations or placing first instar larvae in the whorls of young seedlings with a dispenser (Agrawal and House 1982) and scoring for leaf damage or dead hearts. Midge resistance screening is carried out through natural infestation in delayed sowing (with materials grown as per maturity groups) in hot-spot locations followed by cage screening (Agarwal and House 1982). Screening for resistance to head bug is done through natural infestation by sowing the materials in hot-spot locations after adjusting the sowing dates so that flowering coincides with maximum bug density. Infester rows with susceptible lines are sown where genotypes of different maturity groups are involved. Final selection is made through the head cage technique (Sharma 1997).

The technique of screening sorghum lines for low strigol production was standardized at ICRISAT-Patancheru and several lines were screened (ICRISAT 1978a). Screening for mechanical resistance based on thick-walled endodermic cells and associated sclerenchyma tissue was also developed (ICRISAT 1977). Among the other techniques developed were a field screening based on a checkerboard to differentiate between genotypes (ICRISAT 1983), the double pot technique (Parker et al. 1977) and the agar gel assay (Hess et al. 1992) to assess the quantity of strigol. Several techniques to screen for drought resistance were developed — emergence under high temperature (ICRISAT 1981b), emergence under soil crusting (ICRISAT 1981b), recovery from early seedling stress (ICRISAT 1981b), recovery from mid-season stress (ICRISAT 1981b), tolerance to terminal drought using line-source irrigation (ICRISAT 1980; ICRISAT 1981b) and selecting for yield potential and resistance to drought (ICRISAT 1981b).

Reddy (1985) has described techniques to screen for resistance to various drought situations. These have been used by scientists in many developing countries. However, there is scope for further refinement in screening techniques (Thakur et al. 1997).

4.7. Male Sterility and its Exploitation

Several genetic sources of male sterility were identified in sorghum, and all the cases showed that a recessive allele in homozygous condition contributes to male-sterility. These sources (Andrews 1966; Appadurai 1968; Andrews and Webster 1971) are given in Table 4.7. By 1970, *ms_3* was widely used in population improvement programs for its stability in expression over a range of environments. The next best in terms of usage is the *ms_7* allele. At ICRISAT, *ms_3* and *ms_7* are being maintained in different bulks.

Cytoplasmic nuclear male-sterility (cms) was discovered in sorghum by Stephens and his colleagues (Stephens and Holland 1954). This makes the commercial production of hybrid seed a

Table 4.7. Genetic male-sterility sources identified in sorghum.

Sterility gene	Sterility features	References
ms_1	Anther without pollen	Ayyengar and Ponnaya (1937); Stephens and Quinby (1945)
ms_2	Empty pollen cells	Stephens (1937); Stephens and Quinby (1945)
ms_3	Empty pollen cells	Webster (1965)
ms_4	Empty pollen cells	Andrews (1966)
ms_5	Empty pollen cells	Barabbas (1962)
ms_6	Micro-anthers without pollen	Barabbas (1962)
ms_7	Empty pollen cells	Andrews (1966)

low-cost affair. Male sterility results from an association of milo cytoplasm with sterility genes found primarily among the *Kafir* race and also in some varieties of other races. The genetics involved is not completely clear; however, when the two genes *ms* c_1 and *ms* c_2 are recessive in the presence of milo cytoplasm, the result is male sterility. Parents used as pollinators in hybrid programs should restore fertility in the hybrids produced when crossed with the male-sterile lines. Several types of cytoplasms were recognized depending upon the pattern of restoration and male sterility in hybrids produced by a set of testers used as pollinators (Schertz and Pring 1982), the most common ones being A_1, A_2, A_3 and A_4. The A_4 cytoplasm consists of at least three variants - VZM, Maldandi and GI. Research at ICRISAT identified the following minimum differential testers (Reddy and Prasada Rao 1991):

- TAM 428 [A_2 gives fertile F_1S only on milo cytoplasms (A_1)]
- IS 84B (A_4-Maldandi) gives fertile F_1s on A_1 and A_2 cytoplasms
- IS 5767 R (A_4-Maldandi) gives fertile F_1s on all cytoplasms except A_3
- CK 60B (A_1) gives sterile F_1s on all cytoplasms.

The A_1 system is better than A_2, A_3 and A_4 (Maldandi), A_3 is better than A_2 and A_4 (Maldandi), and A_2 is better than A_4 (Maldandi) for maintaining the stability of male sterility across environments (Reddy and Stenhouse 1996).

The genetics of fertility restoration is not clear. ICRISAT research showed that the frequency of recovery of restorer plants was least on A_3 than on A_2, A_4 and A,, indicating that more genes were involved in controlling fertility restoration on A_3 than in the other systems (Reddy and Prasada Rao 1992).

Several researchers have reported the role of temperature in male sterility and its restoration (Downes and Marshell 1971; Li et al. 1981). Research at ICRISAT has shown that restoration is poor at temperatures below 10°C at night before the flowering season in India, and that there is a need to screen for restoration ability for postrainy season sowing (Reddy and Stenhouse 1996). Temperature-induced female sterility in cms female lines like 296A may be reduced by using their nonparental single cross F_1 male-sterile lines (Reddy 1992).

Using A_1 cytoplasmic genetic male sterility, several high-yielding male-sterile lines were developed at ICRISAT-Patancheru. These B-lines were crossed with resistant restorers and several male-sterile lines resistant to various pests, diseases and *Striga,* and lines having special attributes were also developed. Some high-yielding maintainer lines were converted into male sterility using other cytoplasms. Milo (A_1 source) sorghums may have originated in Sudan and belonged to the *Durra* race (Duncan et al. 1991). Diversification for grain yield and resistance has been brought about by involving lines belonging to *Durra* and *Caudatum* races. At ICRISAT-Patancheru, further diversification of male-sterile lines is being attempted involving the *Guinea* race.

4.8. Breeding Concepts Developed

Several concepts such as the use of tropical germplasm with temperate materials to exploit dominant alleles for height, maturity and grain yield; at intermediate optima of maturity (100-110 days) and height (2.0-2.5 m); productivity of hybrids based on the performance of lines *per se* and the availability of high general combining ability for various economic traits were available (Rao and Rana 1982). These concepts were used effectively in ICRISAT programs. ICRISAT scientists further developed the following concepts:

1. **Heterosis and landraces.** Several *Zera-zera* landraces such as IS 3541, E 35-1, IS 12611, E 36-1, IS 3443 and IS 19614 (race: *Caudatum/Guinea)* were used extensively in this program. By evaluating the hybrids obtained by crossing five representative lines from each of the landraces *(Caudatum, Durra, Guinea, Bicolor* and *Kafir)* to six common *[Caudatum-Kafir* derived) male-sterile lines, it was revealed that *Guinea* restorer lines contributed to the highest heterosis and grain yield *per se* in hybrids across the seasons followed by *Caudatum* restorer lines (Reddy and Prasada Rao 1993). Thus, it became clear that further gains could be made by making use of *Guinea* sorghums; but to do so accompanying problems such as the clasping of glumes to the grain in hybrids of *Caudatum-Kafir* male steriles and *Guinea* restorers need to be corrected.

2. **Drought resistance breeding methodology.** An approach to breeding for drought resistance and yield potential was established. It involved evaluating materials bred for adaptation for emergence under crust, seedling drought recovery and grain yield under drought-prone and yield potential areas for early-stage drought, mid-season drought recovery and grain yield under drought-prone and yield potential areas for mid-season drought and stay green, non-lodging and grain yield under drought-prone and yield potential areas for terminal drought (Reddy 1986).

3. **Landracc hybrids approach to the postrainy season.** Postrainy-season sorghum landraces possess excellent adaptive characteristics suited to the prevailing moisture limiting conditions. It was demonstrated that landrace hybrids would have almost all the characteristics preferred by farmers and a 15% superiority in grain yield over cultivated landraces (ICRISAT 1995). Therefore, restorers of postrainy-season landraces can be exploited to produce postrainy season landrace hybrids to break the yield plateau during this season in India.

4. **Combining earliness and productivity.** It was revealed that earliness, grain yield productivity and biomass can be combined by following S_1 family selection in a gene pool development by incorporating the selected landraces in ms_3 bulk. (Rattunde 1998 unpublished).

5. **Breeding methods for specific purposes.** ICRISAT-Patancheru has globally released more materials derived from its pedigree program than from its population improvement program. Thus it was reconfirmed that pedigree selection is better than population improvement for short, specific adaptation. Several NARS breeders have found that trait-based gene pools developed at ICRISAT-Patancheru arc useful for selecting for specific needs. Thus, it is evident that the targeted gene pool approach is appropriate for a program that aims at a broader geographic mandate.

6. **Moving average to evaluate a large number of progenies.** A new checkerboard design was developed and used to account for local variation and increase the precision of the experiment for screening for *Striga* resistance (Rao 1985). However, the design requires lot of land and resources; and the fixed checkerboard arrangement is cumbersome to execute under field conditions. Therefore, the moving average concept to screen for resistance to shoot fly, stem borer and *Striga* was developed (Reddy 1993). For example,

   Striga resistance index (%) $= \dfrac{[S-(C1+C2)/2] \times 100}{[1+(C1+C2)/2]}$

   where S = number of *Striga* plants in the test entry and C1 and C2 are the number of *Striga* plants in the two adjacent resistant check plots.

7. **Simultaneous selection and conversion method.** A breeding scheme 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.

8. **Selection methodology for stem borer mechanism.** Considering the independence of antibiosis (Singh and Rana 1984) and the differences in patterns of inheritance of resistance to flower and peduncle damage plus dead heart formation, it was proposed that breeding for resistance to stem borer should involve three traits - foliar and stem damage and percentage of dead hearts. A paired plot technique with comparisons between infested and noninfested plots has been used successfully to identify genotypes with resistance to stem borer.

9. **Season specificity of shoot fly resistance.** Season specificity of trichome development was established based on evaluation of rainy-season- and postrainy-season-developed shoot fly-resistant materials. Therefore, it is suggested that materials should be selected for resistance to shoot fly in the season for which the materials are intended (Jayanti 1997).

10. **Combining selection for resistance and grain yield.** While breeding for grain yield and resistance, selection for resistance on the basis of family, and selecting single plants within the selected resistant family based on grain yield were found to be most effective (ICRISAT 1995).

11. **Method to develop resistance hybrids.** It was demonstrated that high-yielding shoot fly- and midge-resistant hybrids could be developed by crossing resistant male-sterile lines with resistant restorer lines. It was also revealed that crossing female lines resistant to shoot fly with postrainy season-landrace restorers or with bred resistant restorers can produce hybrids resistant to shoot fly (Jayanti 1997).

12. **Methods to select stable restorers and male-sterile lines.** It was demonstrated that efficient and stable restorers could be selected by evaluating their testcrosses or hybrids under conditions where night temperatures are below 13°C during the flowering phase. Conversely, it was shown that stable male-sterile lines could be selected by growing them in environments where the day temperature exceeds 40°C during flowering.

13. **Single-cross vs three-way cross hybrids.** The seed industry used three-way cross hybrids for commercial hybrids before it was demonstrated that single-cross hybrids were equally productive (Reddy 1992).

14. **Selection efficiency in single cross vs multiple crosses.** In combining resistance of characters which are simply inherited (eg, resistance to downy mildew) with grain yield, three- or four-way multiple crosses are as effective as single crosses. However, selection for resistance of quantitatively inherited traits such as resistance to stem borer or shoot fly was not effective in four-way crosses (Reddy 1993).

4.9. Limitations and Future Plans

The limitations can be grouped under three heads — technology transfer constraints, research area gaps and funding constraints.

The technology transfer constraints are:

- Insufficient seed production and marketing mechanisms, especially in Africa
- Insufficient support to NARS scientists to popularize products of research partnership with ICRISAT
- Inability of farmers to perceive the advantages of resistance in cultivars derived from ICRISAT/ NARS partnership

- Overemphasis on yield in the variety release criteria stipulated by national programs
- Lack of government support to coarse cereals compared to fine cereals.

Participatory Varietal Selection (PVS) and Participatory Varietal Breeding (PVB) may address some of these issues.

The gaps in the research area are:

- Though there has been progress in improving sorghums for grain mold resistance by mostly utilizing grain hardness and flavan-4-ols content, there is a need to exploit other mechanisms such as *Guinea* glume and grain characteristics.
- Research inputs to improve photoperiod sensitive sorghums has been meagre in the past although there is a demand for them in WCA and for postrainy-season sorghum in India. There is a need to devise a breeding strategy and develop suitable products for these areas.
- Farmers demand large-grained sorghum. However, the grain size in the breeding material available is less than acceptable. Selection for hard grain to minimize the effects of mold have resulted in small grains. Currently, a private sector-funded project is emphasizing on large-grained sorghum.
- The *Caudatum* race has been overexploited in breeding. There is a need to diversify the breeding material by involving other races. Studies have shown that the *Guinea* race contributes significantly (after *Caudatum)* to higher mean and heterosis for grain yield.
- Of late, there has been an increase in demand for forage in Asia. The variability in forage restorers (Sudan sorghum) is limited and overexploited by the private sector. There is also scope to diversify the genetic base for resistance to leaf diseases (eg, downy mildew) and stay-green ability.
- Biotechnology offers new tools such as transformation using *Bt* gene to augment resistance to stem borer and shoot fly and marker-assisted selection to develop parental lines with resistance to shoot fly, stem borer, *Striga,* acid-soil tolerance and grain mold.
- PVS and PVB may be useful for developing sorghum for the postrainy season in India, and *Guinea* sorghum for WCA.
- Information technology facilitates the development of databases of various breeding products - varieties, seed parents, restorers, hybrids, gene pools and genetic stocks-which can be accessed worldwide.

Funding support in recent years has been highly restricted and at times insufficient, forcing researchers to prioritize research themes. However, as mentioned earlier, ICRISAT's approach has helped tap private sector resources without sacrificing CGIAR's position on keeping the research products under international public goods.

4.10. Conclusions

Sorghum, a self-pollinated crop, is an important food crop in Africa and Asia. It is also used for feed, breweries and industrial products. Domestication occurred as early as 5000 years ago. The availability of male-sterile genes has enabled breeders to not only follow pedigree breeding methods as in other self-pollinated species, but also several recurrent selection procedures developed for cross-pollinated species. The cytoplasmic genetic male-sterile system has helped exploit heterosis through hybrids. Though varieties and hybrids were initially ICRISAT's target outputs, its breeding processes underwent several changes over the years. Currently, there has been a shift from developing finished products to intermediate products, partnership research with NARS, and from applied research to developmental and upstream research. In future, ICRISAT intends to concentrate on a few targeted set of themes such as resistance to *Striga,* grain mold, anthracnose, shoot fly, stem borer and head bug in the context of production systems. Through marker-aided selection and conventional and participatory breeding methods, it aims to improve intermediate products - restorers, seed parents and gene pools - as international public goods. In Africa it lays more emphasis on developmental aspects, including finished products, while in Asia it focuses on upstream research.

4.11. References

Agrawal BL and House L R. 1982. Breeding for pest resistance in sorghum. Pages 435-446 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P., 502 324, India: ICRISAT.

Andrews DJ. 1966. New male sterile grain sorghum released. Crops and Soils 19:19-21.

Andrews DJ and Webster OJ. 1971. A new factor for genetic male-sterility in *Sorghum bicolor* (L.) Moench. Crop Science 11:308-309.

Appadurai R. 1968. Development of new male sterile sorghums. Madras Agricultural Journal 55:474-480.

Bandyopadhyay R and Mughogho LK. 1988. Evaluation of field screening techniques for resistance to sorghum grain molds. Plant Disease 72:500-503.

Doggett H. 1988. Sorghum. Second edition. New York, USA: John Wiley and Sons. 512 pp.

Downes RW and Marshell DR. 1971. Low temperature induced male sterility in *Sorghum bicolor.* Australian Journal of Experimental Agriculture and Animal Husbandry 11:352-356.

Duncan RR, Bramel Cox PJ and Miller FR. 1991. Contributions of introduced sorghum germplasm to hybrid development in the USA. Pages 69-102 *in* Cultivar development (Shands HL and Weisner LE, eds.). Part I by Division C-1 of the Crop Science Society of America, Las Vegas, Nevada, USA. Wisconsin, USA: Crop Science Society of America.

FAO (Food and Agriculture Organization of the United Nations), website: http://www.fao.org.

Haussman BIG, Hess DE, Reddy BVS, Mukuru SZ, Kayentao M, Welz HG and Gieger HH. 2000. Diallel studies on *Striga* resistance in sorghum. Pages 41-58 *in* Breeding for *Striga* resistance in cereals: proceedings of a workshop, 18-20 Aug 1999, International Institute of Tropical Agriculture, Ibadan, Nigeria (Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds.). Weikersheim, Germany: Margraf.

Hess DE and Ejeta G. 1992. Inheritance of resistance to *Striga* in sorghum genotype SRN 39. Plant Breeding 109:233-241.

House LR. 1985. A guide to sorghum breeding. 2nd edn. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 165 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1975. Sorghum improvement: International testing. Page 10 *in* Annual report 1974-75. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1976a. Cooperative programs. Pages 221-225 *in* Annual report 1975-76. Patancheru, A.P 502 324, India: ICRISAT

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1976b. *Striga:* Resistance breeding techniques. Pages 33-34 *in* Annual report 1975-76. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1977. Mechanical resistance to *Striga.* Pages 34-36 *in* Annual report 1976-77. Patancheru, A.P. 502 324, India: ICRISAT

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1978a. Cooperative programs. Pages 251-275 *in* Annual report 1977-78. Patancheru, A.P, 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1978b. *Striga* resistance. Pages 39-42 *in* Annual report 1977-78. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1980. Breeding for resistance to drought. Pages 25-34 *in* Annual report 1978-79. Patancheru, A.P. 502 324, India: ICRISAT

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1981a. *Striga* resistance. Pages 22-23 *in* Annual report 1979-80. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1981b. Breeding for resistance to stress factors. Pages 23-33 *in* Annual report 1979-80. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1982. Physical environment: Drought. Pages 37-41 *in* Annual report 1981. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1983. *Striga:* Resistance breeding techniques. Pages 33-35 *in* Annual report 1982. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Sorghum: Plant improvement. Pages 40-47 *in* Annual report 1984. Patancheru, A.P. 502 324, India: ICRISAT

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Sorghum: Plant improvement. Page 48 *in* Annual report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Sorghum: Plant improvement. Pages 47-62 *in* Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1991. Varietal improvement: Three-way hybrids versus single-cross hybrids. Pages 47-50 *in* Annual report 1990. Patancheru, A.P. 502 324, India: ICRISAT (Semiformal publication.)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1992a. Medium term plan, 1994-98: Research theme data sets. Patancheru, A.P. 502 324, India: ICRISAT. 221 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1992b. Sorghum varietal improvement: Three-way and single-cross hybrids. Pages 66-68 *in* Annual report 1991. Patancheru, A.P. 502 324, India: ICRISAT. (Semiformal publication.)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1992c. Network activities. Pages 96-103 *in* Annual report 1991. Patancheru, A.P. 502 324, India: ICRISAT. (Semiformal publication.)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1993a. Sorghum: Diseases, insect pests. Pages 16-40 *in* Annual report 1992. Patancheru, A.P. 502 324, India: ICRISAT. (Semiformal publication.)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1993b. Varietal improvement: Hybrid development and testing. Pages 45-48 *in* Annual report 1992. Patancheru, A.P. 502 324, India: ICRISAT. (Semiformal publication.)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1993c. Network activities. Pages 91-96 *in* Annual report 1992. Patancheru, A.P. 502 324, India: ICRISAT. (Semiformal publication.)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1995. Restorers. Pages 75-76 *in* Annual report 1992. Patancheru, A.P. 502 324, India: ICRISAT.

Jayanti, Kamala PD. 1997. Genetics of shoot fly resistance in sorghum hybrids of cytoplasmic male-sterile lines. Ph.D. thesis, Acharya NG Ranga Agricultural University, Rajendranagar, Hyderabad, A.P. 500 030, India. 279 pp.

Jotwani MG. 1976. Host-plant resistance with special reference to sorghum. Proceedings of the National Academy of Science (Biological Sciences) 46:42-48.

Li ZJ, Zhang KJ, Oing YX and Xo JX. 1981. Effect of climate on male sterility in sorghum. Agronomica Sinica 7:129-133.

Mahalinga DM, Anahosur KH and Hegde RK. 1989. Screening sorghum types against stalk rot and grain mold caused by species of fusarium. Current Research 18:5-6.

Maiti RK and Bidinger FR. 1979. A simple approach to identification of shoot fly tolerance in sorghum. Indian Journal of Plant Protection 7:135-140.

Maiti RK, Bidinger FR, Seshu Reddy KV, Gibson P and Davies JC. 1980. Nature and occurrence of trichomes in sorghum lines with resistance to sorghum shoot fly. Joint Progress Report No. 3, Sorghum Physiology and Sorghum Entomology. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Maiti RK, Prasada Rao KE, Raju PS and House LR. 1984. The glossy trait in sorghum: Its characteristics and significance in crop improvement. Field Crops Research 9:279-289.

Miller FR. 1982. Genetic and environmental characteristics of sorghum. Pages 393-402 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P. 502 324, India: ICRISAT.

Musabyimana T, Sehene C and Bandyopadhyay R. 1995. Ergot resistance in sorghum in relation to flowering inoculation technique and disease development. Plant Pathology 44:109-115.

Omori T, Agrawal BL and House LR. 1983. Component analysis of the factors influencing shoot fly resistance in sorghum *(Sorghum bicolor* L. Moench). Experimental Agricultural Research Queensland 17:215-228.

Pande S and Karunakar RI. 1992. Stalk rots. Pages 219-234 *in* Sorghum and millets diseases: A second world review (de Milliano WAJ, Frederiksen RA and Bengston GD, eds.). ICRISAT, Patancheru, A.P. 502 324, India.

Pande S and Singh SD. 1992. Successful transfer of ICRISAT downy mildew resistance screening technology: An example of transfer of technology. Pages 331-334 *in* Sorghum and millets diseases: A second world review (de Milliano WAJ, Frederiksen RA and Bengston GD, eds.). ICRISAT, Patancheru, A.P. 502 324, India.

Pande S, Thakur RP, Karunakar RI, Bandyopadhyay R and Reddy, Belum VS. 1994. Development of screening methods and identification of stable resistance to anthracnose in sorghum. Field Crops Research 38:157-166.

Parker C, Hitchcock AM and Ramaiah KV. 1977. Germination of *Striga* species by crop root exudates. Techniques for selecting resistant cultivars. Pages 67-74 *in* Proceedings of the 6th Asian Pacific Weed Science Society Conference, Djakarta, Indonesia.

Ramaiah KV. 1987. Breeding cereal grains for resistance to witchweed. Pages 227-242 *in* Parastic weeds in agriculture. Vol. I. (Musselman LI, ed.). Boca Raton, Florida, USA: CRC Press.

Ramaiah KV, Chidley VL and House LR. 1990. Inheritance of *Striga* seed germination stimulant in sorghum. Euphytica 45:33-38.

Rana BS, Jotwani MG and Rao NGP. 1981. Inheritance of host plant resistance to the sorghum shoot fly. Insect Science and its Application 2:105-109.

Rana BS and Murty BR. 1971. Genetic analysis of resistance to stem borer in sorghum. Indian Journal of Genetics and Plant Breeding 35:350-355.

Rao NGP and Rana BS. 1982. Sorghum breeding in India: Recent developments. Pages 141-142 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, Patancheru, A.P. 502 324, India: ICRISAT.

Rao NGP, Rana BS, Balakotaiah K, Tripathi DP and Fayed MFS. 1974. Genetic analysis of some Exotic X Indian crosses in sorghum VIII: F_1 analysis of ovipositional nonpreference underlying resistance to shoot fly. Indian Journal of Genetics and Plant Breeding 34:122-127.

Rao, Vasudeva MJ. 1985. Techniques for screening sorghums for resistance to *Striga.* Information Bulletin no. 20, ICRISAT, Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Reddy, Belum VS. 1985. Relatorio final de consultoria (Consultant's report). Submitted to IICA/ EMBRAPA/IPA. 83 pp.

Reddy, Belum VS. 1986. Genetic improvement for drought resistance in sorghum: A plant breeder's viewpoint. Pages 28-32 *in* Genetic improvement of drought resistance. Proceedings of a discussion series of the drought research seminar forums.

Reddy, Belum VS. 1992. Varietal improvement: Three-way single cross hybrids. Pages 66-67 *in* Cereals Program, ICRISAT Annual Report 1991. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Semiformal publication.)

Reddy, Belum VS. 1993. Varietal improvement: Breeding Striga-resistant seed parents. Page 43 *in* Cereals Program, ICRISAT Annual Report 1992. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Semiformal publication.)

Reddy, Belum VS, Mughogho LK and Jambunathan R. 1992a. Breeding grain mold resistance seed parents and hybrids. Pages 28-29 *in* Annual report 1991. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Semiformal publication.)

Reddy, Belum VS, Mughogho LK and Singh SD. 1992b. Sorghum downy mildew: Breeding for resistance. Pages 26-27 *in* Annual report 1991. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Semiformal publication.)

Reddy, Belum VS and Prasada Rao KE. 1991. Breeding new seed parents: Identification of a minimum set of testers to differentiate male-sterile cytoplasms. Pages 46-47 *in* Cereals Program, ICRISAT Annual Report 1990. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Semiformal publication.)

Reddy, Belum VS and Prasada Rao KE. 1992. Breeding new seed parents: Breeding nonmilo restorer lines. Pages 63-64 *in* Cereals Program, ICRISAT Annual Report 1991. Patancheru, A.P 502 324, India. (Semiformal publication.)

Reddy, Belum VS, and Prasada Rao KE. 1993. Varietal improvement: Genetic diversification. Pages 48-51 *in* Cereals Program, ICRISAT Annual Report 1992. ICRISAT, Patancheru, A.P. 502 324, India. (Semiformal publication.)

Reddy, Belum VS and Singh SD. 1993. Sorghum anthracnose: Inheritance of resistance. Page 17 *in* Annual Report 1992. Patancheru 502 324, India: ICRISAT. (Semiformal publication.)

Reddy, Belum VS and Stenhouse JW. 1993. Genetic enhancement research on sorghum at ICRISAT Asia Center, 1972-1992. Pages 15-18 *in* Evaluating ICRISAT research impact: Summary proceedings of a workshop on Research Evaluation and Impact Assessment, 13-15 Dec 1993, ICRISAT Asia Center, India (Bantilan MCS and Joshi PK, eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Reddy, Belum VS and Stenhouse JW. 1994. Sorghum improvement for semi-arid tropics region: Past, current and future research thrusts in Asia. P K V Res. J. 18:155-169.

Reddy, Belum VS and Stenhouse JW. 1996. Improving postrainy-season sorghum, a case for landrace hybrids approach. Presented at AICSIP (All India Coordinated Sorghum Improvement Project) Workshop, 18-20 Apr 1994, Pantnagar, Uttar Pradesh, India.

Reddy, Belum VS and Taneja SL. 1993. Breeding stem borer-resistant seed parents, restorer lines and hybrids. Pages 32-35 *in* Annual report 1992. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Semiformal publication.)

Schertz KF and Pring DR. 1982. Cytoplasmic sterility systems in sorghum. Pages 373-383 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Seshu Reddy KV and Davies JC. 1979. A new medium for mass rearing of sorghum stem borer *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) and its use in resistance screening. Indian Journal of Plant Protection 6:48-55.

Sharma GC, Jotwani MG, Rana BS and Rao NGP. 1977. Resistance to sorghum shoot fly *Atherigona soccata* (Rondani) and its genetic analysis. Journal of Entomological Research 1:1-12.

Sharma HC. 1993. Host plant resistance to insects in sorghum and its role in integrated pest management. Crop Protection 12:11-34.

Sharma HC. 1997. Screening for resistance to head bugs. Pages 65-71 *in* Plant resistance to insects in sorghum (Sharma HC, Faujdar Singh and Nwanze KF, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Sharma HC, Abraham CV, Vidyasagar P and Stenhouse JW. 1996. Gene action for resistance in sorghum in midge, *Contarinia sorghicola.* Crop Science 36:259-265.

Sharma HC, Taneja SL, Leuschner K and Nwanze KF. 1992. Techniques to screen sorghum for resistance to insects. Information Bulletin no. 32. Patancheru 502 324, A.P., India: International Crops Research Institute for the Semi-Arid Tropics. 48 pp.

Sifuentes JA, Mughogho LK and Thakur RP. 1993. Inheritance of resistance to sorghum leaf blight. Pages 16-17 *in* Cereals Program ICRISAT 1993. Annual Report 1992. Patancheru, A.P 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Semiformal publication.)

Singh BU and Rana BS. 1994. Influence of varietal resistance on disposition and larval development of stalk borer, *Chilo partellus* Swinhoe and its relationship to field resistance in sorghum. Insect Science and its Application 5:287-296.

Stephens JC and Holland RF. 1954. Cytoplasmic male sterility for hybrid sorghum production. Agronomy Journal 46:20-23.

Tegegne G, Bandyopadhyay R, Mulatu T and Kebede Y. 1994. Screening for ergot resistance in sorghum. Plant Disease 78:873-876.

Thakur RP, Frederiksen RA, Murty DS, Reddy, Belum VS, Bandyopadhyay R, Giorda LM, Odvody GN and Claflin LE. 1997. Breeding for disease resistance in sorghum. Pages 303-315 *in* Proceedings of the International Conference on Genetic improvement of sorghum and pearl millet, 22-27 Sep 1996, Holiday Inn Plaza, Lubbock, Texas, USA.

Thomas MD, Bocoum F and Thera A. 1993. Field inoculation of sorghum with sclerotia and conidia of *Ramulispora* sorghum formed *in vivo.* Mycologia 85:807-810.

Vidyabhushanam RV, Rana BS and Reddy, Belum VS. 1989. Use of sorghum germplasm and its impact on crop improvement in India. Pages *85-89 in* Collaboration on genetic resources: summary proceedings of a Joint ICRISAT/NBPGR (ICAR) Workshop on Germplasm Exploration and Evaluation in India, 14-15 Nov 1988, ICRISAT, Hyderabad. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Widstrom NW, Wiseman BR and McMillian WW. 1984. Patterns of resistance in sorghum to the sorghum midge. Crop Science 24:791-793.

Appendix 4.1. Populations maintained at ICRISAT-Patancheru.

Name of population	Seed available cycles	Years of impro-vement	Seed multiplied season	Maintained/ developed at	Original source	Parents incorporated	Male-sterile gene	Target traits
US/B	C_0-C_8	1974-84	89R/90R	Patancheru	PP2, PP6, NP2, NP4	296B, 323B, 2219B, 2077B	ms_3	High yield
US/R	C_0-C_8	1974-84	89R/90R	Patancheru	PP1, PP3, PP5, NP4, NP5, NP8	296B, 323B, 2219B, 2077B	ms_3	High yield
Rs/B	C_0-C_8	1973-84	89R/90R	Patancheru		296B, 323B, 2219B, 2077B, Sel. from US/R-C_1, RS/R, Ind. Syn., FLR 101, FLR 274, RS1 x VGC, IS 12645C, IS 9327	ms_3	High yield
Rs/R	C_0-C_8	1974-83	89R/90R	Patancheru		GGS 370, 1483, Ind. Syn-250, Diallel 876, FLR 101, IS 1082, IS 9327, IS 11758, SPV 249, SPV 393, SPV 351, SPV 475, SAR 2, SAR 4, PS 19230, SB 8104-1, PMs 7348, 7349, 7061, 7495	ms_3	High yield
FL/B	C_0-C_4	1981-84	89R/90R	Patancheru	NP2, NP6		ms_3	High yield
FL/R	C_0-C_4	1981-84	89R/90R	Patancheru	NP1, NP3, NP4, NP5, NP8		ms_3	High yield
WAE	C_0-C_4	1981-84	84R/90R	Patancheru	S_1 selections from Nigerian, WABC and Bulk Y	CS 3541, GG 370, SPVs 86, 422, 424, 393, Ind. Syn-323, ETs 1966, 4789, ISs 6373, 22233, 23555	ms_7	High yield, photo-period sensitivity populations
Tropical conversion	C_0-C_3	1974-76	89R/91R	Patancheru	Puerto Rico population and early lines	Heterozygous material from BC1/BS2S of Puerto Rico conversion program crossed to Serere RS population	ms_3	High yield
Ind.Synthetic	C_0-C_1	1983	91R	Patancheru		GPRs 370, 148, CSV 4, IS 3691, CK 60B, 2219B, E 35-1, FLRs 101, 266, UChV2, SARs 2,4,6, PMs 7061, 7495, 7348, 7349, PB 8284, PS 19230	ms_3	High yield
Good grain	C_0-C_1	1974	91R	Patancheru	Serere	GPR 370 and 120 white corneous sorghums	ms_7	High yield, photo-period sensitivity
Serere	C_0-C_1	1976	90R/91R	Patancheru	RS5DX, RS5DXCSF, RS1 x VGC, Hyd RS	GPR 370 and 120 white corneous sorghums	ms_7	East African adaptation
Serere Elite	C_0-C_1	1976	74R/87R	Patancheru			ms_3	East African adaptation
ICSP1 B/ R MFR	C_0-C_4	1984-89	89R/90R	Patancheru	US/R, RS/R, Ind.Syn.	6 shoot fly, 9 stem borer, 7 midge, 6 downy mildew, 5 leaf diseases, 3 *Striga*, 6 drought, 2 seedling vigor lines	ms_3	Multifactor resistance

...continued

Appendix 4.1. *Continued*

Name of population	Seed available cycles	Years of impro-vement	Seed multiplied season	Maintained/ developed at	Original source	Parents incorporated	Male-sterile gene	Target traits
ICSP2 B/ R MFR	C_0-C_1	1984-89	87R/89R	Patancheru	US/R, RS/R, Ind.Syn.	39 temperature insensitive, 22 photoperiod sensitive, 9 shoot fly, 2 *Striga*, 13 rabi breeding lines	*ms*$_3$	Multifactor resistance
ICSP B/ R MFR	C_0-C_1	1987-89		Patancheru	ICSP1 B/R MFR and ICSP2 B/R MFR	15 shoot fly, 5 stem borer, 7 midge, 6 nonsenescence, 29 photoperiod sensitive and temperature insensitive, 30 bold grain, 17 terminal drought, 9 ms$_3$ rabi adapted lines, 3 dwarf and early lines	*ms*$_3$	Multifactor resistance
ICSP-LG	C_0-C_1	1993-99	93R/99R	Patancheru	US/B C6	ISs 80, 808, 2322, 2409, 9761, 9991, 10469, 10513, 14789, 15551, 15594, 16201, 18372, 18729, 18762, 22643, 23891, 23985, 23986, 24737, 33843, 33844, SS 25, 35, ICSV 735, E 36-1, M35-1	*ms*$_3$	Large grain, shoot pest resistance
ICSP-HT	C_0-C_1	1994-99	94R/99R	Patancheru		A 2267, B 24, SSG 59-3, SP 36257, IS 12611, 8 early lines and 3 high-tillering lines, 7 sweet stalk lines, 3 Sudan grass lines, 3 tall, late-maturing tillering lines	*ms*$_3$	Tillering
ICSP-B	C_0-C_7	1994-99	94R/99R	Patancheru		10 bold grain lines, 5 midge-resistant lines, 8 dwarf stem borer-resistant lines, PS 19349, 47 progenies of QL3 x 296 B	*ms*$_3$	High yield, shoot fly resistance
Early dual-purpose		1976		Patancheru	ICSP-US/R (DP)	ISs 869, 8101, 18758C-591-T, 18758C-618, 19159, 20545, 22500, 23897, 24335, 24436, HC 260	*ms*$_3$	Early maturity
Medium/late			90R	Patancheru			*ms*$_3$	Medium maturity
Early dual-purpose		1991-97		Patancheru	US/R S1	12 high-biomass landraces: HC 260, ISs 869, 3496, 8101, 19159, 20545, 22500, 23897, 24335, 24436, 18758C-591T, 18758C-618	*ms*$_3$	Early maturity
Early, photoperiod-insensitive sorghum population		1996-		Patancheru	MFR steriles, Russian x bold grain R-lines	CSV 15, SPV 881, AKR 150, ICSV 38, CSV 4, RS 29, CB 43, Seredo, Framida, Naga White, ISs 8744, 8785, 18520, 36571		Early maturity, photoperiod insensitivity

...continued

Appendix 4.1. ***Continued***

Name of population	Seed available cycles	Years of impro-vement	Seed multiplied season	Maintained/ developed at	Original source	Parents incorporated	Male-sterile gene	Target traits
Conspicum sorghum population		1995-		Patancheru	Grain mold-resistant *Guinea* population steriles	Conspicum landraces _ ISs 7173, 23770, 23773, 23783, 24135, 24173, 24189, 24191, 24196, 24221, 24286, 24296		Yield, yield stability, photoperiod sensitivity
Sudan sorghum population				[US/R(DP)C1 x	IS22500]	ISs 366, 921, 3492, 9884, 13444, 18297, 22500, Ajab-Seido (drought tolerant, grain quality line)	*ms*$_3$	Yield and early maturity (<95 days)
East African Bulk			87R/90R					Regional adaptation
Indian Diallel			90R	Patancheru	45 entries from world collection		*ms*$_3$	High yield
Brown			90R	Patancheru			*ms*$_3$	
WABC			91R	Patancheru			*ms*$_3$	High yield
Bulk-Y			91R	Patancheru			*ms*$_3$	High yield
NP10 BR Bulk			1976	Patancheru			*ms*$_3$	High yield
High altitude				Patancheru			*ms*$_3$	High yield
PR1 BR Sub Sorghum			1974	Patancheru			*ms*$_3$	
Shoot pest	C_0-C_8		1978-96	Patancheru	Resistant lines from advanced populations – US-B/R, RS-B/R, FLB/R, Serere, tropical conversion.	F_2s from crossing among 98 landraces, and 17 breeding lines representing diverse sources for shoot fly and/or stem borer resistance	*ms*$_3$/*ms*$_7$	Shoot pest resistance
Head pest	C_0-C_9		1985-96	Patancheru	Resistant lines from advanced populations - USB/R, RSB/R, FLB/R, Serere, tropical conversion.	F_2s from crossing among 27 landraces, and 6 breeding lines representing diverse sources of resistance for head bug and midge	*ms*$_3$/*ms*$_7$	Head pest resistance

...continued

Appendix 4.1. *Continued*

Name of population	Seed available cycles	Years of improvement	Seed multiplied season	Maintained/ developed at	Original source	Parents incorporated	Male-sterile gene	Target traits
Grain mold			1984-97	Patancheru	US/R and US/B	58 mold-resistant and 4 susceptible lines, 27 high-yielding and 14 dwarf and early lines.	ms_3	Grain mold resistance
SDSP-hot/dry				Zimbabwe	TP24R04/TP15R05, P21RB03, 84PP-19M, PP-19			
SDSP-cool/dry				Zimbabwe	TP24R04/TP15R05, TP8, WAE, KP8			
SDSP-drought conditions				Zimbabwe	TP24R04/TP15R05, TP15, TP21RB03, KP9BSO			Drought resistance
SDSP-broad adaptation				Zimbabwe	TP24R04/TP15R05, TP21RB03			
Guinea				Nigeria		13 *Guinea* lines from West Africa	ms_3	Racebased
Caudatum				Nigeria		12 *Caudatum* lines with grain mold resistance, mostly colored, from Mali	ms_3	Racebased
Guinea-Caudatum				Nigeria		Selected improved and adapted landraces, high-yielding lines and a few resistant sources	ms_3	Racebased

Sorghum Breeding Research in Africa

5

AB Obilana

Sorghum Breeding Research in Africa

AB Obilana[1]

5.1. Introduction

Originating in Africa, the sorghums, including the cultivated, weedy and wild types, have travelled around Asia, Australia and the Americas, and now exist in the arid, semi-arid, subhumid tropical and sub-tropical lowlands and highlands. Recognizing the differences that occurred as a result of this movement and the resulting changes, farmers used their indigenous knowledge in crop production, improvement and utilization. Crop improvement was initiated by these farmers through selection over the centuries. Sorghum was domesticated around 3000 B.C. (Doggett 1965a). Plant breeding, which involves hybridization and selection following testing, replaced farmer selection activities and became established with the rediscovery of Mendel's genetic studies at the beginning of the 20th century. However, sorghum breeding in Africa did not begin until the late 1930s.

National programs had their own priorities when it came to crop improvement. Across Africa, research programs on sorghum were given low priority; the focus was mainly on collecting local germplasm, characterization and selection from local landraces. This led to the identification, selection and release of better landraces. Breeders then began introductions and conversion programs using exotic material. Priority was given to grain yield and resistance to endemic insects and diseases. The methodologies employed then, such as phenotypic selection, hybridization, pedigree and bulk breeding, population improvement and recurrent selection with line development, still continue in many African countries. Between 1930 and 1950, a multilateral collaboration in Eastern Africa involving Kenya, Uganda and Tanzania began (Doggett 1988a). Greater prominence was given to wide adaptation and increased productivity. In the late 1970s, a regional approach to breeding surfaced, the result of such collaborations. The first of such regional approaches to breeding sorghum was the OAU/STRC (Organization of African Unity/Scientific Technical and Research Commission) Joint Project 31 on Semi-Arid Food Grain Research and Development in Africa (SAFGRAD) initiated in 1976.

The major producers of sorghum in Africa are Nigeria (36.7%, 6.1 million t), Sudan (19.3%, 3.3 million t), Ethiopia (0.7%, 1.2 million t) and Burkina Faso (0.73%, 1.25 million t). Countries like Mali (0.73 million t), Tanzania (0.59 million t), Niger (0.60 million t), South Africa (0.48 million t) and Uganda (0.38 million t) produce less than 1 million t (FAO/ICRISAT 1996).

Achievements in sorghum breeding in Africa have mainly been in the development and release of improved varieties based on higher grain yield and resistance to diseases, insect pests and *Striga.* Many of the released varieties did not find acceptance among farmers and their clients since they did not possess preferred traits. This resulted in the scanty adoption of these "book releases". In effect sorghum breeding had negligible or no impact in Africa before the 1990s, with the exception of sorghums used for brewing beer in Nigeria and commercial opaque beer in South Africa and

[1] International Crops Research Institute for the Semi-Arid Tropics, PO Box 39063 Nairobi, Kenya.

Obilana AB. 2004. Sorghum breeding research in Africa. Pages 105-136 *in* Sorghum genetic enhancement: research process, Dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Zimbabwe. However, since 1990, there has been an improvement in the adoption and impact of improved sorghum varieties with the incorporation of farmer-acceptable varieties, inclusion of industrial processing traits into new improved varieties and participatory selection for several end-use qualities (such as food, feed and raw materials in brewing and composite flour for baking).

This chapter traces the progression of sorghum breeding in Africa, with details of trends in breeding (genetic enhancement) strategies, methodologies, germplasm exchange and utilization, achievements and impacts in WCA, ECA and Southern Africa (SADC). Some suggestions are made for the future of sorghum breeding research in Africa.

5.2. Genetic Enhancement Strategies

5.2.1. Africa-wide Constraints, Agroecologies and Breeding Methodologies

Sorghum is grown as a rainfed crop in diverse environments across tropical and sub-tropical agroecologies in Africa; from the extreme lowland arid and semi-arid zones (of Libya, Sahel of West Africa and Botswana) to the sub-humid and humid lowlands (of southern Guinea Savanna of West Africa) and the mid-highlands (of the Great Lakes Zone of East Africa). The semi-arid and sub-humid highlands are typified by the sorghum highlands of Ethiopia, ECA and Lesotho (where sorghums are cultivated around Mokhotbug at an altitude of 2400 m). In all these areas, traditional sorghums are grown amidst the weedy wild species. A few specialized types such as transplanted sorghums occur in inland swamps that experience receding floods (as in Okavango in northern Botswana) and hydromorphic black soils (around Lake Chad and the mid-Niger River zone in central Mali). These diverse agroecologies with their varying production systems determine the different production constraints affecting sorghum production and consequently research in Africa.

Following are some constraints to production that cut across the three regions (WCA, ECA and SADC):

- Understanding and conserving landrace varieties and farmer knowledge with utilization
- Biotic stresses such as insect pests (mainly stem borers and shoot fly) and diseases (mainly leaf blight, sooty stripe and anthracnose); *Striga* (the two economically significant species S. *hermonthica* and S. *asiatica);* and bird damage which can be managed
- Abiotic stresses such as soil infertility and degradation.

The distribution of *Striga* presents an interesting scenario. S. *hermonthica* occurs mainly north of the equator while *S. asiatica* (red flower) occurs south of it. Studies (Mbwaga and Obilana 1994) show that in Tanzania and possibly in countries along the same latitude, these two species overlap while they co-exist in central Tanzania. The specific endemic constraints in each of the three regions - drought, low temperatures, photoperiod sensitivity, soil toxicity, grain mold, midge, leaf diseases and other adoption-related constraints - are addressed.

Africa abounds in variability and genetic diversity of sorghum. Given the abundant genetic resources coupled with the appropriate agroecosystem and farmer knowledge, sorghum breeding programs began with the collection, characterization and conservation of landraces. This was followed by selections among landraces, leading to the identification of better accessions which were then tested in replicated trials and analyzed. The best accessions were released as 'improved local selections'. Several of these earlier releases form the basis of the first set of 'improved sorghum varieties' in national and multilateral programs. Some of these are still being used as checks in national and regional trials.

Useful cultivars from such local varietal trials were identified as parents in order to begin a pedigree breeding program. At the same time, exotic materials were introduced, adapted and tested. Between 1948 and 1960, pedigree breeding programs were initiated, beginning with the crossing of local X local, local x exotic and exotic x exotic parents. Formal selections then began using bulk single plants and modified pedigree methods. Population improvement with recurrent selection and line development, together with hybrid development too started. This was made possible with the availability of male sterility (ms) and sources of *ms* genes. All three forms of sterility - cytoplasmic, genetic and cytoplasmic-genetic - were utilized at different times by different programs from 1958. By this time there were more players in sorghum improvement, both from within Africa and outside it. International organizations and ARIs such as ICRISAT, INTSORMIL, Arid Lands Agricultural Development (ALAD), Centre de cooperation internationale en recherche agronomique pour le developpement (CIRAD), IRAT and other regional networks were initiated between 1958 and 1978.

5.2.2. Eastern and Central Africa

Sorghum research in Eastern Africa began with the collection and screening of local sorghum germplasm in Kenya, Uganda and Tanzania (1930-50). Useful local selections were identified; the more popular ones being Dobbs (from western Kenya) and L 28 (from Uganda) (Doggett 1988a). With sorghum gaining significance in Uganda and Tanzania, a breeding program for short-season, white- and brown-grained 'bird-resistant' types was started in Tanzania in 1948. The outcome of this breeding program was the development in 1956/57 of the brown sorghum variety Serena (Swazi PI 207 X Dobbs). This led to an Eastern African regional sorghum improvement program at Serere, Uganda, in 1958 focusing on managing *Striga* and bird damage in the next two decades (1958-78). Three varieties came out of this exercise, two of which - Seredo (Serena X CK60) with brown grain and Lulu-D (SB77 X Seredo) with white grain - are still popularly grown by farmers in Kenya, Uganda and Tanzania. ICRISAT came to the region in 1978 to assist in sorghum improvement; the focus was on using selected landraces as parents and adaptive testing of crossbreds. ICRISAT operated from India and Kenya under a project of the Tanzanian Government, later expanded into two successive regional networks (1986-93) - the East Africa Regional Cereals and Legumes (EARCAL) network and the East Africa Regional Sorghum and Millets (EARSAM) network. In 2002, the East and Central Africa Regional Sorghum and Millets (ECARSAM) network was set up. While EARCAL/EARSAM were funded by USAID through SAFGRAD/ICRISAT collaboration, ECARSAM is funded by the European Union through ASARECA. Between 1993 and 1999, ICRISAT's involvement in Eastern Africa was strengthened with inputs of improved varieties from the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP).

During 1986-2000, ICRISAT made significant progress in its collaboration with national programs in the region. Though more than 500 improved sorghum varieties were identified, less than 10% of them are being grown by farmers in seven countries (Table 5.1). Low adoption was mainly due to inadequate on-farm testing and interaction with farmers. Farmers' participatory testing was stepped up from 1996. This was expected to boost the adoption of newer varieties. Collaborative adaptive testing on station and on farm in Ethiopia during 1995-2000 resulted in the release of five sorghum varieties for production in the Western Lowlands (ICSV 210, PP 290), Central mid-Highlands (IS 29415) and Eastern Lowlands Wadi (89MW5003, 89MW5056). The impact of these varieties on farmers' fields needs to be urgently monitored and assessed. In Rwanda, the impact of the increased adoption of ICRISAT-bred variety 5D x 150 has been experienced in its use for brewing clear lager beer since 1998. Serena and Seredo varieties are popularly used to make porridge with finger millet and with cassava flour to make *ugali* in the Great Lakes Region.

Ethiopia and Sudan can be regarded as leaders in sorghum improvement in the region. The Ethiopian Sorghum Improvement Program (ESIP) began full-fledged operations in 1973. The

Table 5.1. Sorghum varieties released and available in seven Eastern and Central African countries.

Country	Varieties and hybrids released	Year of release	Remarks
Uganda[1]	Epuripur (Tegemeo)	1995	
	Serena	1967	Also grown in Rwanda
	5D x 150	1982	
	Seredo	1982	Also released in Tanzania
	Sekedo	1995	
Burundi	IS 9198	?[3]	.4
	Gambella 1107	?	-
	5D x 150	?	
Kenya[2]	KARI Mtama 1	1994	-
	ICSV III (PGRC/E) 216740) (KARI Mtama 3)	2001	-
	IS 8193 (KARI Mtama 2)	2001	-
	Serena	1972	-
	Seredo	1982	-
Eritrea	ICSV 210 (Bushuka)	2000	For the Western Lowlands
	PP 290 (Shambuko)	2000	For the Western Lowlands
	89MW5003 (Shieb)	2000	For the Eastern Lowlands Wadi
	89MW5056 (Laba)	2000	For the Eastern Lowlands Wadi
	IS 29415	2000	For the mid-Highlands
Rwanda	5D x150	1980	For brewing
	KAT 369	-	White grain for food
	ICSB 41	-	White grain for food
	IS 8193	2001	Brown grain
	IS 21016	2001	For brewing
	Seredo	-	For brewing
	Ikinyaruka	?	For brewing (local)
Somalia	Gedam Hammam	2000	Grey and popular
	CR35:3	2000	Grey grain
	IESV92043DL	2000	Grey grain
	F6YQ211	2000	Grey grain
Tanzania	2K x 17 (Tegemeo)	1988	White grain for brewing
	Pato	1995	White grain for food
	Macia	1999	White grain for food
	Lulu-D	1980	White grain for food
	Bangala	?	White grain for food (local)
	Serena	1958	Brown grain for brewing

1. Five other varieties (making a total of 10) were released between 1960 and 1995. Their adoption rates and area are not known, and need to be determined.
2. Seven other varieties were released or prereleased between 1960 and 1995. Their adoption rates and area are not known and need to be determined.
3. Year of release not known.
4. Not formally released.

focus was on collecting and screening local varieties, development of varieties and hybrids, ensuring grain quality and marketing and *striga* research. The program was home to the popular *Zera-zera* (*Caudatum* race) type of sorghum which served as parent material in ICRISAT sorghum improvement programs until the 1990s due to its good combining ability. Nationally, ESIP made significant progress with the release of Awash 1050, the popular ETS series and Gambella 1107 (E 35-1), that are widely used in ICRISAT breeding programs.

Since 1972, the Sudan national program at Wad Medani has been collaborating with the ALAD program in local germplasm collection, screening, hybridization (local X exotic and local X local crosses), and hybrid development with emphasis on *Striga* management. The most significant outcome of Sudan's cooperative program with ICRISAT (1977) was the release in 1982 of commercial hybrid Hageen Durra 1 (T x 623A x karper 1597) by ICRISAT and the Sudan Agricultural Research Corporation (ARC) (Doggett 1988a; Ejeta 1986). A review of sorghum improvement and production in Eastern Africa has been detailed by Gebrekidan (1987). Table 5.2 lists the sorghum varieties released and available in Ethiopia and Sudan.

Table 5.2. Sorghum varieties released and available in Ethiopia and Sudan[1].

Country	Varieties and hybrids released	Year of release	ECA regional impact
Ethiopia	Gambella 1107(E35-1)	1980	Released in several ECA countries
	Dinkmash (ICSV 1)	1988	
	Seredo	1980-98	Released in several ECA countries
	76 Ti # 23	1980	
	M-36121 (MEKO)	1980	
	IS 9302	1980	
	Birmash	1980-98	
	Baji (85MW 5334)	1980-98	
	Alemaya 70	1980-98	
	ETS 2752	1980-98	
	ETS 5946	1980-98	
	Hararghe Coll. #4	1980-98	
Sudan	Hageen Durra 1	1982	
	Mugawim Buda 1 (SRN 39)	1991	Used in *Striga* host-plant resistance and check
	Dabar	2	
	Ingazi (M90393)	1992	
	Gedam el Hamam	2	Used in relief seed, becoming popular in the region
	CR35:5	2	

1. Ten other varieties are available/released and grown by farmers in the country. Their adoption rates and area grown need to be determined.
2. Year of release not known.

5.2.3. Southern Africa

Sorghum research in the SADC region, mainly in South Africa and Botswana, began before World War II with emphasis on selections within landraces, bird resistance and resistance to *Striga* and drought. These activities spilled over into Zimbabwe and Zambia with a diversified focus on hybrid development and production. As early as in 1940, converted sorghum genotypes, especially combined *Kafirs* and white grained male-sterile lines were introduced into South Africa. To this day, both locally-developed varieties and hybrids introduced from USA are produced. Soon the advent of seed companies led to the commercialization of sorghum for industrial use (brewing of opaque beer and malting for foods and drinks). Significant achievements were made with the development and widespread cultivation of sorghum varieties and hybrids. In South Africa, selections from landraces included Red Swazi, one of the earliest-maturing varieties (90-95 days) in the region and Framida, selected for *Striga* resistance from an introduced Chadian/Nigerian landrace. Radar, a crossbred variety, was until recently cultivated in South Africa and Botswana for *Striga* resistance. The most popular sorghum hybrid to date has been DC 75, commercially grown for brewing opaque beer. Its male parent (Red Nyoni) is a landrace selection popular in Zimbabwe and Zambia, selected from the improved landrace Red Swazi in Zimbabwe (Doggett 1988a). Segaolane is a very popular and widely grown sorghum variety in Botswana and the rest of Southern Africa. It too was selected from landraces, together with Town. Among the other varieties released earlier in Botswana and derived from introduced *Kafirs* from USA are 8D and 65D (Saunders 1942).

Between 1960 and 1980, there was a lull in sorghum breeding as maize development and production was expanding in Southern Africa. Cyclical droughts became predominant and severe drought in the late 1970s led to the deliberations of the heads of States of SADCC (Southern Africa Development Conference Community) on interventions to minimize the effects of the disaster. This led to the establishment of the SADC/ICRISAT SMIP in 1983/84. Details of the regional process, germplasm introductions, breeding, testing and selection of sorghum in Southern Africa were reported by Obilana (1998).

SADC/ICRISAT SMIP has used a regional, collaborative and multidisciplinary approach to sorghum improvement. Between 1983/84 and 1997/98, improved varieties and hybrids were developed, tested on station and on farm and released by the NARS of the eight countries in the SADC region. Breeding, crop protection and crop management research focused on drought tolerance, early maturity, grain and fodder productivity and resistance to downy mildew, leaf blight, sooty stripe and *Striga.* Sorghum grain was also evaluated for food, malting and feed qualities.

The program made significant achievements in germplasm movement and utilization; cultivar development, testing and release; assessment of grain quality for different end uses; strengthening research capacities in national programs and fortifying linkages with NGOs, the private sector and seed companies in Zimbabwe and South Africa, millers in Botswana and Zimbabwe and breweries and feed companies in Zimbabwe and farmers' organizations and universities across countries. More than 12,000 sorghum germplasm accessions were assembled from all over the world and made accessible to NARS for sorghum improvement. Of these, 10,075 enhanced breeding lines, 4634 advanced varieties, 379 hybrid parents and 3436 experimental hybrids were developed (Table 5.3) and provided to Angola (100), Botswana (2398), Lesotho (681), Malawi (1449), Mozambique (322), Namibia (139), South Africa (147), Swaziland (326), Tanzania (3702), Zambia (5330) and Zimbabwe (3930). A total of 27 varieties and hybrids were released in eight SADC countries (Table 5.4). Of these, only 9 (33%) are cultivated on about 20-30% of the sorghum area in six countries (Obilana et al. 1997). Five sources of resistance to three *Striga* species were identified (Obilana et al. 1988; Obilana et al. 1991). Twenty-three drought-tolerant male parents (R-lines) and 36 female parents (A-lines) with their maintainer (B-lines) parents were developed and are presently being used in South Africa, Tanzania, Zambia and Zimbabwe in their hybrid development programs (Obilana 1998). Variety Macia proved to be most popular in the region; it was released in five SADC countries and the area under it is increasing.

An assessment of the grain quality of more than 2500 improved sorghum genotypes, including the 27 released and 100 indigenous varieties, led to the adoption by farmers of more released

Table 5.3. Improved sorghum genetic material (number of samples and collaborative trials) supplied by SMIP to SADC countries, 1983/84 to 1997/98.

Country	Number of samples					Number of trials
	Breeding lines	Advanced lines	Hybrid parents	Hybrids	Total	
Angola	0	91	0	9	100	15
Botswana	916	790	60	632	2398	53
Lesotho	96	212	0	373	681	21
Malawi	411	681	0	357	1449	42
Mozambique	69	233	0	20	322	20
Namibia	0	87	0	52	139	9
South Africa[1]	0	87	60	0	147	3
Swaziland	13	130	13	170	326	18
Tanzania	2350	936	0	416	3702	53[2]
Zambia	4032	551	96	651	5330	39[2]
Zimbabwe	2188	836	150	756	3930	335[2]
Total	10,075	4634	379	3436	18,524	608

1. SMIP started responding to South Africa's requests from 1994/95.
2. Includes breeding, pathology, entomology and *Striga* hot-spot trials and observation nurseries.

Source: Obilana (1998).

Table 5.4. Sorghum varieties and hybrids released in eight SADC countries as a result of collaborative NARS/ICRISAT SMIP research, 1984/85 to 1997/98.

Country	Variety name	Year of release	Recommended production/adaptation zones	Remarks[1]
Botswana	BSH 1	1994	Short season, 250-750 mm rainfall	White, DT
	Mahube	1994	Very short season, 200-600 mm rainfall	Red, SG
	Mmabaitse	1994	Short season, 250-750 mm rainfall	White
	Phofu (Macia)	1994	Short season, 250-750 mm rainfall	White, DT, SG
Malawi	Pirira 1	1993	Intermediate season, hot and humid areas, 400-850 mm rainfall	White, TSB
Mozambique	Chokwe	1993	Intermediate season, 400-850 mm rainfall	White, SSB
	Mamonhe	1989	Intermediate to long season, 750-950 mm rainfall	White
	Macia	1989	Short season, 250-750 mm rainfall	White, DT, SG
Namibia	Macia	1998	Short season, 250-750 mm rainfall	White, DT, SG
Swaziland	MRS 12	1992	Intermediate season, 400-850 mm rainfall	White
	MRS 13	1989	Intermediate season, 400-850 mm rainfall	Red
	MRS 94	1989	Intermediate season, 400-850 mm rainfall	Brown, RSS, RLB
Tanzania	Tegemeo	1988	Intermediate to long season, 450-850 mm rainfall	White
	Pato	1995	Intermediate season, 400-800 mm rainfall	White
	Macia	1999	Short season, 250-750 mm rainfall	White, DT, SG
Zambia	Kuyuma	1989	Intermediate season, 450-900 mm rainfall	White
	Sima	1989	Intermediate season, 450-900 mm rainfall	White
	MMSH 413	1992	Intermediate season, 450-900 mm rainfall	Brown
	MMSH 375	1992	Intermediate season, 450-900 mm rainfall	Brown
	WSH 287	1987	Intermediate season, 450-900 mm rainfall	White
	ZSV 12	1995	Intermediate season, 450-900 mm rainfall	Mainly white
Zimbabwe	SV1	1987	Intermediate season, 400-850 mm rainfall	White
	SV2	1987	Short season, 250-750 mm rainfall	White, DT
	Macia	1998	Short season, 250-750 mm rainfall	White, SG, DT
	ZWSH1	1992	Intermediate season, 400-850 mm rainfall	White speckled
	SV3	1998	Short to intermediate season, 300-900 mm rainfall	White
	SV4	1998	Short to intermediate season, 300-900 mm rainfall	White

1. DT = drought tolerant; SG = stay-green trait; TSB = tolerant to stem borer; SSB =susceptible to stem borer; RSS = resistant to sooty stripe and RLB = resistant to leaf blight.

Source: Obilana (1998).

cultivars (Obilana 1997). Consequent to the success of farmer participatory variety selection methods, three countries are now retargeting their breeding approaches. Training in seed production and pollination techniques are being provided to country scientists and in-country training is being organized in Botswana, Tanzania and Zimbabwe. SMIP has also helped identify future research needs and options for the commercialization of sorghum in each country.

Sorghum breeding in Southern Africa from 1983/84-1997/98 by SADC/ICRISAT SMIP in collaboration with 10 country NARES (national agricultural research and extension services) in the region has generated significant impacts (Obilana 1998; Obilana et al. 1997).

The 27 cultivated releases are more than double the number released from 1973-74 to 1983-84 in the region. Eighty-seven percent of the releases contain ICRISAT-derived materials. Of the 20 cultivars released in Botswana, Namibia, Zambia and Zimbabwe, 8 (40%) have been adopted and are presently being grown by farmers. Adoption studies based on seed sales and distribution, and estimates by breeders in the region (based on quantity of seed produced) indicate a variable diffusion pattern — one year for Phofu variety in Botswana, two years for Kuyuma in Zambia and five years for SV 2 in Zimbabwe (SADC/ICRISAT 1996). The cultivated areas follow a similar pattern. In Botswana, Phofu covered 25% of the total sorghum area (22, 000 ha) within one year of diffusion, while Kuyuma covered less area in more years in Zambia. SV 2 covered 36% of the area after three years of diffusion in Zimbabwe following emergency seed production in response to the severe drought in 1990/91.

Going by the release, on-going adoption and impact of improved varieties in SADC countries, survey data (1994-95 to 1995-96) from SADC/ICRISAT SMIP showed an internal rate of return of 27-34% and net benefits ranging from $7.8 to $28.9 million in Zimbabwe for SV 2 and PMV 2 (Anandajayasekeran et al. 1995). Impact assessments are being carried out on the other varieties released in Botswana, Tanzania and Zambia. Farm-level impacts of new, improved varieties have been enhanced by the introduction and development of improved germplasm with farmer-preferred traits such as early maturity, drought tolerance, acceptable grain quality, seed production, effective on-farm testing for farmer verification, breeder participation and commitment to technology exchange.

5.2.4. West and Central Africa (WCA)

West and Central Africa is the largest and most important sorghum-producing region in Africa. The total area (13-14 million ha) is essentially rainfed, extending from latitudes 8°N to 14°N, ranging from the agroclimatic zones of the humid Southern Guinea Savanna and sub-humid Northern Guinea Savanna to the semi-arid Sudan Savanna and arid Sudano-Sahelian conditions. The West African semi-arid and arid zones cover more than one-third of the landmass in WCA, characterized by sharply varying rainfall - 600-1200 mm in the Guinea Savanna to 250-600 mm in the Savanna (Sudan and Sudano-Sahelian zones) - and soil conditions. In addition, varying day-length periods and photosensitivities result in production constraints and adaptation requirements.

Before 1940, there was little breeding work on sorghum. By the early 1950s, local landraces were collected and selections began in Burkina Faso, Cameroon, Mali, Niger and Nigeria. In Nigeria, the landraces were initially grouped into four main types — namely *Guinea, Kaura* (mostly yellow endosperm, race *Durra-Caudatum), Fara-fara* (white grained, race *Durra)* and *Caudatum* (Curtis 1967). Several landrace selections were made, the most popular being Warsha, short Kaura and Janjare from Niger and Nigeria and Muskwaris/Masakwa (transplanted sorghums in vertisols and hydromorphic soils) around Lake Chad and the inland delta of Niger River in Mali. By 1966, exotic materials were introduced and tested, and pedigree breeding programs began with local X local, local x exotic and exotic X exotic crosses. Soon extensive breeding programs were established across the region (Andrews 1970, 1975a and 1975b; Barrault et al. 1972; Ogunlela and Obilana 1982b). Chantereau and Nicou (1994) gave a review of such activities in French West Africa which were initiated by IRAT in 1964. Several improved pure line varieties were developed, tested and released during 1971-1989 (Obilana 1979, 1981, 1981a and 1981b; Chantereau and Nicou 1994; Andrews 1975a and 1975b; Carson 1977; El Rouby 1977; Chantereau 1982. Table 5.5 lists the varieties and hybrids released and available in the WCA countries as a result of sorghum breeding.

Following selections among landraces, introductions and lines derived from crossing and backcrossing, hybrid development and population improvement with recurrent selections began across the region. In Nigeria, after the initial failure of adapting and directly selecting from hybrids introduced from the USA and India, exotic male sterile lines were crossed with local materials to develop new materials from 1970 onwards. The outcome was CK60A (semi-dwarf and early); ISNIA, Kurgi A and RCFA [(CK60B X FF60) x (CK60A), semi-tall and long duration] (Obilana 1982a). From 1977, development and testing of F_1 hybrids intensified using three (RCFA, ISNIA and Kurgi A) of the four developed and adapted male sterile lines (Obilana 1982b) with improved and released sorghum varieties. Five good hybrids (SSH 1, SSH 2, SSH 3, SSH 4 and SSH 5) selected from hundreds of test crosses were recommended for production by 1982 (Obilana 1982a). Similar experiences in Niger resulted in the development and production of NAD-1 by 1989. The breeding and potential of hybrid sorghum in other African countries are described by House et al. (1997).

ICRISAT's involvement in sorghum breeding in WCA began in 1979 with the setting up of centers at Kamboinse and Ougadougou in Burkina Faso; later shifted to Niamey in Niger, and operating from Samanko in Mali since 1985. ICRISAT's genetic enhancement work in West Africa was preceded by IRAT's involvement in francophone territories from 1964. Segregating materials (of exotic and local crosses) and exotic germplasm introductions were the focus of both programs. ICRISAT was also involved in population improvement for grain and food quality among *Guinea* sorghums in Sotuba and Samanko. Breeding for *Striga* resistance was initiated by ICRISAT in Burkina Faso in 1979. Joint ICRISAT-IRAT efforts led to the development of IRAT 204, derived from a cross between IRAT 11 and IS 12610. IRAT 11 is derived from a cross of Senegal local (Hadien-kori) and Niger local (Mourmoure). IS 12610 is an Ethiopian germplasm accession from ICRISAT's Gene Bank.

The impact from sorghum breeding in WCA has not been significant compared to that in other regions. ICRISAT's major impacts have been in the form of improved released varieties (more than 40 releases in 10 countries); less than 15% of which have had impact on farmers' fields. Impact assessment studies of varieties such as S 35, ICSV 111 and ICSV 400 (Ogungbile 1998, Yapi et al. 1998, Yapi et al. 1999, Ndjomaha et al. 1998) have revealed adoption rates ranging from 10 to 38% in Chad, Cameroon, Nigeria and Mali. The significant economic impact of sorghum breeding (development, testing and production) has been seen in the brewing industry in Nigeria. This happened because breeding programs focused on using sorghum as raw material. The need to locally produce raw material for the brewing industry was felt because of the drain on foreign exchange due to the import of raw material. Malt barley could be used as a substitute through genetic research, grain quality testing for end use, pilot malting and brewing and test marketing

Table 5.5. Sorghum varieties available or released in several countries of West and Central Africa.

Country	Variety	Year of release	Remarks
Burkina Faso	IRAT 204	1980	Pure line variety (OPV)[1]
	S 29	[2]	Pure line variety
	Framida	1986	Pure line variety (OPV)
	E 35-1	1970s	Pure line variety (OPV)
	ICSV1049	1989	Pure line variety (OPV)
	Sariago B	1992	Pure line variety (OPV)
Cameroon	S 35	1987	Pure line variety (OPV)
Chad	51-69	-	Pure line variety
	S 35	1989	Pure line variety (OPV)
Ivory Coast	Framida	1986	Pure line variety (OPV)
Ghana	Naga White	-	Local selection
	Framida	1986	Pure line variety (OPV)
	ICSV 111	1986	Pure line variety (OPV)
Mali	SH2D2	-	Pure line variety (OPV)
	CSM 388	-	Pure line variety (OPV)
	IRAT 10	-	Exotic x local (OPV)
	IRAT 11	-	WP local xWA local
	ICSV 1063	1991	Pure line variety (OPV)
	ICSV 1095	1991	Pure line variety (OPV)
	ICSV 1063 BF	1993	Pure line variety (OPV)
	ICSV 1079 BF	1993	Pure line variety (OPV)
Nigeria	SK 5912	1971	Irradiated selection from local Kaura
	L187	1980	Pure line variety (OPV)
	L 1499	1980	Pure line variety (OPV)
	H.P.3	1982	OPV
	H.P.8	1982	OPV
	KBL	1982	OPV
	YG5760	1982	Local selection
	BES	1984	OPV
	L539	1984	OPV
	L408	1984	OPV
	RZ1	1982	Local selection
	A-9025	1984	OPV
	C-7-4	1984	OPV
	ML-4	1984	OPV
	FD1	1984	OPV
		1985	OPV
		1985	OPV
	SSH3	1981	Hybrid
	SSH4	1981	Hybrid
	SSH5	1981	Hybrid
	SSH2	1980	Hybrid
	ICSH 89002 NG	1995	Hybrid
	ICSV 111	1995	OPV
	ICSV 400	1995	OPV
Niger	NAD-1	1989	Hybrid
	Bajoba	-	OPV
	Jan-Jare	-	OPV local selection
	IRAT16		OPV
		1982	OPV
Senegal	IRAT 204	-	OPV
Togo	Framida (SRN 4841)	-	OPV

1. OPV = Open Pollinated Variety.
2. Year of release not known.

(Obilana 1985a). Collaborative grain quality testing, malting quality and proximate analyses between IAR, Ahmadu Bello University (Samaru, Zaria) and the Federal Institute of Industrial Research (FIIRO), Oshodi, Lagos (Obilana and Olaniyi, unpublished; FIIRO 1986) led to the identification of SK 5912 as the best malting sorghum. These were followed in 1984 by pilot brewing and test marketing of lager beer using sorghum malt (barley malt was replaced in ratios of 25%, 50%, 75% and 100% by sorghum malt) in collaboration with three breweries. Following its acceptability, quality testing and successful marketing of sorghum malt, the Government of Nigeria banned the import of barley malt in 1988, thus saving more than US$100 million in foreign exchange. In 1988, Nigeria had an installed production capacity of 18 million hectolitres of beer (Bogunjoko 1992). A spillover effect of this impact was the setting up of intermediate malt industries. This led to a huge increase in sorghum malt and sorghum malt syrup production by beverage industries producing malt drinks (Maltina, Malta and Amstel) and beverage companies in Nigeria (such as Cadburry Ltd., Lagos). Another spillover impact was the use of sorghum malt in composite flour along with wheat and maize, for use as weaning food (Murty et al. 1997).

Following use of the largely produced variety SK 5912 for malt, a need was felt to improve its quality and source better productive cultivars, leading to the selection by Nigerian and ICRISAT scientists of ICSV 400, another white-grained sorghum variety (Murty et al. 1997).

5.3. Regional Breeding Efforts

Sorghum's regional breeding approach began separately and at different periods in three regions (ECA, SADC and WCA). Methodologies and approaches differed, resulting in differential impacts, both of intermediate genetic products and cultivars on farmers' fields. These regional breeding programs were set up with the objective of tackling different agroecological zones for wider and specific adaptation.

5.3.1. East and Central Africa

The approach in ECA consisted of reasonably successful national, bilateral and multilateral programs (1930-1980s). The EARCAL and EARSAM networks (1986-1993) were facilitated by SAFGRAD/ICRISAT in Nairobi (Kenya) for the 10 ECA countries. This cooperative program focused on regional trials and nurseries and the introduction of germplasm and workshops to exchange information and technology. Elite varieties were identified by various national programs (Gebrekidan 1987). The lack of good national seed industries and networking among various agencies limited the use of promising varieties. ICRISAT's core program bridged the gap between 1993 and 2000 by targeting lowland and highland agroecologies in the region. By 2001, ECARSAM, a new European Union-funded regional network was started by ASARECA. The network's focus was on market orientation, technology exchange, capacity building of participating NARS and working with wider stakeholders including farmers' groups and the private sector. Since the year 2000, ECA's regional breeding program has involved more on-farm activities, farmer inputs and community development organizations including NGOs, with a focus on enhanced technology exchange and seed strategy. It targets two major production systems - the drought-prone zones in the eastern parts of the region and the Lake Zone, occupying the sub-humid and dry parts in the west.

5.3.2. Southern Africa

House (1987) describes the growing interest in regionalization in SADC with the beginning of SADC/ICRISAT SMIP in 1983/84. SMIP's emphases was on introduction and genetic diversification, breeding for dry areas, crop management, food quality/technology and alternative crop uses. Obilana (1998) summarized the 15 years of sorghum improvement in SMIP, including methodologies and processes of regional approach to breeding; accomplishments in germplasm exchange and utilization; cultivar development and testing, farmer participatory selection, *Striga* management and host-plant resistance breeding; release of improved cultivars and the process of release and assessment of grain quality for several end uses. Regional networking and linkage impacts comprised of both intermediate (genetic materials and new methodologies for use by researchers) and direct impacts of finished products (released varieties and seed multiplication directly benefiting farmers and consumers). The socioeconomic impacts from genetic improvement in the SADC region are described as case studies and experiences for developing countries (Obilana et al. 1997). The major factors that enhanced the impact of sorghum breeding in SMIP were:

- Extensive germplasm introduction, exchange and utilization
- Development and availability of improved varieties and hybrids; and grain quality testing for several end uses
- On-farm testing and farmer preference evaluation
- Effective collaboration among partners
- Long-term and committed donor support
- Scientists' commitment to promoting improved cultivars in collaboration with partners
- Emergency seed production following the severe drought of 1991 in the region
- Identification and involvement of markets and the seed industry, and linking consumers and producers.

An achievement which had implications on impact was the speeding up of the breeding process (Fig. 5.1.) during a 15-year period. In addition, a regional off-season location was set up coupled with 5-10 test locations across five countries in the region. The continuous introduction of germplasm, hybridization and screening for priority traits (especially drought and *Striga* resistance) across a range of sites has helped. The release and growing adoption of sorghum variety Macia in Mozambique, Botswana, Zimbabwe, Namibia and Tanzania between 1989 and 1999 has been a major achievement which has generated impact. Details of the other cultivars released for grain yield and maturity are given in Tables 5.6. and 5.7.

In WCA, regional cooperation for sorghum breeding began from 1961, supported by IRAT in 1964, and later by ICRISAT under its West Africa Sorghum Improvement Programs (WASIP) stationed at Bamako (Mali) and Bagauda (Nigeria). By 1990, a joint initiative was launched by the Institute du Sahel (INSAH) and the Special Programme on African Agricultural Research (SPAAR) to promote NARS-driven regional cooperation. This led to a regional sorghum "pole" system in the Inter-State Committee for Drought Control in the Sahel (CILSS) which later became the West and Central Africa Sorghum Research Network (WCASRN) or Reseau Ouest en Centre Africain de Recherche sur le Sorgho (ROCARS) by 1995. WCASRN's objectives (missing in the other two regional approaches) are the improvement in production, productivity and utilization of sorghum.

Table 5.6. Impact of sorghum varieties released in Botswana as a result of collaborative technology development, testing and exchange between NARS and ICRISAT, 1984-1995.

Variety name (ICRISAT/NARS)	ICRISAT germplasm used (yes/no)	Year of release	Year of first significantt diffusion	Area of expected coverage (% of total)	Area of current coverage (% of total)	Average grain yield (t ha1) On station	on farm	Maturity (days)	Remarks
Phofu (SDS 3220) (Macia)	Yes	1994	1995	40,000-50,000 ha (45-56%)	22,000 ha (25%)	3.25	0.73	69	White-seeded, stay-green trait, dual purpose (food grain and stover)
Mahube (SDS 2583)	Yes	1994	1995	20,000 ha (22%)	900 ha (1%)	1.22	0.59	58	Red-seeded, for malting and animal feed, tannin free
BSH I (SDSH 48)[1]	Yes	1994	1995	10,000-15,000 ha (11-17%)	130 ha (0.2%)	3.83	-	72	White-seeded with excellent flour quality, used mainly for food
Mmabaitse (BOT 79)	No	1994	-	-	-	1.93	-	70	White-seeded with brown specks
Check/famer variety (Segaolane)	No	Indige-nous	Before 1970		About 40%	2.34	0.51	86	White-seeded, susceptible to grain mold

1. The first sorghum hybrid was released by NARS; and one of the first white-seeded sorghum hybrids was released in the SADC region.

Source: Modified from Obilana et al. 1997.

Table 5.7. Sorghum varieties released in Zimbabwe as a result of collaborative technology development, testing and exchange between NARS, the private sector and ICRISAT, 1984-1999.

Variety name (ICRISAT/NARS)	ICRISAT germplasm used (yes/no)	Year of release	Year of first significant diffusion	Area of expected coverage (% of total)	Area of current coverage (% of total)	Average grain yield (t ha-1) On station	On farm	Maturityf (days)	Remarks
SV I (ICSV 112)	Yes	1987	-	500 ha (4%)	500 ha (4%)	4.06	-	75	White-seeded, used for food, out of production
SV 2(A6460)	Yes	1987	1992	60,000 ha (54%)	40,000 ha (36%)	3.38	2.15	63	White-seeded, used for food
ZWSH 1	No	1992	-	-	-	4.91	2.37	72	White-seeded with brown specks, never produced
Macia	Yes	1998	1999	50,000 ha (45%)	20,000 ha (18%)	4.45	2.95	69	White-seeded used for food, feed and residue/stover
Check/farmer variety	No	Indigenous	Before 1970	-	-	2.73	1.56	76	

Source: Modified from Obilana et al. 1997.

	Germplasm acquisition ↓	Initial screening Germplasm evaluation
	Breeding and observation nurseries	
SMIP nurseries	-farmer participation ↓	Line development
Country crossing blocks	Crossing program ↓	Hybrid parent development
Breeding lines SMIP nurseries and semi-finished products selected by advanced NARS into their nurseries	Backcrossing program F_4/F_5 lines ↓ Modified pedigree breeding ↓	Early generation testing in one location
SMIP nurseries	F_6/F_7 lines ↓	Advanced generation testing in 1-2 locations. Head bagging of 2-3 plants/line for seed increase
SMIP test locations	New line trials/testcross evaluation ↓	Replicated trial in 2-3 locations, selection based on visual observation and analyzed data (1 year)
NARS-specific selections of breeding lines from SMIP test locations	Preliminary cultivar testing -new varieties, new hybrids -new hybrid parental lines and restorers ↓	1-2 years 2 locations
NARS selections and promotion of advanced materials into their national variety trials	Regional advanced cultivar testing ↓	1st Stage Regional Collaborative Trials of SMIP and NARS, beginning of multilocational trials (SMIP - 4 locations NARS - 6 to 10 country locations), Joint NARS/SMIP evaluation
	Bilateral cooperative trials -specific to requesting NARS Regional collaborative trials -across all countries ↓	2-3 years for variety replacement. 6-10 locations in cooperating countries and SMIP.
Breeder seed increase. Seed production training by SMIP regional and in-country	National program testing ↓	NARS activity in national experiment stations, multilocational advanced testing, compilation of data (2 years)
Large-scale seed production (NARS and industry)	On-farm testing ↓	Major farmer involvement to identify farmer preferences and release of varieties by NARS. 2 years, multiform locations
Increase in breeder seed (NARS and SMIP)	On-farm verification ↓	NARS/SMIP activity
Variety description and production of leaflets	Cultivar release, seed multiplication farmer adoption and production	NARS activity facilitated by SMIP

Figure 5.1. The sorghum breeding process in Southern Africa.

It also included markets, processing and contribution to the well being of the 18 sorghum-producing countries of the region. WASIP-Nigeria was set up in Kano in 1988 to assist in improving sorghum production and productivity in the Sudano-Sahelian zone of West Africa, while WASIP-Mali (Samanko) in collaboration with CIRAD-CA [Centre de cooperation internationale en recherche agronomique pour le developpement-Department des Cultures Annuelles), targeted sorghum improvement in the Sudano-Guinean and Guinean zones of West Africa. Both made significant achievements in the development of sorghum hybrids (Nigeria) and improved *Guinea* sorghum populations and varieties (Nigeria), HPR research and management of *Striga.*

Sorghum breeding in Africa has utilized technology exchange and partnerships to foster progress, which has been well documented (ICRISAT 1993; Obilana 1998; Obilana et al. 1997) and used to achieve impacts in Southern Africa.

5.4. Germplasm Exchange and Utilization

Sorghum breeding programs in Africa were initially characterized by the collection and description of existing local germplasm and introductions of exotic germplasm. This was more so in Southern Africa as SADC/ICRISAT SMIP's genetic improvement efforts were tailored to meet the needs of and enhance the capacities of national program partners in these areas. The stronger NARS were provided intermediate outputs, including random mating populations, segregating populations, breeding lines and hybrid parental lines to be able to develop a wider range of finished products. Specialized traits and sources of resistance to biotic and abiotic stresses have been incorporated into these intermediate outputs. The weaker NARS were provided with finished products, including varieties and hybrids. Table 5.8 shows the diverse germplasm introduced and assembled by SMIP as working collections at Matopos, for use by NARS and SMIP. Most of the 12,343 germplasm accessions are from ICRISAT programs across the globe (51%), Southern Africa (18%) and Latin America (12%).

5.4.1. Germplasm Collection and Characterization

In Nigeria, Curtis (1967) identified four sorghum races and grouped them into *Guinea, Kaura* (*Durra-Caudatum*), *Fara-fara* (*Durra*) and *Chad* (*Caudatum*). The group *Fara-fara* here should not be confused with the vernacular 'Fara-fara' widely used to refer to any white-grained sorghum. In 1983, IAR, Samaru, made a 'pointed' collection of sorghums in the Guinea and Sudan Savanna zones of northern Nigeria. It focused on describing the collected *Kaura, Fara-fara* and *Guineanse* sorghums (Prasada Rao et al. 1985). Later in 1985, drought sorghums were collected in the Nigerian Sahelian zone and described as sand dune sorghums (Obilana and Harkness 1985).

Table 5.8. The sorghum germplasm collection at Matopos, assembled by SMIP for regional use.

Source	Supplier	No of accessions
Worldwide	ICRISAT	6,303
USA	INTSORMIL	**652**
Southern Africa	National programs and ICRISAT	**2,234**
Eastern Africa	National programs and ICRISAT	**936**
Western Africa	National programs and ICRISAT	**383**
Latin America	National programs and LASIP[1]	**1,536**
China	National program	**15**
Asia	National programs	**305**
Total		12, 343

1. ICRISAT Latin American Sorghum Improvement Program.
Source: Obilana (1998).

Sorghum races similar to those described by Curtis (1967) were identified in other parts of West Africa but named separately. These groups include *Keninke* (*Guineanse* variety gambicum) and *Kende (Guineanse* variety margaritiferum) from Mali and *Muskwari* or *Masakwa* (*Durra*) from Nigeria, Cameroon and Chad. On the other hand, the *Feterrita* (Hageri) are common in Sudan, while the *Zera-zera* (*Caudatum*) are found in the Ethiopian Gambella Hills and Bizanay (*Guinea-Durra* and *Bicolor*) in the southwest lowlands of Eritrea, all in East Africa.

To enable NARS to use available genetic material more effectively, indigenous sorghum germplasm from the SADC region was characterized at Matopos. Table 5.9 summarizes the classification of germplasm sorghums into 5 basic and 10 intermediate hybrid races. *Guinea* (23%), *Kafir* (11%), and *Caudatum* (10%) are the most common basic races. The distribution of races was also studied (Obilana et al. 1996). *Durra* sorghums were recorded for the first time in Botswana and Namibia. Among the intermediate races, a wild and weedy group, *Drummondii,* was identified in Angola (20% of the accessions collected were *Drummondii),* and to a lesser extent in Namibia.

The *Guinea-Caudatum* combination of hybrid races has been most successful in the SADC region, together with the *Caudatum-Bicolor* and *Durra-Caudatum.* It would seem that the *Guinea* and *Caudatum* races, together with their stable hybrid combinations *Guinea-Caudatum, Durra-Caudatum* and *Caudatum-Bicolor,* can be successfully used in sorghum improvement programs in the SADC region.

Table 5.10 shows some important agronomic and grain traits evaluated in the 1354 SADC-indigenous accessions. Almost all the accessions were found to be small seeded, two-thirds had white grain and nearly half were late maturing (>85 days to 50% heading). Despite this, there is considerable diversity among indigenous accessions. Phenotypic correlations were determined among various agronomic and grain traits in germplasm from Southern Africa. Plant height was significantly correlated ($P \leq 0.01$) with days to 50% heading, leaf midrib color and seed color. Panicle shape was significantly correlated with days to 50%) heading.

Massive efforts in germplasm exchange have created a foundation for the generation of impact in the form of intermediate products for use by scientists and farmers. Both NARS and the private

Table 5.9. Classification of sorghum germplasm from eight SADC countries[1].

	Basic races (% of accessions from each country)					Intermediate hybrid races (% of accessions from each country)											
Country	*Bicolor* (B)	*Guinea* (G)	*Caudatum* (C)	*Kafir* (K)	*Durra* (D)	DC	GB	CB	KB	DB	GC	GK	GD	KC	KD	DR[2]	Total no of accessions
Angola	30	5	5	0	5	0	0	15	0	0	10	0	0	0	0	20	18
Botswana	0	11	4	17	20	14	2	8	0	3	5	1	0	3	12	0	100
Lesotho	0	1	2	14	1	18	1	27	5	2	28	1	0	4	0	0	104
Malawi	1	67	4	0	1	2	5	2	0	1	14	0	4	0	0	0	229
Namibia	0	5	22	2	15	21	0	0	0	0	17	4	2	4	2	2	123
Swaziland	0	2	7	28	0	2	19	26	0	2	9	0	0	2	2	0	43
Tanzania	0	25	18	0	6	4	4	3	2	3	40	0	3	0	0	0	67
Zimbabwe	1	16	11	16	3	11	1	17	1	2	14	1	1	2	5	0	526
Across region	1	23	10	11	5	10	2	12	1	1	15	1	1	2	4	1	1210

1. Does not include germplasm from South Africa (not available with SMIP). The Zambia collection is stored at Mt Makulu Research Station. In Mozambique, the very long duration race does not mature at Matopos.
2. DR = Drummondii.

Source: Obilana (1998).

Table 5.10. Agronomic and grain traits in 1354 sorghum germplasm lines[1] from southern Africa.

Trait[2]	Range	Mean	Remarks[3]
Days to 50% heading	46-167	92.4	72% of accessions are medium-maturing (66-105 days)
Plant height (cm)	74-441	221.7	21 % of accessions are dwarf types (74-173 cm)
Awns	1 or 2	1.86	90% are awnless
Panicle shape	1-9	4.96	50% are compact or semi-compact
Leaf midrib color	1-5	1.85	1% have brown midrib
Waxy bloom	1-5	1.89	
Seed size	1-3	2.96	96% are small seeded
Seed color	1-5	2.37	65% are white seeded
100-grain mass (g)	0.35-4.33	2.18	
Testa	1 or 2	1.46	

1. Data shown for 1354 SADC indigenous accessions are part of the Matopos collection.
2. Awns: 1 = awns present, 2 = awns absent; panicle shape: 1= very lax, 2 = very loose drooping branches, 3 = loose dropping branches, 4 = semi-erect branches, 5 = semi-compact elliptic, 6 = compact elliptic, 7 = compact oval, 8 and 9 = broom corn; leaf midrib color: 1 = white, 2 = dull green, 3 = yellow, 4 = brown and 5 = purple; waxy bloom: 1 = no waxy bloom, 2 = slightly waxy, 3 = medium waxy, 4 = mostly waxy and 5 = completely waxy; testa: 1 = present, 2 = absent; seed color: 1 = white, 2 = yellow, 3 = red, 4 = brown and 5 = buff; and seed size: 1 = large, 2 = medium and 3 = small.
3. Percentages obtained from histograms of group ranges.

sector in the region now have wider access to world sorghum germplasm, thus increasing the variability and diversity available for improvement. Through a series of regional and national breeding nurseries, crossing blocks, off-season nurseries and preliminary screening, about 25,000 breeding lines and enhanced germplasm were provided for regional testing between 1983/84 and 1997/98. A total of 18,524 samples, comprising 10,075 breeding lines, 4634 varieties, 379 hybrid parents and 3436 hybrids were supplied to national research and extension services, universities and the private sector (Table 5.3). During the same period, 244 genetic materials were received from 9 SADC countries and 608 collaborative sorghum trials were jointly evaluated by 11 countries in the region.

5.4.2. Population Breeding and Hybrid Development

The improvement of sorghum populations involving the generation of broad-based gene pools and their improvement through recurrent selection has served as a complimentary breeding methodology to the conventional pedigree method. This methodology was employed by national and international breeders in Mali (by John Scheuering of ICRISAT and later by J Chantereau of CIRAD and DS Murty of ICRISAT) to improve *Guinea* populations for food grain quality, *Guinea* and *Caudatum* populations for yield and *Guinea* x *Caudatum* populations for yield, respectively. In Nigeria, the national breeding program developed six random-mating populations between 1963 and 1978 using the ms_7 gene (Obilana and El-Rouby 1980a). Only three of these (B composite, Y composite and YZC composite) were used as base populations for yield improvement, while a fourth, MSRC (modified *Striga*-resistant composite) was used in recurrent selection for *Striga* resistance. Obilana and El-Rouby (1980a) and Obilana (1985b) have described population improvement combined with pure line development in Nigeria.

The progress made in recurrent selection in these populations, calculated as expected gains from mass selection and S1 testing, were reported by Obilana and El-Rouby (1980b) and Lukhele and Obilana (1980). After three cycles of mass selection, gains in grain yield of 38.4% in B composite and 40.4% in Y composite were observed.

Random mating populations developed in Southern Africa jointly by ICRISAT and NARS after four cycles of syntheses targeted three contrasting agroecological zones (Obilana 1989) in the region. The four populations — SDSP-hot/dry, SDSP-cool/dry, SDSP-often draughted conditions and SDSP-broad adaptation (Obilana 1989) — provided a broad genetic base and gene pools from which SADC national programs could develop improved lines and varieties using recurrent selection. The populations were synthesized from the four best introduced populations (from a total of 26) tested across four agroecological locations (represented by Sebele in Botswana; Makoholi, Matopos, Muzarabani and Lucydale in Zimbabwe and Golden Valley in Zambia) in 1986/87 and 1987/88. The combined yields of the test random mating populations in each of the agroecological locations (1.03, 2.01, 3.12 tha^{-1}) were significantly better than check varieties (0.93, 1.40, 2.30 t ha^{-1}) and as good as check hybrids (1.06, 2.35, 2.75 t ha^{1}), respectively for the hot/dry, cool/dry and often-droughted zones.

House et al. (1997) have discussed the opportunities and potential of hybrids in developing African countries. In most comparisons, hybrids outyielded the landraces and improved varieties by 20-60%. Under stress conditions, yields of both hybrids and varieties declined, but yield differences widened favoring hybrids. Due to seed production and marketing problems associated with hybrids, the take off and impact from hybrid programs in Africa have been slow. Except in South Africa and Zimbabwe where private seed companies produce and market hybrid seeds, the rest of Southern Africa and West Africa are yet to benefit from the availability of high-yielding hybrids. For example in Botswana, BSH 1 (most preferred, white-grained hybrid for milling and grain yield) has not been produced commercially after being released in 1994. On the other hand, success stories of hybrid development and commercial seed production have been reported in Sudan (Ejeta 1985; 1986); Niger (Kapran et al. 1995; House et al. 1997) and Nigeria (Rana and Obilana 1979; Obilana 1982b; House et al. 1997). In Sudan, the most popular hybrid is Hageen Durra 1. It outyields local varieties by 50-85% on farmers' fields and by 300-400% under irrigated conditions (Ejeta 1986). In Niger, NAD-1 is being commercially produced, as is ICSH 89002NG in Nigeria.

5.4.3. Resistance Breeding and Control of *Striga*

Striga is the most economically significant biotic constraint to sorghum production in Africa. The major species are *Striga hermonthica* (endemic in West, Central and East Africa) and *Striga asiatica* (endemic in Southern Africa). The distribution and occurrence of this parasitic weed in Africa have been studied in detail by Musselman 1987; Musselman and Hepper 1986; Musselman and Riches 1985 in West, Central and East Africa (Doggett 1965b) and by (Obilana et al. 1988; 1991) in Southern Africa. Research to control *Striga* through host-plant resistance and field crop management were initiated more than 50 years ago. Several books, workshop proceedings, journal papers and newsletters have documented research outputs from strigologists and others. However, only a few sustainable and practical technologies are available to control *Striga* on farmers' fields.

In the last 90-100 years, research on host-plant resistance, plant physiology, biocontrol and agronomic and cultural practices in Africa has involved national, regional, international and advanced institutions. Much of *Striga* control research through host-plant resistance began in South Africa, Nigeria (IAR, Samaru, Zaria), Sudan (University of Khartoum), Uganda and Kenya, before 1970. However, following intensification of research on resistance, regional approaches to controlling *Striga* began in West Africa. In 1987, ICRISAT's *Striga* research efforts in India moved to WASIP in Bamako, Mali. ICRISAT had shifted breeding for resistance in sorghum to Ouagadougou, Burkina Faso in 1979. The emphasis was on identifying sources of resistance through international and regional nurseries. Research on the use of chemicals, herbicides, nitrogenous fertilizer, soil fumigation and manual pulling of *Striga* plants before and after flowering also continued (Doggett 1988b; Ramaiah 1987; Hess et al. 1996; Ejeta et al. 1997).

Using several testing methods, field arrangements and unique statistical tools, sorghum cultivars resistant to both S. *hermonthica* and S. *asiatica* were identified (Obilana and Reddy 1999). Research on host-plant resistance to control *Striga* and ICRISAT's contribution and effectiveness in the efforts were reviewed with the focus being on available methodologies, mechanisms of resistance, breeding strategies and recommendations for future studies. It must be mentioned here that research on resistance mechanisms and gene action for resistance to *Striga* actually began in Africa! The identification of mechanical barriers as a first mechanism of resistance in South Africa was done as early as in the 1930s (Saunders 1933), followed by low stimulant production (Ramaiah and Parker 1982) and four other mechanisms, the latest being post-infection resistance (Lane et al. 1996). Similarly, gene action conditioning resistance to *Striga* was first identified by Saunders (1933) as recessive and partially dominant. Obilana (1984) followed with the identification of non-additivity, multigenicity and overdominance of the susceptibility of genes controlling resistance to *Striga* in Nigeria. The dominance of susceptibility was corroborated by Ramaiah (1987).

Table 5.11 shows the list of *Striga*-resistant varieties identified in West Africa (Ramaiah 1987; Hess et al. 1996), Nigeria (King 1975; Obilana 1979a, 1983; Zummo 1974), Sudan (Bebawi 1981), East Africa (Doggett 1988a) and Southern Africa (Saunders 1933; Obilana et al. 1991; Riches et al. 1987; Mbwaga and Obilana 1994). Less than 50% of these varieties are in use today, as others have been discarded in favor of better resistant lines and are used as parents in developing new, improved resistant lines and varieties.

Over six decades of testing for host-plant resistance, identification of adapted varieties and the control of *Striga* using host-plant resistance in combination with agronomic practices have been described and reviewed by Doggett (1988a) and Obilana and Ramaiah (1992). However, good crop husbandry combined with host-plant resistance is the key to solving the *Striga* problem in Africa. Of late, breeding for *Striga* resistance in sorghum and other cereals has taken a new turn. New biotechnological approaches are being proposed for a better understanding of specific mechanisms of resistance to *S. hermonthica* (Ejeta et al. 2000; Heller and Wegmann 2000), elaborating on inheritance of *Striga* resistance (Saunders 1993; Obilana 1984; Ramaiah 1987; Haussman et al. 2000a; Ejeta et al. 1997), identifying better screening and selection methods (Omanya et al. 2000) and the use of molecular markers and genetic engineering to control *Striga* (Rattunde et al. 2000; Haussman et al. 2000b; Bennetzen et al. 2000). Current and future research for *Striga* control in Africa needs to be more interactive and farmer-oriented while at the same time using biotechnological and nonconventional tools. The new approaches, recommended in 1999 (Haussman et al. 2000c) include:

- Adopting new breeding strategies towards *Striga* control, including marker technology and QTL analyses
- Identifying the physiological basis of *Striga* pathogen variability
- Adopting nonconventional approaches to *Striga* control, including transposon-based mutation
- Integrated *Striga* control and technology exchange.

Table 5.11. List of sorghum varieties and lines developed and identified with resistance to the two major species of *Striga* (S. *hermonthica and* S. *asiatica* red and white flowered) and S. *forbesii* in Africa.

Varieties/lines	Country/region identified	Organization/scientist	Remarks[1]
37R9 (Radar)	South Afnca	Saunders 1933	SAR, out of use
Framida (IS 3167) (SRN 4841) (ICSV 1007)	South Africa, Nigeria	King 1975, Obilana 1979	SAR, Sh, used in crosses
Dobbs (IS 8577)	East Africa	Doggett 1965b	Sh, used in crosses with Swazi P127 to derive Serena
SAR I to SAR 34	India		Sa, improved varieties
L 187 (KurgiB x SK 5912)	Nigeria	Obilana 1979a, 1983	Sh, improved variety
ICSV 1002 (E 35-1 x Framida)	West Afnca	Ramaiah and Parker 1982	Sh, improved variety
N13, 535, IS 9830, SRN 6838A	West Afnca		Sh, lines
SRN, Framida (ICSV 1007), IS 9830	Sudan, Ethiopia	ICRISAT	Sh, improved lines
SAR 16, SAR 19, SAR 35, SPL 38A x SAR 29	Southern Africa	Riches et al 1987, Obilana et al 1991	SAR, improved vaneties
SAR 29	Tanzania	Mbwaga and Obilana 1994	Sh, improved variety
SAR 19, SAR 29, SAR 33	Zimbabwe	Obilana et al 1991	Sf, improved varieties

1 SAR = *Striga asiatica* red flower Sh = *Striga hermonthica,* Sa = *Stnga asiatica* white flower and Sf = *Striga forbesii*

5.4.4. Breeding for Resistance to Diseases and Insect Pests

Sorghum is ravaged by several biotic and abiotic constraints. Among the biotic constraints are diseases, insect pests, nematodes, arachids and birds. Breeding to control these constraints can be done through resistance (genetic), avoidance (trait manipulation and environmental management) and crop mixtures. The sorghum diseases include those pertaining to the seed and seedling, including storage fungi; leaf and stem diseases such as mildews, bacterial leaf diseases, viruses; and panicle diseases like grain molds, smut, anthracnose and ergot. The major insect pests include shoot fly, stem borer, armyworms, aphids, grasshoppers, armoured crickets (affecting seedlings) and sorghum midge (damaging the panicle and developing grain).

Host-plant resistance has been widely used for virus infections (sugarcane mosaic virus and maize dwarf mosaic virus) (Doggett 1988a), leaf blights (Williams et al. 1980), sooty stripe, for which the maximum resistance was found in West African germplasm (Futrell and Webster 1966; Williams et al. 1980), grey leaf spot (Williams et al. 1980) and anthracnose and downy mildew (Williams et al. 1980). Williams et al. (1980) listed sorghum germplasm with useful combinations of leaf disease resistance. Smuts are major fungal diseases of economic importance in very dry and hot agroecologies. In the Sudan Savanna and Sahel zones of West Africa, parts of Southern Africa and ECA, long smut is very common on indigenous germplasm and susceptible introductions. Crop losses due to it can reach 5-20%, with an annual loss of 5-7% reported in Nigeria (Doggett 1988a). Although dressing seed with fungicide is common in controlling smuts (especially grain or covered smut and loose smut), sorghum resistance to smuts can range from the simple (covered smut) to the complex (head smut).

Thakur et al. (1997) have estimated (provided by various authors) yield losses due to various sorghum diseases ranging from 5% due to sooty stripe to 10-80% because of downy mildew and ergot. They also listed the major diseases occurring in three regions of sub-Saharan Africa (Table 5.12).

Table 5.12. Major sorghum diseases[1] in three regions of sub-Saharan Africa.

	Disease ranking[2]						
Region	Grain mold	Anthracnose	Leaf blight	C. Smut	L. Smut	DM	S. Stripe
West Africa	7	5	1	1	6	1	3
East and Central Africa	3	7	5	6	2	2	1
Southern Africa	7	5	6	4	3	3	1

1. C. Smut = covered smut; L Smut = long smut; DM = downy mildew and S Stripe = sooty stripe.
2. Scale of importance (nonoccurrence): 7 = most important and 1= least important.

Source: Modified from Thakur et al. (1997).

Breeding cultivars for disease resistance and acceptable productivity is the most effective and environmentally friendly way of reducing losses. The estimated loss in global crop production due to diseases in the late 1970s was 540 million t, valued at US$50 billion (James 1981). Genetic manipulation leading to the development of resistant varieties, germplasm deployments and management, coupled with integrated disease management including crop mixtures, are being used to reduce losses due to plant diseases. Several resistance sources to the diseases are now available (Thakur et al. 1997) but their usefulness in Africa has been limited (Obilana et al. 1983). Combining these resistance sources with more productive, adapted and farmer-acceptable cultivars could generate the impact desired. Research is on at all ICRISAT's African and Indian locations in collaboration with INTSORMIL, ARIs and NGOs, to achieve this goal. Recently, five sources of downy mildew resistance — improved cultivars ICSV 42, 1CSV 2, SDS 2620 derivative, SDS 2658 and PAN 171 — were identified using the infester and spreader row technique at Matopos and Golden Valley. More than 80% of the 375 test entries were resistant to downy mildew while 42-49% of the entries showed resistance to sooty stripe in varietal trials in 1989/90 and 1990/91 (ICRISAT 1997, 1994; Obilana 1990).

In countries producing hybrid sorghum and in Southern Africa in particular, ergot is a major problem for the hybrid seed industry. Annually, between 25-40% of female (male sterile) rows in seed production fields of a very popular brown hybrid DC75 are ergot infected (unpublished data). Preliminary results of ergot studies at Matopos (ICRISAT 1994) suggested that seed-set varies more between rows of 6A-lines than between rows of 4A-lines; under intense disease pressure, seed set in a 4-row plot of A-lines is significantly more than in a 6-row plot. Disease severity is characteristically signoidal in hyprid production plots just as in A-lines.

Over the decades the use of resistant plant varieties has been recognized in integrated insect pest management. Sorghum in Africa is damaged by a number of insect pests; those of major economic significance include shoot fly (one specie), stem borer (four species), armyworm (one specie), grasshoppers (five species) including amoured crickets, sorghum midge, head bugs, aphids and storage insects (two species). Obilana et al. (1983) have emphasized the use of integrated pest management along with host-plant resistance. In Nigeria, Adesiyun and Ajayi (1980) found that partially burning sorghum stalks after harvest reduced *Busseola fusca* (stem borer) larvae within stalks by 95%. Such information can benefit farmers in Africa, where sorghum stalk is used extensively for fencing, roofing, as mulch and for building grain storage structures. Sources of resistance to stem borers have been identified from Nigeria (8), Sudan (5), Uganda (2), Ethiopia and Zambia (1) (Taneja and Leuschner 1985).

Resistance to shoot fly in sorghum is a complex characteristic. For example, considering the level of resistance, lines with primary or low resistance could have up to 70% of dead hearts under severe conditions. Blum et al. 1972 classified resistance into four components — antibiosis, nonpreference for oviposition, recovery resistance and seedling resistance. Of these, about 50% of indigenous sorghum germplasm in Africa possess recovery resistance. Serena, an improved variety derived from an indigenous germplasm cross, is one of the best sources of recovery resistance (Doggett et al. 1970). Other germplasm lines with stable resistance across locations include IS 1054, IS 1071 (Indian origin), IS 2394 (a *Kafir* from Southern Africa), IS 5484 (Indian origin) and IS 18368 and IS 18551 from Ethiopia (Thakur et al. 1997). These lines are still being converted for adaptation and productivity; so their impact is yet to be felt.

Sugarcane aphid is the most serious among aphids. It has been the target of extensive research. Resistance has been reported from Africa and includes TAM 428 (from INTSORMIL) and SDSL 87049-T, SDSL 87049-D, SDSL 90173, SDSL 89426 and SDS 2293-6 (released in Tanzania as Pato) from the Southern African regional SMIP program in addition to Sima (released in Zambia).

There is enormous damage to stored sorghum grain or panicles in Africa. R&D efforts have benefited farmers, more so in areas where improved varieties have not been released. However, it has been observed that indigenous cultivars withstand damage from storage insects better than their improved counterparts. There have been earlier studies on storage structures (indigenous and industrial), storage methods and use of chemicals that have alleviated damage to stored grain (Doggett 1988a; Anonymous 1942; Wrigley 1982). Until recently, there was little or no documentation on the use of host-plant resistance to storage insects. The most important storage pests of grain sorghum in Africa are *Sitophilus oryzae* (rice weevil) followed by *Sitotroga cerealella* (grain moth). A methodology to screen for resistance to storage pests has been developed (ICRISAT 1994; Leuschner 1996). Seven *Sitophilus-resistant* and 10 *Sitotroga-resistant* lines were identified from among 270 test entries. The popular improved local selection Segaolane was used as a resistant check. The best of these are SPV 475 (ICSV 112/SV1) for *Sitophilus* and SDSL 87040, NL 575, SDSL 87029 and SDSL 87013 for *Sitotroga* (Leuschner 1993). These resistance sources need further studies.

5.5. Recent Research-for-development Targets

Conventional breeding programs have resulted in the development of improved genetic stock, breeding lines and populations, as well as the release of improved varieties. While these constitute achievements, they alone do not generate impacts. These breeding activities are usually followed by the release of improved germplasm in the form of varieties or hybrid parents as end products after on-station evaluation. However, very little effort has gone into promoting the new varieties in farmers' fields, resulting in limited adoption. This shortfall has been a major constraint to increased production and productivity of improved sorghum varieties, especially in developing countries.

Current trends in genetic enhancement research have shown that targeted and more appropriate varietal releases can result in the increased production of improved varieties, leading to greater adoption of technologies by farmers through on-farm testing and farmer verification in Southern Africa (Chintu et al. 1996; Mangombe and Mushonga 1996; SADC/ICRISAT SMIP 1995; 1996). Similar trends have been reported in Western, Eastern and Central Africa.

Improved varieties should incorporate farmers' preferences so that they accept, adapt and adopt the new varieties. It has been observed (Anandajayasekeran et al. 1995; Jenkins et al. 1996) that incorporating technology transfer activities into genetic improvement can greatly enhance the release of farmer-preferred varieties in Southern Africa. This innovative strategy has led to increased adoption of new improved varieties and hybrids released in national programs for commercial production. Breeders should therefore move outputs from genetic improvement into farmers' fields for greater adoption. The application of molecular marker technologies is already having major impacts on our understanding of the genetics of plants (though less so in SAT crops, including sorghum) and on the activities of commercial sorghum breeders (still in its infancy in Africa, except possibly in South Africa, Zimbabwe and Sudan). It also helps in understanding the genetics of metabolic processes and the physiology of productivity, the genetic basis of traits and the interaction between pathogens, *Striga* and the host crop.

5.5.1. Breeding for Impact

Breeding for impact involves a sequence of events conducted in a phased and overlapping series of progressive activities. SADC/ICRISAT SMIP's strategy in Southern Africa has involved the rationalization of the objectives of genetic improvement followed by a systematic breeding, selection and testing program.

Rationalization of breeding. Based on SADC/ICRISAT SMIP's initial success in Southern Africa during the first two phases (1983-84 to 1993-94) of the development of improved varieties, populations and breeding lines, the objectives of the genetic improvement program for sorghum were rationalized for the third phase (1994-95 to 1998). This shift in approach that also included ensuring that the cultivars developed are adopted, released and produced by farmers, was meant to enhance the success of the program.

The objectives focused on two major production systems —the lowland, drought-prone short-season (<100 days) sorghum/millet/rangeland system and the semi-arid, often drought-stricken intermediate season (100-125 and 125-150 days) sorghum/maize/rangeland/millet/legumes system.

Events and processes. Activities to generate impact in genetic improvement included technology development, testing, transfer and exchange. Table 5.13 shows the events and overlapping activities involved. Sets of activities within each event determine the type of outputs from the process. Germplasm movement and utilization generate breeding lines, populations and cultivars, including pure line varieties, hybrid parents and hybrids for testing. On-farm and on-station technology testing in farmers' fields evaluated performance and adaptation for productivity and preference of genetic products. Technology transfer and exchange events were based on promising genetic products resulting from technology generation and testing. Farmer verification and preference tests usually enhance the success of technology transfer activities. In Southern Africa, the systematic progression of breeding, testing and selection as a strategy for technology testing is shown in Figure 5.1. In short, a multidisciplinary approach to genetic improvement is needed to generate impact. This depends on partnerships with national programs, NGOs and industries in developing countries of Southern Africa. National programs in West Africa come under the umbrella of WCASRN. Some countries like Nigeria, Senegal, Mali and Niger are achieving such impacts on their own. Achievements made and impacts generated in Botswana, Zambia and Zimbabwe have been documented by Obilana et al. (1997).

The success of technology transfer depends on how good a technology is. A good technology sells itself, and the confidence reposed in it by its adopters enhances its impact.

NARS in Botswana, Zambia and Zimbabwe have in collaboration with ICRISAT sorghum breeders developed good, improved sorghum varieties and hybrids. The improved cultivars were

Table 5.13. Events and overlapping sets of activities that can generate impact in genetic improvement.

Event	Activities	Collaboration
Technology generation	Germplasm movement	Breeder
	*Exotic introduction	Genetic resources scientist
	*Indigenous collections	Farmers
	*Distribution,germplasm utilization	Breeder
	*Crossing block	Entomologist
	*Trait management	Pathologist
	*Initial selections	
	*Varietal development	
	*Population and lines development	
Technology testing	On-station trials	Breeder
	*Multilocational effects	Technology producers
	*Year effects	Technology exchange
	On-farm evaluation and verification	Specialist/agronomist
	Farmer preference tests	Extension specialist
	Laboratory grain and food quality screening	Food technologist/scientist
		Farmers
Technology transfer and exchange	Cultivar release	Breeder
	*Line and population releases	Seed producers
	*Breeder seed multiplication and production	Technology exchange specialist
	*Training in genetic improvement and breeder seed production	Extension specialist
		Economist
	Linkages and partnerships	Farmers
	Pilot processing and utilization	Millers, processors
	Monitoring adoption	Traders, outlets
	Markets	
	Assessing impact	

Source: Obilana et al. 1997.

jointly evaluated on station (for 4-8 years) and on farm (for 2-4 years) in several locations (2-8 locations) in each country. Farmers have taken a liking to them, preferring them to indigenous cultivars mainly due to their early maturity and good grain quality for food and malting. Breeders have taken the lead in encouraging farmers, working with other scientists, extension officers, NGOs and the seed industry. This trust in the performance of improved cultivars has been one of the driving forces for impact. Implications for impact can be viewed in the context of the intermediate level products (improved genetic material and new methodologies) and direct impact (finished products on farmers' fields and used by industry).

5.5.2. Farmer Participation in Breeding

Improved cultivars generated from collaborative NARS/SMIP research have shown yield improvements ranging from 9-85%, and improved earliness (7-23% earlier) over local checks across six SADC countries (Obilana 1998).

Farmer participation was a novel exercise launched to allow farmers to identify preferred traits and genotypes, and help breeders refine breeding objectives (Obilana 1998; ICRISAT SEA Region 1995). For this, breeders in Southern Africa assembled a sorghum nursery known as the

Diverse Germplasm Observation Nursery (DGON). Farmers worked with NARS/SMIP sorghum breeders to evaluate the DGON, which consisted of 40 improved genotypes, indigenous varieties and popular commercial varieties. Two years of farmer participatory testing (1993/94 and 1994/95) in two drought-prone locations in Zimbabwe (Matopos and Lucydale) showed that farmers preferred (in order of priority) short-to-medium plant height (0.95-1.54 m), drought tolerance, early maturity (63-86 days to 50% pollen shed), medium-large grain size and good grain yield (1.66-2.83 t ha^{-1}). The range of farmer-acceptable values for the priority traits were calculated and correlated using data from the 12 best genotypes.

The outcome of on-farm tests and farmer preference evaluations led to the release of new varieties and hybrids in the SADC countries. Farmer pressure together with commercial needs influenced cultivar releases in Botswana (1994), Zimbabwe (1998) and Tanzania (1995). It must be noted that early maturity and grain quality were the two main traits that influenced the choice of cultivars and preference for release. Industry needs (for milling) and productivity influenced the participation of the private seed industry in varietal releases (such as Macia in Zimbabwe).

5.5.3. Application of New Tools

Applying genetic marker technologies for sorghum breeding in Africa is still in its infancy. Outputs and achievements from ICRISAT's new emphasis on applied genomics, gene manipulation and diagnostics in biotechnology are expected to benefit African national and regional sorghum breeding programs. Areas that would be of interest are the alleviation of major production constraints (eg, *Striga)* and enhancing the productivity and quality of grain and stover/fodder (eg, stay-green trait). Markers, genetic stocks and genetic linkage maps arc being generated for these traits in sorghum (ICRISAT 2000). A better understanding of the sources of resistance (in indigenous and improved cultivars, weedy species and close relatives) and the nature of these useful genes is required for further genetic enhancement using biotechnology tools and their interaction with the environment (in the humid Savannas, SAT Savannas and Sahel).

5.6. Future of Sorghum Breeding in Africa

With the beginning of biotechnology research in sorghum and the identification of strategies to increase productivity and commercialization, the future of sorghum and its breeding impact is very rosy. Sorghum's versatility and its diversity across the sub-humid, arid and Sahel regions of Africa can enhance its future growth.

However, for sorghum to be a major component of the grey to green revolution certain approaches and strategies have to be put in place or enhanced. Biotechnology research and the use of new tools must be combined with large-scale regional testing. Productivity increases and quality improvement in grain, crop residue and fodder must be complimented with their evaluation for end use qualities. Quality assessment and consumer acceptance need to move into the pilot and test marketing stages. Processing methods and product development (for conventional and new products) must be emphasized in R&D. New products and uses need to be incorporated in breeding processes with commercialization in mind: starch, vegetable briquettes, enhanced use in forage, silage and crop residue, as tannins, greater use in poultry feed and malt beverages (as in Nigeria), health foods, lager beer (Nigeria and Rwanda), malt foods (South Africa), snack foods (as in pop sorghum) and non-gluten flour and baked products.

The future of sorghum breeding lies in a market-oriented and farmer-beneficial (producer-beneficial) objective achieved through commercialization with the aim of alleviating poverty and health. A production system approach incorporating mixed farming systems (sorghum-legume based) with livestock and poultry in the sub-humid, semi-arid and Sahel agroecologies of Africa would be required.

Successes and impacts in sorghum breeding and improvement can be achieved through indigenous means, farmer knowledge, impact on industrial manufacturing, wider and novel linkages and partnerships. The curriculum for breeders in secondary and tertiary colleges must be modified to incorporate new methodologies.

5.7. References

Adesiyun AA and Ajayi O. 1980. Control of the sorghum stem borer, *Busseola fusca* by partial burning of the stalks. Tropical Pest management 26:113-117.

Anandajayasekeran P, Martella DR, Sanders J and Kupfuma B. 1995. Report on the impact assessment of the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP). Vol. 1. Gaberone, Botswana: Southern African Centre for Cooperation in Agricultural Research and Training (SACCAR). 148 pp.

Andrews DJ. 1970. Breeding and testing dwarf sorghum in Nigeria. Experimental Agriculture 6:41.

Andrews DJ. 1975a. Sorghum varieties for the late season in Nigeria. Tropical Agriculture 52:21.

Andrews DJ. 1975b. Sorghum grain hybrids in Nigeria. Experimental Agriculture 11:119.

Anonymous. 1942. Grain storage bins. Journal of Rhod. Agric. 39-353.

Barrault J, Eckebil JP and Varille J. 1972. Paint des travaux de l'IRAT sur les sorghos repigues du Nord Cameroon, Muskwari. L'Agronomie Tropicale 27(8):791-814.

Bebawi FF. 1981. Response of sorghum cultivars and *Striga* population to nitrogen fertilization. Plant and soil 59:261-267.

Bennetzen JL, Gong F, Xu J, Newton C and Oliviera de, AC. 2000. The study and engineering of resistance to the parasitic weed *Striga* in rice, sorghum and maize. Pages 197-205 *in* Breeding for *Striga* resistance in cereals: Proceedings of a workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria (Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds.). Weikersheim, Germany: Margraf Verlag.

Blum A, Golan G, Mayer J, Sinmena B and Obilana T. 1992. Comparative productivity and drought response of semi-tropical hybrids and open-pollinated varieties of sorghum. Journal of Agricultural Science (Cambridge) 118:29-36.

Bogunjoko JST. 1992. Industrial uses of sorghum in Nigeria. Pages 115-119 *in* Utilization of sorghum and millets (Gomez MI, House LR, Rooney LW and Dendy DAV, eds.). Patancheru, 502 324, Andhra Pradesh: International Crops Research Institute for the Semi-Arid Tropics.

Carson AG. 1977. Summary of national research results on sorghum in Ghana. International Sorghum Workshop. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Chantereau J. 1982. The contribution of IRAT to the development of sorghum varieties and hybrids in West Africa. Page 748 *in* Sorghum in the eighties (House LR, Mughogho LK and Peacock JM, eds.). ICRISAT, Patancheru PO, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Chantereau J and Nicou R. 1994. Sorghum. The Tropical Agriculturist. CTA (Technical Center for Agricultural and Rural Co-operation) and The MacMillan Press Ltd. London and Basingstoke. 98 pp.

Chintu EM, Chigwe CFB, Obilana AB, Chirwa RW and Msiska FS. 1996. Sorghum variety release in Malawi: The case of Pirira 1 and Pirira 2. Pages 19-25 *in* Drought-tolerant crops of southern Africa: Proceedings of the SADC/ICRISAT Regional sorghum and pearl millet workshop, 25-29 Jul 1994, Gaborone, Botswana (Leuschner K and Manthe CS, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Curtis DL. 1967. The races of sorghum in Nigeria: Their distribution and relative importance. Experimental Agriculture 3:275.

Doggett H. 1965a. The development of the cultivated sorghums. Pages 50-59 *in* Essays on crop plant evolutions (Hutchinson JB et al, ed.). London, UK: Cambridge University Press.

Doggett H. 1965b. *Striga hermonthica* on sorghum in East Africa. Journal of Agricultural Science 65(2):183-194.

Doggett H. 1988a. Sorghum. Second edition. Tropical Agriculture Series; Longman Scientific and Technical Publishers, UK, IDRC: Canada. 512 pp.

Doggett H. (ed.) 1988b. Witchweed (*Striga*). Pages 386-404 *in* Sorghum. Second edition. Essex, UK: Longman Scientific and Technical.

Doggett H, Starks KJ and Ebeshart SA. 1970. Breeding for resistance to the sorghum shoot fly. Crop Science 10:528.

Ejeta G. 1985. Overcoming problems encountered in production, distribution and adoption of sorghum seed in Sudan. *In* La production de In semilla de sorgo en American Latina (Guiragosian V, Perul C and Peterson G, eds.). CIMMYT Londres 90, Apdo 6-641, Mexico. CP 06600 D.F.: Mexico.

Ejeta G. 1986. Breeding sorghum hybrids for irrigated and rainfed conditions in the Sudan. Presented at the International Drought Symposium on Food grain production in semi-arid regions of sub-Saharan Africa, 19-23 May 1986, Nairobi, Kenya. Nairobi, Kenya: Semi-Arid Food Grain Research and Development Project.

Ejeta G, Butler LG, Hess DE, Obilana AB and Reddy BV. 1997. Breeding for *Striga* resistance in sorghum. Pages 504-516 *in* Proceedings of the International Conference on Genetic improvement of sorghum and millet, 23-27 Sep 1996, Lubbock, Texas.

Ejeta G, Mohammed A, Rich P, Melake-Berhan, Housley TL and Hess DE. 2000. Selection for specific mechanisms of resistance to *Striga* in sorghum. Pages 29-37 *in* Breeding for *Striga* resistance in cereals: Proceedings of a workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria (Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds.). Weikershaim, Germany: Magraf Verlag.

El Rouby MM. 1977. Progress in sorghum breeding in Nigeria. International Sorghum Workshop. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

FAO/ICRISAT (Food and Agriculture Organization of the United Nations/International Crops Research Institute for the Semi-Arid Tropics). 1996. The world sorghum and millet economies: Facts, trends and outlook. ICRISAT, Patancheru 502 324, Andhra Pradesh, India, and FAO, Viale delle Termi di Caracalla, 00100 Rome, Italy. 68 pp.

FIIRO (Federal Institute of Industrial Research). 1986. Technical report of pilot-plant brewing with 100% sorghum malt. Oshodi, Lagos, Nigeria: Federal Institute of Industrial Research. 18 pp.

Futrell MC and Webster OJ. 1966. New sources of resistance to the downy mildew disease of sorghum. Plant Disease Reporter 50:641.

Gebrekidan Brhane. 1987. Sorghum improvement and production in Eastern Africa. Pages 141-154 *in* Food grain production in Semi-Arid Africa (Menyonga JM, Bezuneh Tanje and Yondeowei A, eds.). Ouagadougou, Burkina Faso: OAU/STRC-SAFGRAD.

Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH. (eds.) 2000c. Breeding for *Striga* resistance in cereals: Proceedings of a workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria. Weikershaim, Germany: Magraf Verlag. 376 pp.

Haussman BIG, Hess DE, Reddy BVS, Mauro SZ, Kayentao N, Welz HG and Geiger HH. 2000a. Evaluation of laboratory, pot, and field measures *of Striga* resistance in sorghum. Pages 41-58 *in* Breeding for *Striga* resistance in cereals: Proceedings of a workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria (Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds.). Weikershaim, Germany: Magraf Verlag.

Haussmann BIG, Hess DE, Reddy BVS, Mukuru SZ, Seetharama N, Kayentao M, Omanya BG, Welz HG and Geiger HH. 2000b. QTL for *Striga* resistance in sorghum populations derived from IS 9830 and N 13. Pages 159-171 *in* Breeding for Striga resistance in cereals: Proceedings of a workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria (Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds.). Weikershaim, Germany: Magraf Verlag.

Heller R and Wegmann K. 2000. Mechanisms of resistance to *Striga hermonthica* (del.) Benth. in *Sorghum bicolor* (L.) Moench. Pages 19-28 *in* Breeding for *Striga* resistance in cereals: Proceedings of a workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria (Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds.). Weikershaim, Germany: Magraf Verlag.

Hess DE, Obilana AB and Gerard P. 1996. *Striga* research at ICRISAT. Pages 827-834 *in* Advances in parasitic plant research: Proceedings of the Sixth International Parasitic weed symposium, 16-18 Apr 1996, Cordoba, Spain (Moreno MT, Cubero JI, Berner D, Joel D, Musselman LI and Parker C, eds.). SA Sevilla, University of Cordoba, Cordoba, Spain: AG Novograf.

House LR. 1987. A regional effort for the improvement of sorghum in Southern Africa. Pages 155-158 *in* Food grain production in Semi-Arid Africa (Menyonga JM, Bezuneh Tanje and Yondeowei A, eds.). Ouagadougou, Burkina Faso: OAU/STRC-SAFGRAD.

House LR, Verma BN, Ejeta G, Rana BS, Kapran I, Obilana AB and Reddy BVS. 1997. Developing countries breeding and potential of hybrid sorghum. Pages 84-96 *in* Proceedings of the International Conference on Genetic improvement of sorghum and pearl millet, Dec 1997, Lubbock, Texas. INTSORMIL and ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1997. Page 77 *in* Annual report 1996. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 2000. ICRISAT's Medium-Term Plan 2001-2003. Patancheru 502 324, Andhra Pradesh, India: ICRISAT. 39 pp.

ICRISAT Sahelian Center. 1993. ICRISAT West African Programs Annual Report 1992. PO Box 12404, Niamey, Niger. ICRISAT Sahelian Center.

ICRISAT Southern and Eastern Africa Region. 1995. Annual Report 1994. PO Box 776, Bulawayo, Zimbabwe: ICRISAT.

ICRISAT Southern and Eastern Africa Regional Program. 1994. Pages 8-9 *in* Annual Report 1993. Bulawayo, Zimbabwe: SADC/ICRISAT Sorghum and Millet Improvement Program.

James C. 1981. The cost of disease to world agriculture. Seed Science & Technology 9:679-655.

Jenkins G, Miller F, Muchena F and Sanders JH. 1996. Report of Center-Commissioned External Review of ICRISAT Southern and Eastern Africa. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Kapran I, Axtell JD and Ejeta G. 1995. Sorghum hybrids: A viable technology for sustaining Sahelian agriculture. Workshop on Technology development and transfer to improve natural resource management in West Africa, 18-22 Sep 1996, Niamey, Niger.

King SB. 1975. Screening for resistance to witchweed (*Striga hermonthica*) in Nigeria. Abstract *in* Proceedings of the American Phytopathological Society 2, USDA, ARS US Svy. Crops Field Station. Meridian, Mississippi, USA:USDA.

Lane JA, More THM, Child DV, Bailey JA and Obilana AB. 1996. Post-infection resistance mechanism against *Striga* in cowpea and sorghum. Pages 560-565 *in* Advances in parasitic plant research: Proceedings of the Sixth International Parasitic weed symposium, 16-18 Apr 1996, Cordoba, Spain (Moreno MT, Cubero JI, Berner D, Joel D, Musselman LJ and Parker C, eds.). SA Sevilla University of Cordoba, Cordoba, Spain: AG Novograf.

Leuschner K. 1993. Screening for resistance to storage insect pests. Pages 14-15 *in* Annual report 1992 SADC/ICRISAT Southern Africa Programs 1993. P.O.Box 766, Bulawayo, Zimbabwe: SADC/ICRISAT Sorghum and Millet Improvement Program.

Leuschner K. 1996. Methodology for screening sorghum resistance to storage pests. Pages 173-179 *in* Drought-tolerant crops for southern Africa: Proceedings of the SADC/ICRISAT Regional Sorghum and pearl millet workshop, 25-29 Jul 1994, Gaborone, Botswana (Leuschner K and Manthe CS, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Lukheie PB and Obilana A Tunde. 1980. Genetic variability in a long season random grain sorghum population. Zeitschrift for Pflanzensuchtung 92:40-51.

Mangombe N and Mushonga JN. 1996. Sorghum and pearl millet on-farm research work in Zimbabwe. Pages 81-90 in Drought-tolerant crops for southern Africa: Proceedings of the SADC/ICRISAT Regional sorghum and pearl millet workshop, 25-29 Jul 1994, Gaborone, Botswana (Leuschner K and Manthe CS, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Mbwaga AM and Obilana AT. 1994. Distribution and host specificity of *Striga asiatica* and S. *hermonthica* on cereals in Tanzania. International Journal of Pest Management 39:449-451.

Murty DS, Bello SA and Nwasike CC. 1997. Status and breeding requirements for sorghum utilization in beverages in Nigeria. Pages 538-567 in Proceedings of the International Conference on Genetic improvement of sorghum and millet, Dec 1997, Lubbock, Texas. INTSORMIL and ICRISAT.

Musselman LJ. 1987. Taxonomy of witchweeds. Pages 3-12 *in* Parasitic weeds in Agriculture. Vol. 1. Striga (Musselman LJ, ed.). Boca Raton, Florida: CRC Press.

Musselman LJ and Hepper FN. 1986. The witchweeds (*Striga Scrophubriaceae*) of the Sudan Republic. Kew Bulletin 41(1):205-221.

Musselman LJ and Riches CR. 1985. Witchweeds of Botswana. The Bulletin of Agricultural Research in Botswana 4:3-11.

Ndjomaha C, Yapi A and Adamvi A. 1998. Impact of sorghum S 35 in extreme north Cameroon. Pages 26-37 *in* Assessing joint impacts: Proceedings of an International Workshop on Joint impact assessment of NARS/ ICRISAT, Patancheru 502 324, Andhra Pradesh, India (Bantilan MCS and Joshi PK, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Obilana AB. 1979. Recommended sorghum varieties: Their descriptive features. Proceedings of the 3rd NAFPP Sorghum/millet/wheat workshop, 9-11 Apr 1979, Institute for Agricultural Research, Samaru, Zaria. Samaru, Nigeria: Institute for Agricultural Research.

Obilana AB. 1979a. Search for *Striga* control through resistance in Guinea Corn in Nigeria. Proceedings of 3rd NAFPP Sorghum/millet/wheat workshop, 9-11 Apr 1979, Institute for Agricultural Research, Samaru, Zaria. Samaru, Nigeria: Institute for Agricultural Research.

Obilana AB. 1981. New sorghum varieties for three Nigerian Savanna ecological zones. Pages 25-29 *in* Proceedings of the 5th NAFPP National sorghum/millet/wheat workshop, 27-30 Apr 1981, Zaria, Nigeria. Lagos, Nigeria: Federal Department of Agriculture.

Obilana AB. 1981a. Breeding and improvement status of *Sorghum bicolor* L. Moench, in Nigeria. 2nd OAU/ STRC-SAFGRAD JP 31 International workshop on Sorghum and millet. Gaborone, Botswana. 20 pp.

Obilana AB. 1981b. Sorghum hybrids for Nigeria. Proceedings of the 5th NAFPP National sorghum/millet/ wheat workshop. Ahmadu Bello University, Zaria, Nigeria. 6 pp.

Obilana AB. 1982a. Breeding and improvement status of sorghum (*Sorghum bicolor* L. Moench) in Nigeria. Pages 103-122 *in* Proceedings of the Second Workshop on Sorghum and millet. Organization of African Unity (OAU) Scientific Technical and Research Commission (STRC), SAFGRAD JP 31. Gaborone, Botswana.

Obilana AB. 1982b. A report by the action committee on hybrid sorghum project for the technical sub-committee of the national sorghum project on green revolution, Mar 1982. Lagos, Nigeria: Federal Department of Agriculture. 15 pp.

Obilana AB. 1983. *Striga* studies and control in Nigeria. Pages 87-98 *in* Proceedings of the Second International Workshop on *Striga,* 5-8 Oct 1981, Ouagadougou, Upper Volta (Ramaiah KV and Vasudeva Rao MJ, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Obilana AB. 1984. Inheritance of resistance to *Striga.* Protection Ecology 7(4):305-311.

Obilana AB. 1985a. Sorghum breeding and selection for brewing industry in Nigeria. Presented at the National Symposium on the brewing industry - New and in the 21st century: Problems, challenges and prospects. 29 May-1 Jun 1985, Oweni, Nigeria. 22 pp.

Obilana AB. 1985b. Recurrent selection schemes in sorghum. Zeitschrift for pflawzen-suchtung 95:221-229.

Obilana AB. 1989. Progress in sorghum breeding in the SADC region (1984/85-1987/88), and plans for 1988/89. Pages 213-248 *in* Proceedings of the Fifth Annual workshop on sorghum and millets for southern Africa, 21-23 Sep 1988, Maseru, Lesotho. Bulawayo, Zimbabwe: SADC/ICRISAT Sorghum and Millet Improvement Program.

Obilana AB. 1990. Breeding sorghum for the malting and brewing industries. Presented at the CLAIS Workshop-PCCMA Meeting, 29 Mar 1990, San Salvador, Central America. 20 pp.

Obilana AB. 1997. The role of SADC/ICRISAT in grain quality assessment for regional food security. Presented at the 14th SAAFOST International congress and exhibition in combination with ECSAFOST, ICC-SA and ARC-Irene, 1-4 Sep 1997, CSIR Conference Center, Pretoria, South Africa.

Obilana AB. 1998. Sorghum improvement. Pages 4-17 *in* International Sorghum and Millets Newsletter no. 39. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Obilana AB, Adesiyum AA and Manzo SK. 1983. Breeding for disease and pest resistance in sorghum. Pages 125-137 *in* Breeding for durable disease and pest resistance. FAO Plant Production Paper No. 55. Rome, Italy: Food and Agriculture Organization of the United Nations.

Obilana AB and El-Rouby MM. 1980a. Population improvement and pure line development in sorghum (*Sorghum bicolor* L. Moench) in Nigeria. Cereal Research Communication 8:425-430.

Obilana AB and El-Rouby MM. 1980b. Recurrent mass selection for yield in two random-mating populations of sorghum *{Sorghum bicolor* L. Moench). Maydica 253(3): 127-133.

Obilana AB and Harkness C. 1985. Nigerian Sahelian sorghum germplasm collection. Institute for Agricultural Research, Ahmadu Bello University, Samaru Zaria, Nigeria. 7 pp. Mimeo.

Obilana AB, Knepper D and Musselman LJ. 1988. *Striga* (witchweeds) in Zimbabwe. Fourth regional SADC/ICRISAT Sorghum and Millet Improvement Program Workshop, 21-24 Sep 1987, Matopos, Zimbabwe. Bulawayo, Zimbabwe: SADC/ICRISAT Sorghum and Millet Improvement Program. 28 pp.

Obilana AB, de Milliano WAJ and Mbwaga AM. 1991. *Striga* research in sorghum and millets in southern Africa: status and host plant resistance. Pages 435-439 *in* Proceedings of the Fifth International symposium on Parasitic weeds (Ransom JK, Musselman LI, Worsham AD and Parker C, eds.). Nairobi, Kenya: CIMMYT.

Obilana AB, Monyo ES and Gupta SC. 1997. Impact of genetic improvement in sorghum and pearl millet: Developing country experiences. Pages 119-141 *in* Proceedings of the International Conference on Genetic improvement of sorghum and pearl millet, 22-27 Sep 1996, Lubbock, Texas, USA. INTSORMIL/ICRISAT Publication No. 97-5. Lincoln, Nebraska, USA.

Obilana AB and Olaniyi OA. 1983. Preliminary report on the screening of Nigerian sorghums for malting characteristics. Unpublished.

Obilana AB and Ramaiah KV. 1992. *Striga* (witchweeds). Pages 187-201 *in* Sorghum and millets diseases: A second world review (de Milliano WAJ, Frederiksen RA and Bengston GB, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Obilana AB, Rao KEP, Mangombe N and House LR. 1996. Classification of sorghum races in the southern Africa sorghum germplasm. Pages 113-118 *in* Drought-tolerant crops for southern Africa: Proceedings of the SADC/ICRISAT Regional sorghum and pearl millet workshop, 25-29 Jul 1994, Gaborone, Botswana (Leuschner K and Manthe CS, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Obilana AB and Reddy BVS. 1999. Host-plant resistance to *Striga* in sorghum and pearl millet. Pages 11-19 *in* Report on the ICRISAT sector review for *Striga* control in sorghum and millet, 27-28 May 1996, ICRISAT, Bamako, Mali (Hess DE and Lenne JM, eds.). Patancheru PO, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Ogungbilc AO. 1998. Factors influencing awareness and adoption of ICSV 111 and ICSV 400 sorghum varieties. Socio-economics and Policy Program, ICRISAT, Patancheru, 502 324, Andhra Pradesh, India. Mimeo.

Ogunlela VB and Obilana A Tunde. 1982. Masakwa: The Harmattan sorghum in Nigeria. NOMA 4(1).

Omanya GO, Haussman BIG, Hess DE, Reddy BVS, Mauro SZ, Welz HG and Geiger HH. 2000. Evaluation of laboratory, pot, and field measures *of Striga* resistance in sorghum. Pages 59-72 *in* Breeding for *Striga* resistance in cereals: Proceedings of the workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria (Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds). Weikershaim, Germany: Margraf Verlag.

Prasada Rao KE, Obilana AT and Mengesha MH. 1985. Collection of kaura-gara and Guineanse sorghums in northern Nigeria. Journal d'Agriculture Traditionelle et de Botanique Applique (JATBA) 32:74-81.

Ramaiah KV. 1987. Control of *Striga* and *Orobanche* species - a review. Pages 637-664 *in* Parasitic flowering plants: Proceedings of the fourth International symposium on Parasitic flowering plants, Aug 1987, Marburg, Germany, Philipps - Universitat (Weber HC and Forstrenter W, eds.).

Ramaiah KV and Parker C. 1982. *Striga* and other weeds in sorghum. Pages 291-302 in Sorghum in the eighties (House LR, Mughogho LK and Peacock JM, eds.). Patancheru, AP, India: International Crops Research Institute for the Semi-Arid Tropics.

Rana DS and Obilana A Tunde. 1979. Genetics of hybrid sorghum seed development and production. Page 10 *in* Proceedings of the 7th Annual conference of the Genetics Society of Nigeria, 6-8 Dec 1979, NRCRI, Umudike, Nigeria.

Rattunde HFW, Obilana AB, Haussman BIG, Reddy BVS and Hess DE. 2000. Breeding sorghum for *Striga* resistance at ICRISAT: Progress and perspectives. Pages 85-94 *in* Breeding for *Striga* resistance in cereals: Proceedings of a workshop, 18-20 Aug 1999, IITA, Ibadan, Nigeria (Haussman BIG, Hess DE, Koyama ML, Grivet L, Rattunde HFW and Geiger HH, eds). Weikershaim, Germany: Margraf Verlag.

Riches CR, de Milliano WAJ, Obilana AT and House LR. 1987. Witchweeds *[Striga)* of sorghum and pearl millet in the SADC region: Distribution and control. Page 16 *in* Proceedings of the Third regional SADC/ ICRISAT Sorghum and Millet Improvement Project (SMIP) Workshop, 20-25 Sep 1986, Lusaka, Zambia. Bulawayo, Zimbabwe: SADC/ICRISAT SMIP.

SADC/ICRISAT Sorghum and Millet Improvement Program. 1995. Quarterly technical report, Oct-Dec 1995. Bulawayo, Zimbabwe: SADC/ICRISAT SMIP.

SADC/ICRISAT Sorghum and Millet Improvement Program. 1996. Quarterly technical report. Jan-Mar 1996. Bulawayo, Zimbabwe: SADC/ICRISAT SMIP. 25 pp.

Saunders AR. 1933. Studies in phanerogamic parasitism. Department of Agriculture Science Bulletin, Republic of South Africa. 128 pp.

Saunders AR. 1942. Field experiments at Potchefstroom. Department of Agriculture and Forestry Science Bulletin, Republic of South Africa. 14 pp.

Taneja SL and Leuschner K. 1985. Methods of rearing, infestation and evaluation for *Chilo partellus* resistance in sorghum. Pages 175-188 *in* Proceedings of the International sorghum entomology workshop, 15-21 Jul 1984, Texas A&M University, College Station, TX, USA. Patancheru PO, A.P 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Thakur RP, Frederiksen RA, Murty DS, Reddy BVS, Bandyopadhyay R, Giorda LM, Oduody GN and Claphin LE. 1997. Breeding for disease resistance in sorghum. Pages 302-315 *in* Proceedings of International conference on Genetic improvement of sorghum and pearl millets, 22-27 Sep 1996, Lubbock, Texas, USA. INTSORMIL and ICRISAT.

Williams RJ, Rao KN and Dange SRS. 1980. The International sorghum leaf disease nursery. Page 229 *in* ICRISAT 1980 Proceedings of the International workshop on Sorghum diseases. Patancheru PO, A.P., India: International Crops Research Institute for the Semi-Arid Tropics.

Wrigley G. 1982. Tropical Agriculture. 4th ed. Longman, Harlow.

Yapi A, Kergna AO, Debrah SK, Sidibe A and Sorngo O. 1998. Impact of sorghum research in Mali. Pages 76-93 *in* Assessing joint impacts: Proceedings of an International workshop on Joint impact assessment of NARS/ICRISAT (Bantilan MCS and Joshi PK, eds.). ICRISAT, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Yapi AM, Debala G, Ngawara K and Isska A. 1999. Assessment of the economic impact of sorghum variety S 35 in Chad. Impact Series no. 6. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 34 pp.

Zummo N. 1974. Institute for Agricultural Research (IAR). Pages 20-22 *in* Annual Report on Cereals Pathology, Zaria, Nigeria. Zaria, Nigeria: Ahmadu Bello University and Institute for Agricultural Research.

A Research and Network Strategy for Sustainable Sorghum Production Systems for Latin America

6

BVS Reddy, AF Rangel, B Ramaiah and R Ortiz

A Research and Network Strategy for Sustainable Sorghum Production Systems for Latin America

BVS Reddy[1], AF Rangel[2], B Ramaiah[1] and R Ortiz[3]

6.1. Introduction

The Latin America and Caribbean Program was initiated in 1976 by ICRISAT by stationing staff at CIMMYT, Mexico. The program aimed to develop early, dwarf and bold grain varieties for fertile soils in both the highlands and lowlands of Central America. The program was transformed as the Latin American Sorghum Improvement Program (LASIP) in 1990 and led by Varthan Guiragosian and Compton Paul, a cereals breeder. LASIP's work with the NARS in the development and improvement of cropping systems for small farmers in Latin America is well documented in Paul (1993). With coordination of the regional sorghum research network, the Comision Latinamericano Investigadores en Sorgo (CLAIS), LASIP maintained excellent contact with NARS, private companies and institutions, and farmers of the region. As of 1993, the ICRISAT-LASIP/CLAIS collaboration led to the training of 62 scientists in In-Service and Visiting Scientists categories at LASIP in Mexico and ICRISAT in India. An additional 77 scientists have received training in short courses. Several varieties were released and adopted based on the ICRISAT-led program, particularly by Mexico, El Salvador, Guatemala and other countries in the region. These are given in Chapter 7 (Table 7.6) and Chapter 8 (Section 8.4). Due to funding constraints, the program was discontinued in 1993. However, considering the interest in sorghum shown by the Latin American NARS, a program for improving sorghum for acid soil tolerance was initiated in 1996 with funding support from IADB.

The acid and infertile Oxisol areas (71 million ha) in tropical America are dominated by the Savanna system in the *Llanos* of Colombia and Venezuela, and the *Cerrados* of Brazil (Gourley 1991), which are traditionally used for grazing by livestock. Research at CIAT led to the replacement of native grasses with the more productive *Brachiaria* species. This increased productivity tenfold; as a consequence, one animal could be raised on each hectare of *Brachiaria* Savanna (Raul Vera, personal communication 1997). Given the growing awareness for the need to diversify agropastoral systems, CIAT has been experimenting with upland rice, mixed systems with a legume and *Brachiaria* species and maize. Sorghum and pearl millet are considered to have the potential to contribute to sustainable agropastoral systems. The INTSORMIL program identified 20 acid soil-tolerant sorghum lines in the 1980s (Gourley 1991), but they were susceptible to leaf diseases. At its centers in India and Africa, ICRISAT has developed diverse sets of high-yielding sorghum breeding materials useful as base material for testing in the acid soils of Latin America. Since 1996, ICRISAT, CIAT and the national programs of Brazil, Colombia, Honduras and Venezuela have jointly

1 International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
2 Centro Internacional de Agricultura Tropical, Cali AA. 6713, Colombia.
3 Formerly of the International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Reddy BVS, Rangel AF, Ramaiah Band Ortiz R. 2004. A research and network strategy for sustainable sorghum production systems for Latin America. Pages 139-148 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

implemented an IADB-funded project on "A research and network strategy for sustainable sorghum production systems for Latin America" whose objectives are:

- to assemble, multiply and evaluate grain and forage sorghum breeding lines for tolerance to acid soils and resistance to foliar diseases
- to develop a research network of scientists working on this crop in the region and train them in sorghum research
- to test the most promising genotypes in the target production systems.

This chapter summarizes the results and implications of breeding for acid soil-tolerant sorghum cultivars.

6.2. Breeding Processes

Introductions. In 1995, diverse sets of 378 pairs of grain sorghum A/B lines, 784 grain sorghum restorer lines/varieties and 94 forage sorghum lines were introduced into Colombia from ICRISAT. Of the sorghum R-lines, 101 were developed at ICRISAT-Bamako (Mali) while the rest of the sorghum materials were developed at ICRISAT-Patancheru (India). In addition, two *ms*$_3$-based grain sorghum (ICSP LG-large grain and ICSP B-maintainer) populations and a forage sorghum (ICSP HT-high tillering) population developed at ICRISAT-Patancheru were introduced. These populations were earlier bred for resistance to specific biotic constraints in Africa, and specific adaptation and high grain yield in neutral pH fertile soils in India.

Empirical testing. The CIAT farm at Cali with its neutral soil pH was used for seed multiplication and selection for high yield and resistance to leaf diseases (leaf blight, anthracnose, rust, maize dwarf mosaic and sugarcane mosaic viruses) for four years during the first season (Jun 1996 to 1999). Quilichao, Matazul, La Libertad and Carimagua farms in Colombia with their acidic soils (pH<5.7) were used to screen the materials for acid soil tolerance and resistance to foliar diseases in the second season (Jul 1996 to Dec 1999). High early vigor, greater green leaf area at maturity, high grain/forage yields and resistance to foliar diseases (high Al^{3+}) were used as selection criteria to identify materials for acid soil tolerance. High tillering and recovery growth after first cut were used as selection criteria in advancing the forage sorghum lines. The soil characteristics of the farms, including La Libertad, are given in Table 6.1.

Genotype (G) X Environment (E) interaction studies. A set of sorghum R-lines (12) was evaluated for their response under three Al^{3+} (80, 60 and 40%) saturation levels to decide on the

Table 6.1. Soil characteristics at different acid soil locations in Colombia.

	O.M	P			Ca				SAI			Zn			
Location	(%)	ppm	pH	Al	(meq/100g)	Mg	K	CICE	(%)	B	S	(ppm)	Mn	Cu	Fe
Carimagua	3.4	2.2	4.2	1.5	0.5	0.1	0.1	2.2	70.8	0.3		0.5	1.9	0.3	52.7
Matazul	2.6	3.2	4.7	1.8	0.4	0.3	0.1	2.5	72.1	0.7	21.6				
La Libertad	2.3	5.0	5.2	1.2	0.6	0.1	0.1	2.0	60.6	0.2		0.4	1.5	0.4	22.0
Quilichao[1]	6.7	4.9	3.9	2.9	1.6	0.6	0.1	5.1	55.5	0.2		0.8	140.6	1.9	28.0

1. The soils at Zamorano (Honduras) are similar to those in Quilichao. They are low in aluminum saturation (36-55%) with low pH (3.9- 4.7) and high organic matter content (6.6-8.8%).

Source: Seventh season report of the Latin American Network Project.

breeding approach to be followed. Stability analyses (Eberhart and Russel 1966) were carried out for the data collected on grain sorghum R-lines, B-lines and forage lines for agronomic desirability (grain yield) and fresh forage yield. Agronomic desirability (R- and B-lines) and fresh fodder weight (forage lines) were the major criteria used in advancing the lines.

Backup breeding. Improved segregating sorghum populations (of crosses B- and R-lines) were empirically screened in highly acid soils. Large grained (ICSP LG) and maintainer (ICSP B) sorghum populations (ms_3-based) were merged and selected alternatively at the CIAT farm under neutral pH, and at Matazul under highly acid soils.

Hybrid testing. About 200 hybrids were made between the selected A-lines and R-lines and INTSORMiL R-lines, which were then screened for tolerance to acid soil conditions.

Network trials. Network trials involving the selected grain sorghum A/B-lines, R-lines and forage sorghum lines were distributed to national programs in Brazil, Colombia, Honduras and Venezuela from the second season (1997) onwards.

Training. Scientists from Brazil, Colombia and Venezuela were trained in sorghum breeding at ICRISAT-Patancheru from 1997 to 1998.

6.3. Outputs

Sorghum introductions from ICRISAT-Patancheru were tested empirically for grain and forage under acid soil conditions. Fifteen grain sorghum A/B-lines were selected for high yield, resistance to leaf diseases and tolerance to acid soil. Twenty-one restorer lines (on A, cytoplasm) were selected for high yields under acidic soils (Reddy et al. 2000b). Four forage sorghum lines (IS 31496, IS 13868, ICSR 93024-1 and ICSR 93024-2) were selected for tolerance to acid soils. The performance of the selected grain sorghum A/B-lines, R-lines and forage sorghum lines are given in Tables 6.2, 6.3 and 6.4.

In the Genotype (G) x Al^{3+} level trial, variances due to G X Al^{3+} level interactions were significant for agronomic desirability, highly significant for peduncle exersion and not significant for other traits such as head and grain weight. High soil acidity (80% Al^{3+} saturation) significantly reduced early vigor and green leaf area at maturity, and enhanced flowering. It also substantially reduced head and grain weight (Reddy and Rangel 2000). The highest head and grain weights were recorded at 60% Al^{3+} level (Table 6.5). It is possible that previous selection under acid soils might have eliminated the lines that performed well under less acidic (40% Al^{3+} saturation) soil conditions in the present test. Studies by INTSORMIL have also indicated that sorghum lines more tolerant to acid soils showed favorable growth and traits when grown under relatively severe acid soil (60% Al^{3+} saturation, pH 4.1) conditions (Flores et al.1988).

A detailed discussion on stability analyses across locations is reported in Reddy et al. (1998) and Reddy and Rangel (2000). The R-lines with high agronomic desirability and regression coefficient between 0 and 1 (showing wide adaptability) were IS 30469-1187-2, IS 30469C-1508T-2, ICSRs 110, 89005, 89012 and 90004. The R-lines with high agronomic desirability but with a regression coefficient significantly greater than 1.0 (indicating that these genotypes do well only under a more favorable environment) were ICSV 95072, ICSRs 74, 91008, 91012, 91020, 93033, 93042, IS 3049-1187-4, IS 3049-1187-5 and GD 27669. The R-lines with high agronomic

Table 6.2. The performance of male-sterile lines evaluated under six different acid soil conditions in Zamorano, Honduras (1997 and 1999, II season), Matazul (1997 and 1998, II season) and La Libertad (1998 and 1999, II season), Colombia, Latin America.

A/B lines	Pedigree	CIAT origin	Vigor score[1]	Plant height (m)	Days to 50% flowering	Green leaf area score[2]	Leaf disease score[3]	Grain mold score[4]	Agronomic score[5]	Head weight (t ha^{-1})	Grain weight (t ha^{-1})
ICSB 604	[(ICSB 11 x PM 17500-2-1) x PM 17467B]3-2	SPMD 94036	2.0	1.3	73	3.6	2.5	2.4	2.3	3.3	2.8
ICSB 605	[(ICSB 11 x PM 17500-2-1) x PM 17467B]5-2-1-1	SPMD 94004	1.8	1.6	77	4.3	2.4	1.9	2.3	3.0	2.8
ICSB 607	[(ICSB 26 x PM 17467B) x PM 17467B]10-3	SPMD 94045	1.9	1.0	73	4.7	2.8	2.4	1.9	3.0	2.7
ICSB 608	[(SPV 373 x SPV 55) x PD-3-1-11]5-1-1-3-1	SPA_2 94021	1.6	1.4	74	3.7	2.1	1.6	2.2	2.7	2.7
ICSB 609	[(ICSB 101 x PM 17500-2-1) x PM 19268B]2-4-2	SPA_2 94013	1.7	1.7	72	4.5	2.9	1.6	2.3	2.8	2.6
ICSB 611	ICSP 1B/R MFR-S 10-41-2-9-3-2-1-1	SPA_2 94029	1.9	1.4	72	5.4	3.5	2.3	2.6	2.9	2.3
ICSB 614	(SC 108-3 x CSV 4)-51-1	SPA_2 94039	1.8	1.2	77	5.0	3.1	1.3	2.7	2.3	2.3
ICSB 613	(Ind. Syn. 422-1 x Rs/R-20-682)-5-1-6-2-1	ICSB 89002	2.5	0.9	74	4.7	3.3	2.4	2.4	2.6	2.2
ICSB 73	[(296B x SPV 105) x (2077B x M 35-1)]-19	ICSB 73	2.0	1.5	75	5.4	3.1	2.3	2.4	2.8	2.2
ICSB 606	[(ICSB 26 x PM 17467B) x PM 17467B]10-3-1-2	SPMD 94019	1.9	1.1	75	4.3	3.1	2.4	1.8	2.7	2.1
ICSB 601	[(BTx 623 x MR 862) x B lines bulk]-5-1-3-5	ICSB 38	1.7	1.3	72	5.0	2.7	1.7	2.1	3.1	2.1
ICSB 603	[(ICSB 11 x PM 17500-2-1) x PM 17467B]1-1-1-1	SPMD 94036	2.1	1.2	73	5.0	3.4	2.2	2.1	2.5	2.1
ICSB 94	[(296B x SPV 105) x (2077B x M 35-1)]-21	ICSB 94	3.3	1.4	73	5.8	3.8	2.0	2.8	2.7	1.6
ICSB 713	(IS 84 x ICSR 38)8-2-1-1-1-2	SPA_2 94016	1.4	1.3	72	5.1	4.3	2.8	1.7	2.1	1.6
ICSB 89	[(296B x SPV 105) x (2077B x M 35-1)]-8	ICSB 89	3.0	1.4	69	5.2	3.5	2.0	3.1	2.3	1.5
Checks											
REAL 60		Tolerant check	1.3	1.9	72	5.2	4.2	1.7	1.6	4.0	3.1
ICSB 338	(ICSB 51 x PM 1861)4-1-2-2	SPRU 94008 Susceptible check	3.6	1.0	66	5.2	3.3	2.7	4.1	2.1	0.9
Mean			2.1	1.3	72.8	5	3.2	2.1	2.4	2.8	2.2
SE ±			0.15	0.06	0.63	0.14	0.15	0.10	0.14	0.11	0.13
CV (%)			22.3	11.2	4.6	9.4	15.8	27.8	24.6	40.1	35.2

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1= green leaf area, 2 = 1-5% of green leaf area reduced, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% green leaf area reduced.
3. Measured on a 1 to 9 scale, where 1= free of leaf diseases, 2 = 1-5% of leaf area affected, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% of leaf area affected.
4. Measured on a 1 to 9 scale, where 1= no mold and 9 = >50% surface of grain with mold.
5. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.

Table 6.3. The performance of the restorer lines evaluated under six different acid soil conditions in Zamorano, Honduras (1997 and 1999, II season), Matazul (1997 and 1998, II season) and La Libertad (1998 and 1999, II season), Colombia, Latin America.

R-lines/CIAT origin	Pedigree	Vigor score[1]	Plant height (m)	Days to 50% flowering	Green leaf area score[2]	Leaf disease score[3]	Grain mold score[4]	Agronomic score[5]	Head weight (t ha^{-1})	Grain weight (t ha^{-1})
ICSR 91012	(SPV 475 x DKV 74)-1-2-1	1.8	1.6	74	4.8	2.8	1.6	2.1	2.9	2.8
ICSR 93033	NTJ 2122	1.9	1.5	74	4.6	3.2	1.8	2.5	2.3	2.7
ICSR 110	[MR 836 x (CK 60B x IS 84)]-4-1	2.1	1.2	68	4.8	3.1	1.8	2.4	2.6	2.7
ICSV 93042	(ICSV 705 x YT-2-37-2)-10-1-2-1-1	1.9	1.5	77	5.0	3.0	1.7	2.7	2.2	2.6
ICSR 91020-1	(SPV 475 x DKV 74)-1	1.8	1.6	67	4.9	2.5	1.4	2.1	2.5	2.6
ICSR-143	(FLR 101 x CSV 4)-4-1-2-3-1-1	2.3	1.5	75	4.9	3.1	1.6	2.5	2.2	2.5
IS 30469-1187-4	IS 30469-1187-4	1.9	1.6	71	4.7	3.3	1.6	2.4	2.5	2.5
ICSR 194	(PQ 213 x M 35-1)-5-2-2-1	1.9	2.2	66	4.7	3.3	1.7	2.2	2.9	2.5
ICSR 102	[(148 x E 35-1)-4-1 x CSV 4]-1-1-1	1.9	1.2	72	4.7	3.3	1.9	2.4	2.1	2.4
ICSV 1177 BF	GD 27669	1.6	1.6	66	4.9	2.9	2.3	2.3	2.5	2.2
ICSV 95126	(ICSV 705 x YT-2-37-2)-14-1-1-1-1	2.1	1.9	71	4.9	2.5	1.7	2.4	2.2	2.0
IS 30469-1187-2	IS 30469-1187-2	1.9	2.1	70	5.0	2.9	1.6	2.3	2.2	2.0
IS 21629	IS 21629	2.2	2.7	66	5.1	3.2	1.4	2.7	1.3	1.7
Checks										
Real 60 (tolerant)		1.2	1.9	70	5.4	3.9	1.7	1.4	3.2	2.9
SPRU 94008 (susceptible)	(ICSB 51 x PM 1861)4-1-2-2	2.8	0.9	64	5.5	3.5	3.0	3.9	1.7	1.1
Mean		1.96	1.67	70	4.94	3.09	1.77	2.43	2.35	2.34
SE ±		0.09	0.11	1.02	0.06	0.09	0.10	0.13	0.12	0.12
CV (%)		25.8	5.7	7.8	8.0	15.4	19.5	23.9	43.6	37.7

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1= green leaf area, 2 = 1-5% of green leaf area reduced, 3 = 6-10%, 4 = 11-20%, 5= 21-30%, 6= 31-40%, 7=40-50%, 8=51-75% and 9 = > 75% of green leaf area reduced.
3. Measured on a 1 to 9 scale, where 1= free of leaf diseases, 2 = 1-5% of leaf area affected, 3= 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 =51-75% and 9 = > 75% of leaf area affected.
4. Measured on a 1 to 9 scale, where 1= no mold and 9 = 50% surface of grain with mold.
5. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.

Table 6.4. The performance of forage sorghum lines evaluated under eight different acid soil conditions in Carimagua (1996, II season), La Libertad (1996 and 1997, II season; 1998,I and II season and 1999, II season) and Matazul (1997 and 1998, II season) in Colombia, Latin America.

Forage lines/ CIAT orgin	Vigor score[1]	Plant height (m)	Number of tillers	Days to 50% flowering	Green leaf area score[2]	Leaf disease score[3]	Forage yield ($t\ ha^{-1}$)	Recovery score	Grain yield ($t\ ha^{-1}$)	Agronomic score[4]
IS 31496	1.9	2.0	2	79	2.5	2.3	19.3	2.0	3.5	1.7
IS 13868	1.3	2.3	2	73	2.7	2.2	16.9	2.6	0.8	2.0
IS 31446	1.8	1.8		81	1.0		16.1			1.2
ICSR 93024-2	2.9	2.0	1	71	3.5	2.4	14.1	3.6	0.4	2.5
ICSR 93024-1	3.5	1.6	2	75	3.2	2.1	9.7	4.0		2.6
GD 47805	3.3	1.7	2	72	2.2	1.8	8.7	4.0		2.3
IS 19667	2.3	2.2		76	1.0		8.6			1.7
ICSR 93024	2.5	1.7		83	1.3		8.3			2.0
ICSR 93024-3	3.7		2	77	2.5	2.7	7.8	4.0		1.8
IS 32811	2.2	2.0		71	1.0		6.7			1.8
GD 47818	2.5	1.7		74	1.7		6.6			2.2
GD 27668	1.7	1.7		73	1.0		6.3			2.8
ICSR 93026	3.3	1.6		71	2.7		5.8			3.2
ICSR 93011	2.7	1.7		74	1.3		5.4			3.0
IS 19669	2.2	1.8		74	1.7		4.5			2.7
Checks										
Sikuani (maize)	1.6	1.8	1	63	3.8	3.0	14.4	2.7		2.9
Sudax (forage hybrid for sorghum check)	2.6	2.2	1	60	2.3	1.7	13.9	2.7	2.3	2.5
Mean	2.0	1.8	2.6	59.5	1.8	2.1	13.8	2.5	1.7	2.1
VAR	0.5	0.0	1.3	261.2	0.6	0.1	43.6	0.7	0.5	0.3
SD	0.7	0.2	1.1	16.2	0.8	0.4	6.6	0.9	0.7	0.6
SE±	0.13	0.04	0.24	2.90	0.14	0.08	1.48	0.15	0.18	0.10
CV(%)	35.1	10.2	42.7	27.2	42.4	17.2	47.7	34.5	41.4	26.8

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1 = green leaf area, 2 = 1-5% of green leaf area reduced, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% of green leaf area reduced.
3. Measured on a 1 to 9 scale, where 1= free of leaf diseases, 2 = 1-5% of leaf area affected, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 40-50%, 8 = 51-75% and 9 = > 75% of leaf area affected.
4. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.

Table 6.5. The effect of Al^{3+} saturation levels on the performance of sorghum lines, Matazul, Colombia, July-December 1997.

Al^{3+} saturation (%)	Early vigor[1]	Days to flowering	Green leaf area[2]	Agronomic score[3]	Head weight[4]	Grain weight[4]
40	1.52b[5]	76.63a	1.55b	1.88^{b}	2.32^{b}	1.71^{b}
60	1.41b	75.77a	1.66b	2.05^{b}	2.61^{z}	1.94^{a}
80	2.13a	73.97b	2.16a	3.25^{a}	1.92^{c}	1.43^{c}
SE±	0.20	0.83	0.07	0.08	0.20	0.15

1. Measured on 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 5 scale, where 1 = maximum green leaf area and 5 = least green leaf area.
3. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.
4, Measured in $t\ ha^{-1}$.
5. Values followed by the same letter within a column do not differ significantly ($P<0.05$)

Source: Reddy and Rangel (2000).

desirability but with a regression coefficient significantly lower than 0 (showing greater sensitivity to acid soil conditions) were ICSVs 102, 112 and 95126, ICSR 143, ICSR 194, IS 18758C-710-3 and IS 30469-C-1518T-3. It must be noted that as expected, the acid soil-tolerant check Real 60 fell under the first group with wide adaptability (regression coefficient 0.571 ± 0.057), and the susceptible check SPRU 94008 fell under the susceptible group (regression coefficient -0.856± 0.0412) with low mean value.

Among the selected B-lines, ICSBs 73, 81, 102, 88004 and 89002, SPMD 94004, SPMD 94019, SPAN 94008, SPHB 94006, SPA_2 94021 and SPA_2 94039 showed wide adaptability. Lines ICSB 94 and SPA_2 94029 were more responsive to the favorable environment. Lines ICSB 93, SPMD 94006 and SPMD 94036 showed high mean and were more tolerant to acid soils.

Among the selected forage lines, IS 31496 was better adapted to the favorable environment and showed high fresh fodder weight across the locations. Sikuani, the maize check, showed high fresh fodder weight and wide adaptability. On the other hand, ICSR 93024 and IS 32811 showed wide adaptability but less fodder weight. Details of the stability parameter estimated for all the groups of lines are given in ICRISAT (1997).

In a back-up breeding program, large grain (ICSP LG) and maintainer (ICSP B) sorghum populations (ms_3 based) were merged and selected alternatively at the CIAT farm under neutral pH, and at Matazul under acid soil conditions. Some of the selections (male fertiles) were advanced through pedigree breeding. Several promising progenies were also selected from the segregating materials of the specific crosses made among the lines selected for acid-soil tolerance and less susceptibility to foliar diseases.

Nearly 200 sorghum hybrids were evaluated at Matazul (60% Al^{3+} and 4.6% organic matter). Three hybrids produced more than 5.0 t ha^{1} grain yield, while the Al^{3+} tolerant check Real 60 yielded 4.01 t ha^{-1}. The outstanding hybrids (Table 6.6) were ICSA 38 x Real 60, ICSA 73 X ICSR 110, ICSA 89002 x Real 60 and SPMD-A 94045 x A 2267-2 (Table 6.6), of which further details are given in ICRISAT (2000). These were less susceptible to leaf diseases, greener at maturity, and also taller than the check Real 60. Biomass in these is expected to be higher than in Real 60. Hybrids therefore hold promise for improving the sustainability of acid Savannas.

From 1997 to 1999, about 30 network trial sets each with grain sorghum B-lines (32), grain sorghum R-lines (49) and forage sorghum lines (6) were distributed to national programs. Three trial sets were distributed to private sector seed companies. The best sorghum lines selected from these trials in Honduras were ICSB 93 and SPA_2 94029B among female parents, and ICSR 110, ICSV 95072 and CEM 336/10-1-1 among sorghum R-lines. The best sorghum forage lines selected in Colombia were IS 13868, IS 31868 and ICAR 93024-2.

Pedro Jose Garcia (Venezuela), Paulo Cesar Magalhaes, and Fredolino Santos Giacomini (Brazil) and Jaime Humbeto Bernal, Andres Felipe Rangel Becerra and Luis Alfonso Rodriguez Gonzalez (Colombia) were provided training at ICRISAT during 1997-98.

A workshop was conducted at Corporacion Colombiana de Investigation Agropecuaria (CORPOICA), La Libertad, Colombia, from 24-26 Nov 1998, with 25 scientists from Brazil, Colombia, Honduras and Venezuela, ICRISAT and CIAT participating. The workshop reviewed the IADB-funded project's research and identified future needs. These included extending research to other zones (such as fertile neutral areas and drought-prone areas) in addition to the acid Savanna soils, enhancing research on sorghum by 70%), taking up nutrient uptake efficiency studies and exploring the use of sorghum grain as feed (Reddy et al. 2000a).

Table 6.6. Performance of selected sorghum preliminary hybrids at Matazul, Colombia, July-December, 1999.

Genotype	Seedling vigor score[1]	Plant stand	Plant height (m)	Days to 50% flowering	Green leaf area score[2]	Agronomic desirability score[3]	Leaf disease score[4]	Converse bird damage[5]	Grain yield t ha^{-1})[6]
ICSA 38 x Real 60	1.3	32	2.5	65	5.0	1.0	4.3	0.93	5.63
ICSA73x ICSR 110	1.5	36	2.0	68	4.0	1.0	3.0	0.89	5.25
ICSA 89002 x Real 60	1.0	40	2.3	61	5.3	1.0	5.0	0.88	5.10
SPMD-A 94045 x A 2267-2	1.7	45	2.1	68	4.0	1.0	2.3	0.91	5.00
SPHB-A 94006 x CEM 328/3-3-1-1	1.0	37	2.2	65	4.3	1.0	2.3	0.76	4.93
SPMD-A 94045 xICSV 93042	2.3	31	1.5	68	3.7	1.0	2.0	0.89	4.87
ICSA 89 x ICSR 194	1.7	39	2.1	64	6.3	1.0	3.3	0.93	4.80
ICSA 73 x ICSR 143	1.7	42	1.9	68	3.7	1.0	2.7	0.92	4.73
SPMD-A 94045 x ICSR 91012	1.3	47	1.6	68	4.0	1.0	1.3	0.92	4.73
ICSA 73 x ICSV 93042	1.3	43	2.3	71	4.7	1.0	2.0	0.90	4.67
ICSA 89002 x ICSR 110	1.3	25	1.9	65	4.0	1.0	3.0	0.91	4.57
SPHB-A 94006 x Icaravan	1.0	47	2.4	70	5.3	1.0	4.3	0.96	4.57
ICSA 94 x ICSR 194	1.7	22	2.3	67	4.0	1.0	3.0	0.92	4.40
ICSA 89002 x ICSR 102	1.3	25	1.8	67	8.0	1.0	3.3	0.87	4.40
SPMD-A 94006 x ICSR 93033	1.3	34	1.6	62	5.0	1.0	2.7	0.89	4.37
ICSA 73 x ICSR 194	1.3	37	2.2	76	5.0	1.0	2.7	0.95	4.33
SPMD-A 94045 x ICSR 93033	1.3	43	1.6	67	2.7	1.0	1.7	0.82	4.33
ICSA 73 x ICSR 102	1.3	37	1.9	58	2.7	1.0	2.3	0.91	4.20
SPA_2 94021 x Icaravan	1.0	39	1.9	63	6.0	1.0	4.7	0.95	4.13
ICSA 89002 x ICSR 93033	1.0	37	1.7	66	7.3	1.0	3.3	0.88	3.95
SPMD-A 94036 x ICSR 102	1.3	24	1.6	62	6.0	1.0	2.3	0.87	3.87
SPHB-A 94006 x A 2267-2	1.0	45	2.2	62	3.3	1.3	1.7	0.85	3.87
ICSA 89 x ICSR 143	1.0	42	2.0	65	4.0	1.3	2.3	0.87	3.80
ICSA 73 x IS 30469-1187-2	2.0	27	2.7	73	6.7	1.3	2.3	0.79	3.70
SPMD-A 94019 x ICSR 93033	2.7	26	1.5	68	3.3	1.0	2.0	0.89	3.67
SPMD-A 94019 x ICSR 102	2.7	27	1.4	70	5.0	1.0	2.3	0.88	3.60
SPMD-A 94036 x ICSR 143	2.7	21	1.6	69	3.0	1.0	2.3	0.90	3.20
SPMD-A 94004 x ICSR 194	2.7	14	2.0	69	4.7	1.3	2.7	0.92	2.87
Checks									
Real 60	1.33	30.0	1.77	72.0	6.00	1.00	5.33	1.00	4.03
SPRU 94008	3.67	28.7	0.93	67.7	5.33	4.00	2.00	0.89	1.50
Mean	1.60	32.78	1.93	66.3	4.64	1.13	2.89	0.88	3.95
80 (±)	0.62	10.03	0.35	4.63	1.42	0.48	1.14	0.07	0.81
CV(%)	33.9	18.9	8.0	6.6	25.2	19.9	20.9	9.1	16.1

1. Measured on a 1 to 5 scale, where 1 = most vigorous and 5 = least vigorous.
2. Measured on a 1 to 9 scale, where 1 = maximum green leaf area and 9 = least green leaf area.
3. Measured on a 1 to 5 scale, where 1 = most desirable and 5 = least desirable.
4. Measured on a 1 to 9 scale, where 1 = free of leaf diseases, 2 = 1-5% of leaf area affected, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 41-50%, 8 = 51-75% and 9 = > 75% of leaf area affected.
5. Converse of bird damage in fractions.
6. Grain production at 15% moisture.

Source: ICRISAT (2000).

6.4. Implications

The acid soil locations (Quilichao, Carimagua, La Libertad and Matazul) varied in their organic content (Table 6.1). The absence of significant G x Al^{3+} interaction variances for important economic traits meant that genotypes bred under neutral/high-fertility conditions would also do well under acid soil conditions, thereby doing away with the need for a specific breeding program for acid soils. However, the following reasons outweigh this interpretation.

- In a set of varied genotypes, G x E interactions were significant for agronomic desirability, which to a large extent reflects grain weight. G x E interaction was also significant for this trait.
- The Al^{3+} levels study involved selected lines with narrow variability, and did not include lines that performed well under less severe acid soil conditions.
- Decrease in yield levels (26%) due to increase in soil acidity (from 60 to 80% Al^{3+} saturation) was far greater than the increase in head and grain weight (12% from 40 to 60% Al^{3+} level).

Therefore, breeding programs should aim at specific adaptations.

The most standard effect of Al^{3+} toxicity is the inhibition of root growth (Delhaize and Ryan 1995), usually reflected in shoot growth and grain or forage yield. Delhaize and Ryan (1995) and Kochian (1995) reviewed the literature on the mechanisms of resistance. These included Al^{3+} interaction with the root cell wall; Al^{3+} disruption of plasma membrane and plasma membrane transport processes; and Al^{3+} interaction with such synplasmic constituents as calmodulin, a Ca^{2+} binary protein.

Resistance mechanisms differ depending on Al^{3+} levels (or environments); thus genotypes with varied selection histories might vary in their resistance mechanisms. It is likely that ICRISAT-bred lines and INTSORMIL-selected lines (such as Real 60) have different resistance mechanisms. Malate and phosphate exudates contribute to Al^{3+} tolerance, as in wheat that is controlled by dominant alleles in at least two loci (Pellet et al. 1996). There is a need to study resistance mechanisms and their genetics in selected sorghum lines.

6.5. References

Delhaize E and Ryan PR. 1995. Aluminum toxicity and tolerance in plants. Plant Physiology 107:315-321.

Eberhart SA and Russell WL. 1966. Stability parameters for comparing varieties. Crop Science 6:36-40.

Flores CF, Clark RB and Gourley LM. 1988. Growth and yield trials of sorghum grown on acid-soil at varied aluminium saturation. Pages 76-79 *in* International Sorghum and Millet Program (INTSORMIL) Annual Report 1988. Lincoln, Nebraska, USA: INTSORMIL.

Gourley LM. 1991. Breeding sorghum for tolerance to infertile acid soils. Pages 91-98 *in* International Sorghum and Pearl Millet Program (INTSORMIL) Annual Report 1991. Lincoln, Nebraska, USA: INTSORMIL.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1997. A research and network strategy for sustainable sorghum production systems for Latin America. Third season report, September 1996 to January 1997. Patancheru 502 324, Andhra Pradesh, India: ICRISAT. (Limited distribution.)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 2000. A research and network strategy for sustainable sorghum production systems for Latin America. Ninth season report, January to June 2000. Patancheru 502 324, Andhra Pradesh, India: ICRISAT. (Limited distribution.)

Kochian LV. 1995. Cellular mechanisms of aluminum toxicity and resistance in plants. Annual Review of Plant Physiology and Molecular Biology 46:237-260.

Paul CL. 1993. Sorghum in Latin America. Pages 63-91 *in* Sorghum and millets commodity and research environments (Byth DE, ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Pellet DM, Papernik LA and Kochian LV. 1996. Multiple aluminum-resistance mechanisms in wheat roles and root apical phosphate and malate exudation. Plant Physiology 112:591-597.

Reddy Belum VS, Rangel AF and Iglesias C. 1998. Latin American sorghum project: Some results. Pages 70-79 *in* Proceedings of the First International Symposium on Sorghum, 27-30 May 1998, Rio Bravo, Tamaulipas, Mexico. Cali, Colombia: Centro International de Agricultura Tropical.

Reddy Belum VS and Rangel AF. 2000. Genotype (G) and G X Environment (E) interactions in sorghum in acid soils of the oriental llanos of Colombia. Pages 46-51 *in* A research and network strategy for sustainable sorghum and pearl millet production systems for Latin America: Proceedings of a workshop, 24-26 Nov 1998, Villavicencio, Meta, Colombia (Reddy, Belum VS, Ceballos H and Ortiz R, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, and Cali, Colombia: Centro Internacional de Agricultura Tropical.

Reddy Belum VS, Ceballos H and Ortiz R. (eds.) 2000a. A research and network strategy for sustainable sorghum and pearl millet production systems for Latin America: Proceedings of a workshop, 24-26 Nov 1998, Villavicencio, Meta, Columbia. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, and Cali, Colombia: Centro Internacional de Agricultura Tropical. 86 pp.

Reddy Belum VS, Rangel AF, Iglesias C and Bernal J. 2000b. Evaluation of sorghum and pearl millet for acid-soil tolerance in the oriental llanos of Colombia. Pages 37-45 *in* A research and network strategy for sustainable sorghum and pearl millet production systems for Latin America: proceedings of a workshop, 24-26 Nov 1998, Villavicencio, Meta, Colombia (Reddy Belum VS, Ceballos H and Ortiz R, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, and Cali, Colombia: Centro Internacional de Agricultura Tropical.

PART III: Technologies, Technology Exchange and Technology Adoption

Research Partnership and Technology Exchange 7

BVS Reddy, AB Obilana, CLL Gowda, B Ramaiah and I Akintayo

Research Partnership and Technology Exchange

BVS Redely[1], AB Obilana[2], CLL Gowda[1], B Ramaiah[1] and I Akintayo[3]

7.1. Introduction

Sorghum is cultivated over wide geographic areas in the Americas, Africa and Asia. Though ICRISAT's research centers are located at Patancheru in Asia and Bulawayo, Nairobi, Bamako and Niamey in Africa, and there are several special programs at Cali, Colombia in Latin America and with ASARECA to cater to Eastern and Central Africa, it is difficult to serve several areas that need specific agroecological zonal adaptations to varying agroclimates and cropping systems. Research collaborations and partnerships among national, regional and international programs are the best means of meeting developmental needs. Research partnerships are crucial to successful technology exchange. Partnerships could be formal or informal and involve scientists, extension staff and farmers in public institutions, private sector organizations and NGOs. Collaboration and partnership among stakeholders avoid duplication of efforts and bring together comparative advantages to address and solve priority production constraints at relatively low cost. Such associations encourage interaction and exchange of information, knowledge and technologies. This chapter documents ICRISAT's partnership with public sector institutions, private sector organizations, NGOs and other stakeholders.

7.2. Collaboration and Partnerships

ICRISAT was able to develop and maintain stable, dynamic and broad-based partnerships among different stakeholders. The partnership mode followed at ICRISAT for research and technology exchange was a combination of both formal and informal links depending on the need and situation. ICRISAT has collaboration and partnership with:

- Nodal or apex agricultural research institutions or councils (such as ICAR in India)
- Regional bodies or forums (SADC)
- Regional networks (WCASRN and CLAN)
- Advanced Research Institutions (CIRAD and INTSORMIL)
- Bilateral or multilateral ties with NARS.

ICRISAT has tie-ups in the following research areas:

- ICAR: Improvement of seed parents for grain mold, shoot fly and stem borer resistance through formal, inter-institutional projects.
- SADC: SMIP/ICRISAT has a formal regional collaboration with several Southern African countries to improve sorghum for the region.

1 International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
2 International Crops Research Institute for the Semi-Arid Tropics, PO Box 39063, Nairobi, Kenya.
3 International Crops Research Institute for the Semi-Arid Tropics, BP 320, Bamako, Mali.

Reddy BVS, Obilana AB, Gowda CLL, Ramaiah B and Akintayo I. 2004. Research partnership and technology exchange. Pages 153-178 *in* Sorghum genetic enhancement: Research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.J. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

- WCASRN and CLAN: Breeding nurseries at Cinzana, Longorola, Farako Ba, Samaru, Minjibar, N'Dali and Maradi in West and Central Africa through WCASRN; regional and national trials conducted by various NARS in Asia; and exchange of breeding materials in various international and regional nurseries/trials through CLAN. The objective is to identify materials for local adaptation.
- CIRAD and INTSORMIL: Collaborative agreement with ICRISAT in Mali with the goal of improving sorghum for the Sudano-Guinean zone (Production Systems 15 and 16). CIRAD scientists based at Montpellier, France, are engaged in basic research on the molecular basis of head bug resistance and the role of temperature/photoperiod in adaptation and grain quality. All ICRISAT's regional programs collaborate and exchange seed and information with INTSORMIL and advanced institutions in developed countries.
- ICRISAT is engaged with Purdue University, Texas A&M University, etc, in the sphere of biotechnology.

7.3. Developmental Activities

Breeding materials developed at various ICRISAT locations are shared with national programs and farmers through Scientists' field days, Farmers' field days, on-farm testing and participatory varietal selection (PVS) and participatory plant breeding (PPB).

Sorghum scientists' field days provide an opportunity for national breeders to evaluate and select materials developed at ICRISAT locations, and to get feedback on the relevance of ICRISAT's research to NARS. Field demonstrations of elite materials are organized to display the range of high-yielding varieties available to farmers. On-farm testing of promising materials developed by the centers provides an opportunity to interact with farmers and identify the strengths and weaknesses of the materials that will help in modifying breeding programs. PVS and PPB have been used more recently to involve farmers in the early stages of breeding so that the material selected meets their needs. In both India and a few countries in Africa, breeder seeds of ICRISAT-derived varieties and parents of hybrids are multiplied by ICRISAT to meet national demand.

7.4. International Trials and Nurseries

International trials and nurseries have been major vehicles for channelling breeding material developed by ICRISAT to scientists in national programs at different locations. Sets of materials in the form of international trials and nurseries have been distributed to cooperators around the world based on requests. The trials and nurseries contain either lines bred for specific traits/and or adaptation, or germplasm lines screened for a specific trait. The objectives of trials and nurseries are to:

- Make value-added materials available to partners
- Provide collaborators with a mechanism of exchange of enhanced germplasm
- Obtain feedback on the performance or value of the materials to their programs.

The trials or nurseries can be grouped under:

- Yield and adaptation trials
  - Varieties and hybrids
  - Populations and converted lines
  - Early generation lines

More than 150 trials and nurseries have been organized from all ICRISAT centers since 1976. Details of the types of nurseries or trials (Fig. 7.1)for cooperators, collated from ICRISAT's Annual Reports, are summarized in Table 7.1.

- Trait-based nurseries of seed parents and/or restorers
  - Grain and food quality
  - Disease resistance
  - Pest resistance
  - *Striga* resistance
  - Drought tolerance (stay-green lines)
  - Forage and sweet sorghums.

ICRISAT-Patancheru-based Nurseries and Trials. Nearly 157 trials or nurseries were organized by ICRISAT from 1976 to 1999, mostly targeting grain yield and adaptation (62) followed by resistance to diseases (35), pests (33), *Striga* (5) or other traits such as large grain (5), earliness (5), terminal drought (2), drought resistance (1), milo/non-milo (2), food quality (1) and sweet stalk (1) apart from five other trials (Fig. 7.1). They were mostly targeted globally. International Sorghum Preliminary Yield Trials (ISPYT) consisting of S_1/S_2 progenies derived from populations were initiated in 1977 for yield and adaptation, followed by other trials such as the Sorghum Elite Progeny Observation Nursery (SEPON) which consisted of pure lines derived from grain quality progenies. SEPON had considerable impact on breeding programs in many countries. Up to 1982, scientists at ICRISAT-Patancheru (and other ICRISAT centers) used to organize the trials at the project level. The projects were mostly theme based. Since collaborators complained of overburdening with too many materials, the international trials - one for hybrids and another for varieties - were organized by pooling the best materials across projects in the sorghum improvement program from 1982. From 1988 to 1995, trials for hybrids and varieties were clubbed into the International Sorghum Variety and Hybrid Adaptation Trial (ISVHAT). In the meantime, recognizing specific regional demands, two trials - the Asian Regional Sorghum Varietal Adaptation Trial (ARSVAT) and the Asian Regional Sorghum Hybrids Adaptation Trial (ARSHAT) - were organized exclusively for Asia.

From 1976 to 1999, several international sorghum nurseries (14) were organized, mainly comprising lines identified as resistant to grain mold (ISGMN), leaf diseases (ISLDN), charcoal rot (ISCRN) and downy mildew (ISDMN). An International Anthracnose Virulence Nursery initiated in 1980 continued up to 1998. Various international nurseries comprising lines resistant to shoot fly (ISSFN), stem borer (ISSBN) and midge (ISMN) were organized; so were those for resistance to *Striga* or to assess food quality.

All these nurseries and trials were provided to cooperators in response to specific requests. After 1993, there was a major shift from routine trials to demand-driven ones. Consequently, several trait-based nurseries comprising B-lines or R-lines were organized. For example, the Sorghum Durra Large grain Red B-lines Observation Nursery (SDLBON) contains red, bold grain B-lines and R-lines; the Early Generation Bold grain Observation Nursery (EGBON) contains early generation B-lines; the Sorghum Leaf Blight B-lines Observation Nursery (SLBBON) consisted of leaf blight resistant B-lines, etc. The availability of these nurseries was announced in advance, and cooperators were sent nurseries based on specific requests. These B-line or R-line nurseries had profound impact on national breeding programs. For instance, many of the shoot fly-, leaf blight-and anthracnose-resistant B-lines were utilized either directly or indirectly as parents in the national program.

From 1987 onwards, in addition to ICRISAT-bred lines, national program materials too were included in ISVHAT trials, thus providing a basis for ownership and global exchange of materials and their testing. Some of these materials, such as IRAT 204, CSH 9 and GPR 148, have done well.

ICRISAT-Regional Centers-based Nurseries and Trials. ICRISAT centers based in West Africa (Kano in Nigeria and Ougadougou in Burkina Faso) organized regional network trials consisting of hybrids and varieties for testing within the region, primarily to assess them for grain yield and adaptation. Similarly, variety and hybrid trials were organized by other regional centers in Bulawayo (Zimbabwe) in Southern Africa (SMIP for the SADC region) from 1988 to 1994; in Nairobi (Kenya) for Eastern Africa from 1985 to 1993 and in Mexico City (Mexico) for Mesoamerica from 1987 to 1989. During 1997-99, the IADB-funded project based at CIAT too organized regional nurseries and trials for testing in Brazil, Colombia, Honduras and Venezuela (for details see Chapter 6).

7.5. Exchange of Breeding Material

Based on specific requests, seed samples of various parental lines, restorers, varieties and populations were supplied to cooperators worldwide. A total of 155, 420 seed samples of breeding lines were supplied from ICRISAT-Patancheru to over 102 countries during 1986 to 1999. These included 38 countries in Africa, 34 in Asia, 21 in America and 9 in Europe. Asia tops the list in the receipt of seed material (69%), followed by Africa (21%) and the Americas (9%). Table 7.2 shows the countrywise distribution of seed materials. The countries which received more than 1 % of the seed samples over the years were India (53%), Thailand (2.6%), Pakistan (2.4%), China (2%), Myanmar (1.6%), Indonesia (1.2%) and Iran (1.1%) in Asia; Kenya (5.3%), Sudan (2.7%), Burkina Faso (2.3%), Mali (2.1%), Egypt (1.9%), Nigeria (1.3%) and Zimbabwe (1.2%) in Africa; and Brazil (2.8%), Mexico (2.8%) and Colombia (1.1%) in the Americas.

Types of sorghum seed samples supplied to different countries from ICRISAT-Patancheru during 1986-99 are summarized in Table 7.3. Among the different types of seed samples supplied, partially converted lines were the highest (17.9% of the total supply) followed by varieties (9.8%), pest-resistant lines (9.5%), populations (8.0%), restorers (7.5%) and maintainer lines *(6.6%).* Table 7.3. reveals that the demand for intermediate products (populations, male sterile lines, maintainers, restorers, etc) has increased over time compared to that for finished products (varieties and hybrids).

The number and types of seed samples supplied to different public research institutes and private seed companies based on requests are listed in Table 7.4. It is evident that the demand for ICRISAT materials from both the public and private sectors in India has increased over time. The demand from public institutions increased from 2105 in 1986 to 4588 in 1999, while that from private seed companies increased from 316 in 1986 to 1376 in 1999. The number of recipients has also increased substantially. It may be mentioned here that multinational private seed companies share their ICRISAT-procured materials among their various branches; hence there is a much wider dissemination of material.

In the Southern African (SADC) and East African (EARCAL and ECARSAM) programs, more than 250, 000 samples of varieties, breeding lines, hybrids and hybrid parents (mainly from

SMIP in SADC) were distributed to NARS, NGOs, collaborators and private seed companies in Zimbabwe and South Africa.

7.6. Participation in AICSIP Trials

AICSIP has been conducting coordinated yield trials at multiple locations since 1972 with a view to identify improved sorghum varieties or hybrids for cultivation in more than one state. ICRISAT-bred varieties/hybrids and those derived from ICRISAT materials by national breeders have been tested in AICSIP trials since 1979-80. Sixty-eight varieties and 74 hybrids were entered into advanced trials directly by ICRISAT and 167 varieties and 74 hybrids developed from ICRISAT materials were entered by national breeders. The names of the varieties and hybrids entered into the AICSIP advanced trials from ICRISAT parent materials are given in Table 7.5. Their number has increased over time and several materials were found promising for rainy-season cultivation.

7.7. Cultivars Released

Several NARS have evaluated hybrids/varieties developed in partnership with ICRISAT in network or regional trials to select for local adaptation. As of December 2002, a total of 194 cultivars (varieties and hybrids) were released for cultivation in 43 countries — 6 in Asia, 27 in Africa, and 10 in the Americas (Table 7.6). The private sector too is marketing several hybrids based on ICRISAT-developed parental materials in India. Details of the names of the cultivars and the countries of their release are given in Table 7.7. Out of the 193 sorghum cultivars released, 110 were in Africa, 50 in Asia and 34 were in the Americas. Among the 50 cultivars released in Asia, 22 were in India.

7.8. Training and Capacity Enhancement of NARS

Capacity building of NARS by providing minimum facilities for research and providing essential supplies and minor equipment has helped to strengthen NARS breeding programs in many countries.

Various training courses, both in-country or at ICRISAT centers, were organized (Tables 7.8, 7.9 and 7.10) to provide basic and practical training in sorghum crop improvement. Individual, tailor-made training was also provided. NARS staff in-service trainees, research fellows, visiting scholars and students were provided facilities for research leading to M.S or Ph.D. degrees.

7.9. Conclusion

Research collaboration, partnerships and developmental activities for the dissemination of sorghum breeding products (mostly finished varieties and hybrids) to national programs, particularly public sector research organizations, through international and/or regional trials and/or nurseries and by directly supplying improved finished materials based on specific request have enhanced NARS capacity in sorghum breeding and had an impact on production and productivity globally.

The last decade has witnessed the private sector playing a key role in making available improved products to farmers in several countries in Asia and Latin America, while such an exercise has yet to take off in Africa. However, several improved products did not reach farmers in many countries due to lack of linkages among farmers, researchers, industries (alternative uses) and market channels. It may also be noted that of late, there has been a growing awareness about health foods in both developing and developed countries.

New innovative partnerships are essential with both public and private sector organizations, and partner involvement right from the early stages of research for development and extension. Issues related to the development of alternative uses of sorghum (apart from food use), growing awareness about health foods and micro-nutrients, building coalitions/forums amongst farmers, industries, researchers and market channels for the effective uptake of improved products by farmers and consumers in order to enhance impact in improving their livelihoods are required.

7.10. References

ICRISAT Seed Distribution Registers.

ICRISAT Annual reports.

AICSIP Annual reports.

ICRISAT Sorghum Varieties and Hybrids Database.

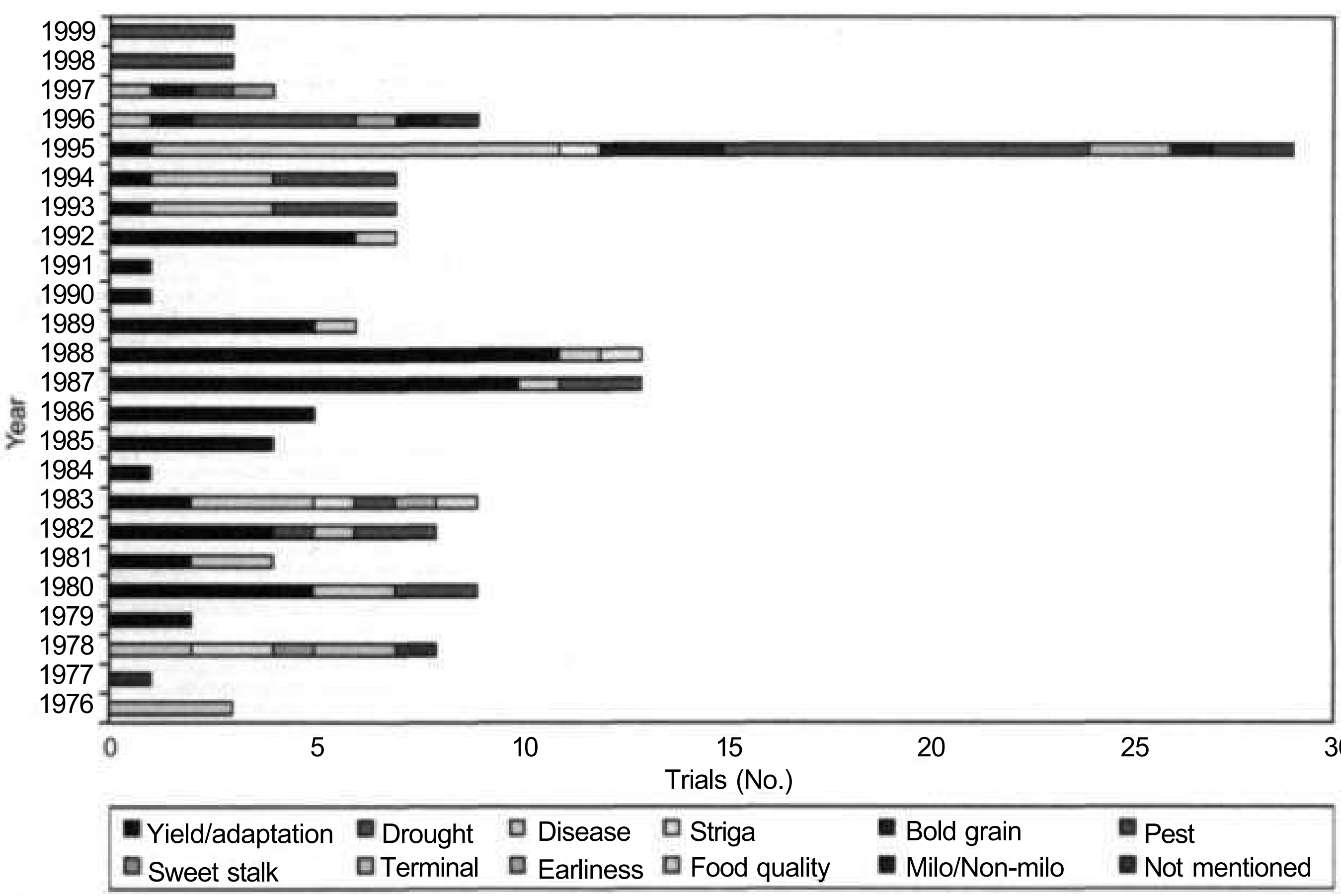


Figure 7.1. Number of international trials conducted by ICRISAT-NARS for different target traits, 1976-99.

Table 7.1. International trials/nurseries distributed from ICRISAT's various centers.

Trial[1]	Year	Origin of trial	Entries	Trials sent	Data received	Top entries/remarks	Target trait
RSAVT-1	88	B	23	4(SA)	4	IS 23586-2	Yield/adaptation
SDAHT	88	B	23	9(SA)	8	SDSH 4	Yield/adaptation
SDEHT	88	B	18	4(SA)	4	SDSH 38	Yield/adaptation
WASHAT[1]	86	BF	36	7(WA)			Yield/adaptation
WASVAT-1	86	BF	20	11 (WA)		ICSV 16-5BF	Yield/adaptation
WASVAT-2	86	BF	20	11 (WA)			Yield/adaptation
WASVAT[1]-E	87	BF	20	10 (WA)			Yield/adaptation
WASVAT-M	87	BF	20	10 (WA)			Yield/adaptation
WASHAT[1]	87	BF	25	15 (WA)	10	ICSH 336	Yield/adaptation
LASDTYT	82	M		7 (MA)		Different lines	Drought
LASEVYT	82	M		7 (MA)		Different lines	Yield/adaptation
MYTLACM	85	M	16	5 (MA)	5	ATX623 x Poor tiller, ICSV 112	Yield/adaptation
CMMHVT	87	M				Sepon 77 Bulk	Yield/adaptation
MASVYT	88	M	21	7 (MA)	7	ICSV-LM-86523	Yield/adaptation
MHYT	88	M	28	11 (MA)	11	ICSH-LM-89504	Yield/adaptation
MASVYT	89	M	25	14 (MA)	9	ICSV-LM-86523	Yield/adaptation
MHYT	89	M	25	14 (MA)	9	ICSH-LM-89504	Yield/adaptation
EVAC	92	M				ICSV-LM-90502	Yield/adaptation
VOLPHIC	92	M	40	3 (MA)	3	B 155, BT x 623, ICSV-LM-90522	Yield/adaptation
EACSSN	85	N	Many	3(EA)	3	(SC 108-3 x CS 3541)-19-1	Yield/adaptation
EALLT	87	N				SAR 24 (Ethiopia)	Yield/adaptation
ISTN	87	N	36	14 (Asia)	14	Different entries in different countries	Yield/adaptation
EESYT-I	88	N	16	9(EA)	2	Seredo	Yield/adaptation
EESYT[1]-L	88	N	25	14 (EA)	2	ICSV 112	Yield/adaptation
EESYT-I	89	N	16	7(EA)	7	IS 9302 and Seredo	Yield/adaptation
EESYT-L	89	N	25	14 (EA)	12	ICSVs 112and335	Yield/adaptation
EPSYT-1	92	N	49	5(EA)	3	PGRC/E#64420	Yield/adaptation
EPSYT-2	92	N	49	13 (EA)	6	3227	Yield/adaptation
EPSYT-3	92	N	36	9(EA)	4	Cyatanobe	Yield/adaptation
WASDRN	88	Ng	36	6(WA)	6	84S82	Disease
WASSN	88	Ng	11	6(WA)	3	IS 9830, ICSV 1007 BF	*Striga*
WARVHAT[1]	88	Ng	20	10 (WA)	10	Naga white, ICSV 210 IN	Yield/adaptation
WASHAT	88	Ng	20	7(WA)	7	ICSH 507	Yield/adaptation
WASVAT	88	Ng	20	10 (WA)	10	ICSV 1063 BF	Yield/adaptation
SDLBON	95	P	Variable	24 (global)	10		Bold grain
SDLRON	95	P	Variable	30 (global)	8		Bold grain
SDRRON	95	P	Variable	16 (global)	4		Bold grain
SDLRON	96	P	212	5 (India)			Bold grain
SDLRON	97	P	20	8 (global)			Bold grain
ISDMN	76	P	0	3 (global)	3	Two are free from mold	Disease
ISGMN	76	P	50	12 (global)	6	E 35-1	Disease
ISLDN	76	P	28	9 (global)	4	QL-3, SC 120-14	Disease
ISCRN	78	P	30	7 (global)	7	(SC 108-4-8 x CSV 4)-64	Disease
ISLDN	78	P	23	12 (global)	12	IS 7254	Disease
ISGMN	80	P	20	8 (global)	7	E 35-1, IS 14332, IS 2328	Disease
ISLDN	80	P	23	6 (global)	6	E 35-1, IS 115	Disease
ISDMN	81	P		12 (global)	5	QL-3, QL-3-2-7	Disease

...continued

Table 7.1. *Continued*

Trial	Year	Origin of trial	Entries	Trials sent	Data received	Top entries/remarks	Target trait
ISLDN	81	P		9 (global)		E 35-1, IS 8283	Disease
ISLDN	82	P	28	17 (global)		ISs 115, 8307	Disease
ISDMN	83	P	19	20 (global)	7	QL-3, NANDYAL-DMRS-ICHA, IS 3442	Disease
ISGMN	83	P	27	17 (global)	8	IS 14375, IS 14384	Disease
ISLDN	83	P	23	9 (global)	9	E 35-1, SPV 351	Disease
ISAVN	92	P	15	16 (global)	12	IS 18758, SC414-12E	Disease
SANRON	93	P	20	16 (global)			Disease
SLBRON	93	P	21	16 (global)			Disease
SRURON	93	P	7	14 (global)			Disease
SANRON	94	P	18	8 (global)			Disease
SLBRON	94	P	19	9 (global)			Disease
SRURON	94	P	5	5 (global)			Disease
ISRBGMN	95	P	25	23 (global)	5		Disease
ISWBGMN	95	P	17	28 (global)	7		Disease
SANBON	95	P	Variable	27 (global)	8		Disease
SANRON	95	P	18	2(SA)	1		Disease
SDMBON	95	P	Variable	11 (global)	4		Disease
SGMBON	95	P	Variable	28 (global)			Disease
SGMRON	95	P	Variable	56 (global)			Disease
SLBBON	95	P	Variable	25 (global)	8		Disease
SLBRON	95	P	30	2(SA)	1		Disease
SRUBON	95	P	Variable	2 (global)	2		Disease
SRURON	95	P	20	5 (global)	2		Disease
SGMRON	96	P	Variable	19 (global)			Disease
SGMRON	97	P	Variable	2 (Asia)			Disease
ISAVN	87/89	P	17	7 (global)	7	A 2267-2, IS 8283	Disease
SEGBON	95	P	Variable	32 (global)	10		Early
SEGRON	95	P	Variable	9 (global)			Early
SEGRON	96	P	30	1 (India)			Early
SEGRON	97	P	Variable	4 (global)			Early
ISFQT	83	P	12	6 (global)	2		Food quality
SA_1 and A_2RON	95	P	31	32 (global)	4		Milo/non-milo
SA_1andA_2BON	96	P	198	5 (India)			Milo/non-milo
ISMN	80	P	13	12 (global)	12	IS 2816, AF 28, DJ 6514	Pest
ISSFN	80	P	20	12 (global)	5	IS-2162, IS 2263	Pest
ISSBN	82	P				PB 8294, PB 8258	Pest
ISSFN	82	P	15	25 (India)		PS 14093, PS 14413	Pest
ISSFN	83	P	23	20 (global)	11	IS 2146, IS 5470	Pest
ISSBN	87	P	25	5(SA)	2	IS 4776	Pest
ISSFN	87	P		3(SA)	3	PS 28062	Pest
SMRON	93	P	25	17 (global)			Pest
SSBRON	93	P	25	21 (global)			Pest
SSFRON	93	P	25	19 (global)			Pest
SMRON	94	P	20	5 (global)			Pest
SSBRON	94	P	19	7 (global)			Pest
SSFRON	94	P	19	7 (global)			Pest
ISSBN	95	P	20	33 (global)	7		Pest

...continued

Table 7.1. *Continued*

Trial	Year	Origin of trial	Entries	Trials sent	Data received	Top entries/remarks	Target trait
ISSFN	95	P	36	28 (global)	7		Pest
ISSPSFN	95	P	25	39 (global)	9		Pest
SMBON	95	P	Variable	14 (global)	3		Pest
SMRON	95	P	Variable	10 (global)	1		Pest
SSBBON	95	P	35	2 (global)			Pest
SSBRON	95	P	20	33 (global)			Pest
SSFBON	95	P	Variable	33 (global)	10		Pest
SSFRON	95	P	Variable	68 (global)			Pest
SHBRON	96	P	20	5 (India)			Pest
SMRON	96	P	56	5 (global)			Pest
SSBRON	96	P	Variable	2 (Asia)			Pest
SSFRON	96	P	Variable	19 (Asia)			Pest
SMRON	97	P	20	1 (Indonesia)			Pest
ISRN-1	78	P	59	10 (global)	8	SRN4841.N13	*Striga*
ISRN-2	78	P					*Striga*
ISSN	83	P	7	(WA)		ICSV 1007-HV	*Striga*
SSBON	95	P	Variable	10 (global)	2		*Striga*
SSSBON	95	P	Variable	2 (global)			
ISTDN	95	P	22	15 (global)	5		
ISTDN	96	P	22	4 (global)			
ISPYT-1	77	P	56	18 (global)	8	FLR-53	
ISPYT-1	78	P	30	28 (global)	17	Diallel-pop-7	
ISPYT-2	78	P	60	28 (global)	20	Ind-syn-1253	Sweet stalk
SEPON	78	P	46	21 (global)	18	E#15and17	Terminal drought
ISPYT-1	79	P	30	38 (global)	16	FLR-1379-1	Terminal drought
ISPYT-2	79	P	60	38 (global)	15	(FLR141 xCS3541)-2-1-5	Yield/adaptation
SEPON	79	P	60	32 (global)	14	(SC 108-3 xCS3541)-88	Yield/adaptation
ISPYT-1	80	P	20	46 (global)	21	Ind-syn-323-1-3	Yield/adaptation
ISPYT-2	80	P	43	46 (global)	16	E 35-1 x RS/B-394-1-1-2	Yield/adaptation
SEPON-E	80	P	39	40 (global)	10	(SC 108 xCS 3541) xSPV 386	Yield/adaptation
SEPON-L	80	P	39	40 (global)	10	(SC 108 xCS 3541) xSPV 386	Yield/adaptation
SEPON-M	80	P	60	40 (global)	10	(SC 108 xCS 3541) xSPV 386	Yield/adaptation
	81	P	24	37 (global)	16	A 6259, A 6298	Yield/adaptation
	81	P	48	50 (global)	20	M 36197, M 36168	Yield/adaptation
	82	P	23	30 (global)		ICSHs 110,120	Yield/adaptation
	82	P	24	37 (global)	16	A 6149	Yield/adaptation
	82	P	23	47 (global)		ICSVs 110,111	Yield/adaptation
	83	P	24	25 (global)	12	ICSH 110-IN	Yield/adaptation
	83	P	24	50 (global)	16	ICSV 120-IN	Yield/adaptation
	84	P	40	(global)	12	ICSVs 112,162	Yield/adaptation
	85	P	25	40 (global)	22	ICSHs 109,159	Yield/adaptation
	85	P	25	77 (global)	32	ICSVs 112,110	Yield/adaptation
	86	P	25	86 (Asia)	12	ICSH 110	Yield/adaptation
	86	P	25	86 (Asia)	14	ICSV 219	Yield/adaptation
	87	P	20	8 (India)	8	ICSH 281	Yield/adaptation
	87	P	20	8 (outside India)	8	ICSH 110	Yield/adaptation
	87	P	22	9 (India)	9	ICSV 112	Yield/adaptation

...continued

Table 7.1. *Continued*

Trial	Year	Origin of trial	Entries	Trials sent	Data received	Top entries/remarks	Target trait
	87	P	22	8 (outside India)	8	ICSV 381	Yield/adaptation
	88	P	20	20 (global)	8	ICSH 310, ICSV 233	Yield/adaptation
	89	P	36	37 (global)	24	ICSH 566, ICSH 88058	Yield/adaptation
	90	P	25	48 (global))	20	ICSH 566	Yield/adaptation
	91	P	26	57 (global)	23	ICSH 871001	Yield/adaptation
	92	P	26	47 (global)	29	ICSH 871001	Yield/adaptation
	93	P	26	35 (global)	27	ICSV 112, ICSH 110, ICSH 89123	Yield/adaptation
	94	P	27	34 (global)	10	ICSH 90061	Yield/adaptation
	95	P	30	30 (global)	-	-	Yield/adaptation
Shoot fly Nursery	98	748	748	3 (India)	3	-	Shootfly screening
Shoot fly Nursery	99	1237	1237	3 (India)	3	-	Shootfly screening

1= National program materials are also included, B = Bulawayo, Zimbabwe; BF = Burkina Faso, Western Africa; EA = Eastern Africa, M = Mexico, Central America; MA = Meso America; N = Nairobi, Kenya; Ng = Nigeria, Western Africa; P = Patancheru, India; and SA = Southern Africa.

RSAVT-1- Regional Sorghum Advanced Varietal Trial; SDAHT- SADCC Advanced Hybrids Trials; SDEHT-SADCC Elite Hybrids Trials; WASHAT-West African Sorghum Hybrids Adaptation Trial; WASVAT-1,2- West African Sorghum Varieties Trial (E=Early; M=Medium); LASDTYT-Latin American Sorghum Drought Tolerant Yield Trial; LAEVSYT- Latin American Sorghum Elite Variety Yield Trial; MYTLACM -Multilocational Yield Trial for the Lowland Areas of Central America; CMMHYT - Central American and Mexico Multilocational Hybrid and Variety Trial; MASVYT -Meso American Sorghum Variety Yield Trial; MHYT - Mesoamerican Hybrid Yield trial; EVAC - CLAIS Advanced Variety Trial; VOLPHIC - CLAIS Hybrid Parental Lines Observation Nursery; EACSSN -East African Cooperative Sorghum Screening Nursery; EALLT - EARSAM Lowland Yield Trial; ISTN - International Sorghum Trial Nurseries; EESYT - 1 - EARSAM Elite Sorghum Yield Trial (L = Late); EPSYT -1,2 ,3 - Elite Progenies Sorghum Yield Trial; WASDRN - West African Sorghum Disease Resistance Nursery; WASSN - West African Sorghum Striga Nursery; WARVHAT - West African Regional Varieties and Hybrids Adaptation Trial; WASHAT - West African Sorghum Hybrids Adaptation Trial; WASVAT - West African Sorghum Varieties Adaptation Trial; SDLBON - Sorghum Durra Large grain red B-lines Observation Nursery; SDLRON -Sorghum Durra Large grain red R-lines Observation Nursery; SDRRON - Sorghum Durra Red Grain Restorers Observation Nursery; SDLRON - Sorghum Durra Large Grain Restorers Observation Nursery ; ISDMN - International Sorghum Downy Mildew Nursery, ISGMN - International Sorghum Grain Mold Nursery; ISLDN -International Sorghum Leaf Diseases Nursery; ISCRN - International Sorghum Charcoal Rot Nursery; ISAVN - International Sorghum Anthracnose Virulence Nursery; SANRON - Sorghum Anthracnose R-lines Observation Nursery; SLBRON - Sorghum Leaf Blight R-lines Observation Nursery; SRURON - Sorghum Rust R-lines Observation Nursery; ISRBGMN - International Sorghum Red B-lines Grain Mold Nursery; ISWBGMN - International Sorghum White B-lines Grain Mold Nursery; SANBON - Sorghum Anthracnose B- lines Observation Nursery; SANRON - Sorghum Anthracnose R- lines Observation Nursery, SDMBON - Sorghum Downy Mildew B- lines Observation Nursery ; SGMBON - Sorghum Grain Mold B- lines Observation Nursery; SGMRON - Sorghum Grain Mold R-lines Observation Nursery; SLBBON - Sorghum Leaf Blight B- lines Observation Nursery; SLBRON - Sorghum Leaf Blight R-lines Observation Nursery; SRUBON -Sorghum Rust B-lines Observation Nursery; SRURON - Sorghum Rust R-lines Observation Nursery; ISAVN - International Sorghum Anthracnose Virulence Nursery; SEGBON - Sorghum Early Generation B-lines Observation Nursery; SEGRON - Sorghum Early Generation R-lines Observation Nursery; ISFQT- International Sorghum Fodder Quality Trial; SA1 and A2RON - Sorghum A1 and A2 R-lines Observation Nursery; SA1and A2BON - Sorghum A1 and A2 B-lines Observation Nursery; ISMN - International Sorghum Midge Nursery; ISSFN - International Sorghum Shoot fly Nursery; ISSBN - International Sorghum Stem Borer Nursery; SMRON - Sorghum Midge R-lines Observation Nursery; SSBRON - Sorghum Stem Borer R-lines Observation Nursery; SSFRON - Sorghum Shoot fly R-lines Observation Nursery; ISSPSFN - International Sorghum Short Pest Shoot fly Nursery; SMBON - Sorghum Midge B-line Observation Nursery; SSBBON - Sorghum Stem Borer B-lines Observation Nursery; SSFBON -Sorghum Shoot fly B-lines Observation Nursery; SHBRON - Sorghum Head Bug R-lines Observation Nursery; SMRON - Sorghum Midge R-lines Observation Nursery; ISRN-1,2 - International Striga Resistance Nursery; ISSN - International Sorghum Striga Nursery; SSSBON - Sorghum Sweet Stalk B-lines Observation Nursery; ISTDN - International Sorghum Terminal Drought Nursery; ISPYT-1,2 - International Sorghum Preliminary Yield Trials; SEPON - Sorghum Elite Progeny Observation Nursery (E = Early, L = Late, M = Medium).

Source: ICRISAT Annual Report (various years).

Table 7.2. Sorghum seed samples supplied to various countries from the sorghum breeding unit, ICRISAT, Patancheru, 1986-99.

Region/	Year															% of
country	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total	total
Africa																
Botswana									27						27	0.02
Burkina Faso	1855	1448	44		25	52	56	26							3506	2.26
Burundi	12	14			103	29									158	0.10
Cameroon	133	99	38		37	38	26	38	50	29					488	0.31
Central African Rep.							30								30	0.02
Chad	72	3		6	12		8								101	0.06
Benin		14			12		26								52	0.03
Egypt	106			25	162	38	887	381	407	443	195		157	193	2994	1.93
Ethiopia	17			66	81	488	15	96	216	133		87			1199	0.77
Gambia		3	31		5										39	0.03
Ghana	11	5	19		1	2								25	63	0.04
Granada			24	24											48	0.03
Guinea		36	6		43										85	0.05
Ivory Coast	66	144	38	14											262	0.17
Kenya	482	171	3444	98	706	192	200	315	178	1137	733		625		8281	5.33
Liberia		4													4	0.00
Malawi			3												3	0.00
Mali	575	96	44	492	147	102	114	115		33	724	643	224		3309	2.13
Mauritania		35													35	0.02
Morocco	4		144												148	0.10
Mozambique		24													24	0.02
Niger	33	108	135	70	257	168	26	80		116	62	4		88	1147	0.74
Nigeria	66		145	75			475	50	120	998			25		1954	1.26
Rwanda	30	9	24		41		26	136			204				470	0.30
South Africa								70		45					115	0.07
S. Islands					118										118	0.08
Senegal	16						1								17	0.01
Sierra Leone										26					26	0.02
Somalia	24	48	37		123	49									281	0.18
Sudan	50	46	118	25	300	58	603	537	851	402	21	962	109	37	4119	2.65
Swaziland		14													14	0.01
Tanzania					66										66	0.04
Togo	33	24	19												76	0.05
Uganda								28		400	11				439	0.28
W.Africa					3			5				10			18	0.01
Zaire		246					26								272	0.18
Zambia	186	2				94									282	0.18
Zimbabwe	761	470	42	194	120	76	76	76						44	1859	1.20
Total	4532	3063	4355	1089	2362	1386	2595	1953	1849	3762	1950	1706	1140	387	32129	20.67

...continued

Table 7.2. *Continued*

Region/ country	Year														Total	% of total
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999		
Asia																
Bangladesh			24					10						101	135	0 09
Bhutan	55	10	24									124			213	0 14
Burma	24	225	68	48	54	114	114	130	455	692	14	449	110	42	2539	1 63
China	65	360	731	48	43	91	225	131	102	670	43	557		6	3072	1 98
India	2421	2279	2033	2442	2154	3618	4548	6888	3362	14900	9776	14857	7726	5964	82968	53 38
Indonesia			96	125	141	89	82	410	161	292	120	355		63	1934	1 24
Iran				280	50	508	137	78	224	321	48				1646	1 06
Iraq					25			101				29	21		176	0 11
Japan													16		16	0 01
Jordan			24												24	0 02
Korea						200				980					1180	0 76
Kuwait		3													3	0 00
Laos PDR									26	29					55	0 04
Lebanon													10		10	0 01
Libya	24			25	25	52	52	52							230	0 15
Malaysia			30										18		48	0 03
Maldives			1												1	0 00
Nepal			2		29	60	26	52							169	011
Oman			3	6											9	0 01
Pakistan	346	436	81	127	488	100	102	258	466	1229	21			22	3676	2 37
Philippines	265	194	218	127	135	16	39	1		110	1			12	1118	0 72
Russia														2	2	0 00
Saudi Arabia					50	52	32	52	52	29					267	017
Singapore												2			2	0 00
Sn Lanka	59	24	3							11	8	10			115	0 07
Syria	55				110	23	290	12	133	93					716	0 46
Thailand	139	102	117	75	166	108	375	407	274	1599	198	468	5		4033	2 59
Turkey											26				26	0 02
UAE													2	107	109	0 07
USSR (former)		41				275	212								528	0 34
Vietnam		24	24	30	25	127	26	26	63	659				34	1038	0 67
Yemen		7			132	163	52	76	154	304	50		443		1381	0 89
Zernograd								338			46				384	0 25
Total	3453	3705	3479	3333	3627	5596	6312	9022	5472	21918	10351	16851	8351	6353	107823	69 38

continued

Table 7.2. *Continued*

Region/ country	Year														Total	% of total
	1986	1987	1988)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999		
Americas																
Argentina	123	20	10		20	40		6		29	4	25	275		552	0.36
Beltsiville						2									2	0.00
Bolivia											65	345			410	0.26
Brazil	4008				37	82		26		255					4408	2.84
Colombia					54		290			1163	93		78		1678	1.08
Costa Rica						82									82	0.05
Cuba			12												12	0.01
Denmark	7	6	5											4	22	0.01
Dominican Rep									24		3				27	0.02
Ecuador						26									26	0.02
El Salvador	56										25				81	0.05
Guyana					30										30	0.02
Guatemala	113					38	12	12							175	0.11
Mexico	110	117	294	60	325	3297	38	38						5	4284	2.76
Nebraska								91							91	0.06
Nicaragua	10			100		38		12							160	0.10
Paraguay						26			6						32	0.02
Peru						46	54		91						191	0.12
USA	952	96	99	1	9	201	28	59		39	43				1527	0.98
Venezuela	140	1			36						268	14		6	465	0.30
Virginia						23									23	0.01
Total	**5519**	**240**	**420**	**161**	**511**	**3901**	**422**	**244**	**121**	**1486**	**501**	**384**	**353**	**15**	**14278**	**9.19**
Europe																
Australia	56	49				2	8	15		1	132	4	55		322	0.21
Belgium								42	1						43	0.03
Canada								3				168			171	0.11
France		5				63								2	70	0.05
Germany	1	2				2	11			5	6	3			30	0.02
Italy	100	52		4	44	12	25	8	16	11			4		276	0.18
Switzerland							4					10			14	0.01
UK	19	1		8	1	1	32	43	3		24	7			139	0.09
West Indies		103					12					9			124	0.08
Total	176	212	0	12	45	80	92	111	20	17	162	201	59	2	1189	0.77
Grand total	13680	7220	8254	4595	6545	10963	9421	11330	7462	27183	12964	19142	9903	6757	155419	

Table 7.3. Types of sorghum seed samples supplied from the sorghum breeding unit, ICRISAT, Patancheru, 1986-99.

	Year															
Type of material	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total	% of total
Varieties	1725	1867	875	1046	1196	843	676	1496	1038	1172	1103	1404	468	329	15238	9.80
Hybrids	3080	1956	1245	631	581	801	1298	1153	359	747	143	199	54	20	12267	7.89
Male steriles	354	302	564	588	793	991	1478	1109	456	758	424	846	304	982	9949	6.40
Maintainer lines	266	331	810	610	935	1082	1476	1036	478	767	415	820	299	987	10312	6.63
Restorers	297	146	537	860	923	1534	1833	942	427	1077	686	1462	628	259	11611	7.47
Bulk seed	881	114													995	0.64
Converted lines	141	2				9	7								159	0.10
Disease resistant	369	57	54	44	40	62	216	851	546	1554	1131	1922	471		7317	4.71
Drought resistant	228	4			9	3	4			386	112			4	750	0.48
Populations	634	27	72	14	11	285	519	109	1143	5353	1037	2137	1030	59	12430	8.00
Pest resistant	455	436	91	179	125	108	43	1527	855	2881	1087	2655	584	3712	14738	9.48
Striga resistant	42	81	119	43	24	9	43		5	177	1096	643	3		2285	1.47
Stay-green lines														67	67	0.04
Early generations	7		1387	110	256	126	38	835	249	396	45	1232	498	37	5216	3.36
Partially converted lines	25		65	230		6	10	1449	1530	11325	4035	5430	3736		27841	17.91
Sweet stalk lines					5	42									47	0.03
Tillering lines						7									7	0.00
Others	734	1154	2043	195	1482	4650	1266	291	154	539	1393	336	79	2	14318	9.21
Ethiopian collections	53	25				2									80	0.05
Forage sorghums						25	22	357					1741	298	2443	1.57
Genetic stocks	8	29					1								38	0.02
Landraces	3190	129	392	45	165	378	491	175	222	51	257	56	8	1	5560	3.58
Named cultivars	7	4													11	0.01
Spontaneous collections	1184	556													1740	1.12
Total	13680	7220	8254	4595	6545	10963	9421	11330	7462	27183	12964	19142	9903	6757	155419	

Source: Sorghum Seed Distribution Register, Sorghum Breeding Unit, ICRISAT.

Table 7.4. Sorghum seed samples supplied to various agencies from the sorghum breeding unit, ICRISAT, Patancheru, 1986-99.

	Year															
Agencies	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total	% of total
ICRISAT sister centers																
ICRISAT Outstation segregating material	3620	1871	3889	416	582		461	337	220	606	1498	643	870	32	15045	9.68
ICRISAT Outstation nurseries	60	288		138	96	80				1534	21				2217	1.43
ICRISAT Outstation trials	158		171	498	517	356	406	299	78	144					2627	1.69
NARS (excluding India)																
International Public sector-nurseries	279	530		194	397	222	240	1028	1325	6972	284	997		652	13120	8.44
International Public sector-on request	6218	1028	1372	482	1382	5052	2796	1770	1827	2021	1385	2558	1307		29198	18.79
International Public sector-trials	738	1200	790	350	1400	1434	887	1008	650	806		87			9350	6.02
International Private sector-nurseries				1	17		83			200				109	410	0.26
International Private sector-on request	75	24													99	0.06
International Private sector-trials	111			74											185	0.12
India																
Public-Central Govt.-on request	164	14	185	273	240	326	359	398	157	872	348	365	1263	418	5382	3.46
Public-Central Govt.-nurseries										1038	1188				2226	1.43
Public-Central Govt.-trials									26						26	0.02
Public-State Govt.-on request	1597	1023	453	147	756	1952	957	1685	1125	1268	2435	5066	2905	459	21828	14.04
Public-State Govt.-nurseries	99			25						9283	2333			3711	15451	9.94
Public-State Govt.-trials	245	288	290	25	25	99	26	317		29	124				1468	0.94
Private seed companies-on request	241	657	985	1816	1010	1067	2914	3102	1657	2064	2986	8882	3370	1208	31959	20.56
Private seed companies-nurseries				50	24	40		1123			97				1334	0.86
Private seed companies-trials	55	240	24		50	89	78	78	172	218					1004	0.65
Farmers/ICRISAT Staff	16	55	55	94	46	238	203	270	225	128	260	544	186	127	2357	0.40
NGOs	4	2	40	2	3	8	11	15			5		2	41	133	0.09
Total	13680	7220	8254	4595	6545	10963	9421	11330	7462	27183	12964	19142	9903	6757	155419	

Source: Sorghum Seed Distribution Register, Sorghum Breeding Unit, ICRISAT.

Table 7.5. List of varieties/hybrids entered in the AICSIP advanced trials from ICRISAT parent materials, 1979/80 to 1997/98.

Contributed directly by ICRISAT

Year of first entry	Varieties (SPV)	Hybrids (SPH)
1979/80	SPV 350, 351, 352, 353, 354, 355	
1980/81	SPV 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 422, 423, 424	SPH 183,184,185,186,187, 188,189,190,191
1981/82	SPV 471,472, 473, 475, 476, 494	SPH 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 232, 233, 256, 257
1982/83	SPV 548, 549, 578, 579, 580, 581	SPH 263, 264, 265, 266, 280
1983/84	SPV 615, 616, 617, 641, 642,643,644,645,646	SPH 295, 296, 297, 298, 320, 321, 322
1984/85	SPV 691, 692, 693, 694, 695	SPH 345, 346, 347, 348, 349
1985/86	SPV 752, 753, 754, 755, 756	SPH 361, 362, 363, 364, 365
1986/87	SPV 818, 819, 820, 821	SPH 416, 417, 418
1987/88	SPV 865, 866, 876, 878, 879	SPH 478, 479, 480
1988/89	None	SPH 530, 531, 532, 533
1989/90	None	None
1990/91	SPV 947, 948, 949, 969	SPH 576, 577, 594, 595, 596, 597, 598
1991/92	SPV 1010,1011	SPH 613, 614, 615, 616, 628, 629
1992/93	SPV 1071,1072	SPH 663, 664, 665, 666, 703, 704

Contributed by NARS

Year of first entry	Contributing research stations and varieties (SPVs)	Contributing research stations and hybrids (SPHs)
1985/86	Hyderabad (SPV 746), Pantnagar (SPV 749), Udaipur (SPV 772, 773), Hyderabad (SPV 775, 788, 824)	Parbhani (SPH 334, 392), NRCS (SPH 379)
1986/87	Hyderabad (SPV 825, 829)	Parbhani (SPH 424), Hyderabad (SPH 430)
1987/88	Akola (SPV 859), Parbhani (SPV 860), Hyderabad (SPV 881)	Hyderabad (SPH 488,489,491)
1988/89	Nandyal (SPV 913), Hyderabad (SPV 921)	SPH 536
1989/90	Indore (SPV 938, 939), Palem (SPV 940), Hyderabad (SPV 944, 945, 946, 970, 973, 993), Parbhani (SPV 953, 954, 955, 956, 957, 998,1005)	Parbhani (SPH 543, 544, 545, 547, 562)
1990/91	Udaipur (SPV 1012), Kanpur (SPV 1017), Indore (SPV 1020,1022, 1041,1042,1043,1044), Hyderabad (SPV 1025,1034,1049), Parbhani (SPV 1029,1030,1031,1032,1055), Surat (SPV 1035)	Dharwad (SPH 567), Parbhani (SPH 575, 578)
1991/92	Parbhani (SPV 1079,1080,1081), Hyderabad (SPV 1084)	Parbhani (SPH 610, 619, 620)
1992/93	Indore (SPV 1117,1118,1119), Udaipur (SPV 1126,1127), Bhavanisagar (SPV 1132,1133), Parbhani (SPV 1140,1141, 1142,1143,1144), Rahuri (SPV 1148), Coimbatore (SPV 1150,1153), Hyderabad (SPV 1178,1179)	Hyderabad (SPH 638, 662), Dharwad (SPH 653), Parbhani (SPH 667, 672, 673, 674, 684)
1993/94	Indore (SPV 1185), Udaipur (SPV 1186), Surat (SPV 1191), Parbhani (SPV 1201,1209), CRIDA (SPV 1205,1206), Palem (SPV 1212)	Surat (SPH 720), Hyderabad (SPH 721, 773,774, 775), Parbhani (SPH 727, 729, 778, 779, 780), Akola (SPH 743, 792) Coimbatore (SPH 783)

...continued

Table 7.5. *Continued*

Year of first entry	Contributing research stations and varieties (SPVs)	Contributing research stations and hybrids (SPHs)
1994/95	Kanpur (SPV 1227,1228), Mauranipur (SPV 1229), Parbhani (SPV 1232,1234), Hyderabad (SPV 1235,1236,1237,1238,1244, 1245,1255,1256,1258,1264,1265), Indore (SPV 1251,1252), Udaipur (SPV 1253,1254), CRIDA (SPV 1274,1275)	Hyderabad (SPH 806, 825), Parbhani (SPH 818, 820), Coimbatore (SPH 823), Dharwad (SPH 835, 836)
1995/96	Hyderabad (SPV 1280,1288,1289,1303,1304,1307,1308, 1319,1321), Deesa (SPV 1284), Indore (SPV 1285,1286), Surat (SPV 1292), Palem (SPV 1293,1295), Coimbatore (SPV 1301), Udaipur (SPV 1297)	Akola (SPH 877, 890, 891, 913, 927), Dharwad (SPH 881), Coimbatore (SPH 889), Parbhani (SPH 892, 893, 915, 952), Hyderabad (SPH 954)
1996/97	NRCS (SPV 1325,1326,1327,1338,1339,1340,1351,1378), Indore (SPV 1329,1330), Palem (SPV 1331,1332), Kanpur (SPV 1336,1337,1348), Parbhani (SPV 1333,1334), Surat (SPV 1342,1346), Deesa (SPV 1347), Rahuri (SPV 1352), Udaipur (SPV 1354), Solapur (SPV 1375)	Palem (SPH 971, 972, 973), Coimbatore (SPH 977, 978), NRCS (SPH 999), Rahuri (SPH 1030), Dharwad (SPH 1034), Vikki (SPH 969), HLL (SPH 982)
1997/98	Indore (SPV 1330), Parbhani (SPV 1333,1389), Palem (SPV 1381, 1382,1383), Indore (SPV 1384,1385), Mauranipur (SPV 1388), Hyderabad (SPV 1400,1401,1404,1406,1428), Dharwad (SPV 1403)	Indore (SPH 1047)
1998/99	Indore (SPV 1022,1443,1444), Parbhani (SPV 1333,1389), Palem (SPV 1293,1432,1454,1455), Surat (SPV 1437,1438), Udaipur (SPV 1455), Nandyal (SPV 1453), Hyderabad (SPV 1463)	Akola (SPH 792), Parbhani (SPH 1120,1140)
1999/200C)	Indore (SPV 1022,1477,1478), NRCS (SPV 1155,1422,1463, 1479,1490,1493,1498), Parbhani (SPV 1333,1390,1411, 1474,1475,1495), Surat (SPV 1481,1482,1483,1484), Deesa (SPV 1485,1486), Palem (SPV 1468,1469), Udaipur (SPV 1473,1489), Mauranipur (SPV 1388,1470), Bijapur (SPV 1380), Dharwad (SPV 1476), Coimbatore (SPV 1488)	Akola (SPH 840, SPH 1120), Indore (SPH 960, SPH 1210), NRCS (SPH 1217), Bijapur (SPH 1224), HLL (SPH 1194)
2000/01	Parbhani (SPV 1411,1474,1475,1512,1551), Surat (SPV 1481,1482,1530,1531,1532,1533,1557,1558,1560), NRCS (SPV 1479,1515,1516,1554), Rahuri (SPV 1521,1522, 1523), Indore (SPV 1534,1535,1536), Akola (SPV 1520,1549), TNAU (SPV 1524,1525), Udaipur (SPV 1489,1527), Bijapur (SPV 1380), Nandyal (SPV 1500), Palem (SPV 1513, 1518), Mauranipur (SPV 1528)	NRCS (SPH 1314,1317,1318) Ganga Kaveri (SPH 1282) Monsanto (SPH 1273)
2001/02	Udaipur (SPV 1489,1579,1580), Palem (SPV 1513,1518,1567), Akola (SPV 1549,1581), Parbhani (SPV 1474,1562), Surat (SPV 1481,1532), NRCS (SPV 1155,1597)	Akola (SPH 1120), Mahendra (SPH 1342), Ganga Kaveri (SPH 1375)

Source: AICSIP Report (various years).

Table 7.6. Countries where ICRISAT and NARS sorghum materials using ICRISAT germplasm have been released.

Country	1975-80	1981-85	1986-90	1991-95	1996-00	2001-02	Total
Africa							
Benin	0	0	0	0	1	0	1
Botswana	0	0	0	4	0	0	4
Burkina Faso	1	1	2	1	2	0	7
Burundi	0	0	2	0	0	0	2
Cameroon	0	0	1	0	0	0	1
Chad	0	0	1	0	0	0	1
Ethiopia	4	1	3	0	0	0	8
Eritrea	0	0	0	0	5	0	5
Ghana	0	0	1	0	1	0	2
Ivory Coast	0	0	1	0	1	0	2
Kenya	0	0	1	1	0	3	5
Malawi	0	0	0	4	0	0	2
Mali	0	0	4	6	0	9	17
Mozambique	0	0	2	1	0	0	3
Namibia	0	0	0	0	1	0	1
Niger	0	0	0	2	0	0	2
Nigeria	0	0	0	3	5	0	8
Rwanda	2	0	0	0	0	3	5
Somalia	0	0	0	0	0	3	3
Senegal	1	0	0	0	0	0	1
Sudan	0	1	0	4	1	0	6
Swaziland	0	0	2		0	0	3
Tanzania	0	0	1		1	0	3
Togo	0	0	1		2	0	3
Uganda	1	0	0		0	0	2
Zambia	0	1	5		0	0	7
Zimbabwe	0	1	1		3	0	6
Americas							
Colombia	0	0	0		0	0	3
Costa Rica	0	0	0		0	0	1
Dominican Rep	0	0	0		0	0	1
Equador	0	0	1	0	0	0	1
El Salvador	2	1	2	0	3	0	8
Guatemala	0	1	0	0	0	0	1
Honduras	0	3	0	0	0	0	3
Mexico	2	0	5	3	1	0	11
Nicaragua	0	1	1	0	0	0	2
Panama	0	0	0	1	0	0	1
Paraguay	0	0	0	1	0	0	1
Asia							
China	0	4	1	1	8	0	14
India	1	1	4	9	*	1	22
Myanmar	1	5	0	0	3	0	9
Pakistan	0	0	0	2	0	0	2
Philippines	0	0	0	2	0	0	2
Thailand	0	0	0	0	1	0	1
Total	15	22	42	51	45	19	193

Table 7.7. ICRISAT and NARS sorghum materials released using ICRISAT germplasm.

Origin	Released name	Country	Region	Year
ICSV 111		Benin	W.Africa	1999
SDS 3220	Phofu/Macia	Botswana	S. Africa	1994
IS 3923 (SDS 2583)	Mahube	Botswana	S. Africa	1994
SDSH 48	BSH 1	Botswana	S.Africa	1994
	Mmabaitse (BOT 79)	Botswana	S.Africa	1994
-	IRAT 204	Burkina Faso	W. Africa	1980
IS 18758	E 35-1	Burkina Faso	W. Africa	1983
ICSV 1001 BF	Framida	Burkina Faso	W. Africa	1986
ICSV 1049	ICSV 1049	Burkina Faso	W. Africa	1989
SARIAGO-B	BF 83-48-2-1	Burkina Faso	W. Africa	1992
Sariabo 13		Burkina Faso	W. Africa	2000
Sariabo 14		Burkina Faso	W. Africa	2000
-	5D x 160	Burundi	C. Africa	1989
-	GAMBELLA-1107	Burundi	C.Africa	1990
ICSV 111	S 35	Cameroon	W. Africa	1987
ICSV 111	S 35	Chad	W.Africa	1989
A 3681	Yuan 1-98	China	Asia	1982
A 3872	Yuan 1-28	China	Asia	1982
A 3895	Yuan 1-505	China	Asia	1982
A 6072	Yuan 1-54	China	Asia	1982
SPL 132A	Liao Za 4	China	Asia	1988
$3197A_2$ x Jin Liang 5(D 71278-4 is converted to $3197A_2$)	Jin X A4	China	Asia	1992
-	Liao Za 5	China	Asia	1996
-	Liao Za 6	China	Asia	1996
-	Liao Za 7	China	Asia	1996
	Jin Za 94	China	Asia	1996
5(D 71278-4 is converted to 319 A_2	Jin X A4	China	Asia	1992
MR 741 R-lines used as male parent	Longsi-1	China	Asia	1997
(SPL 132B x TAM 428B) as female parent	Liao Za 10	China	Asia	1997
IC-A line converted to A_2 and used as its female parent	JinZa 12	China	Asia	1997
IC-A line converted to A_2 and used as its female parent	Gile Za 80	China	Asia	1997
A 3895	ICAYANUBA	Colombia	S. America	1992
.	Sorghica PH 302	Colombia	S. America	1992
.	HE 241	Colombia	S. America	
.	Escameka	Costa Rica	C. America	1991
ICSV 1001 BF	Framida	Ivory Coast	W.Africa	1986
ICSV 1063	ICSV 1063	Ivory Coast	W.Africa	2000
ICSV-LM 90501	Surena -1	Dominican Rep	West Indies	1993
.	INIAP 201	Equador	Latin America	1987
Selection from crosses from Chipango	Centa S 2	El Salvador	C. America	1976
AT x 623 x Sweet Sudan	Centa SS 41 (Forage)	El Salvador	C. America	1978
M 91057 x M 90950	Isiap Dorado (Balanco-86)	El Salvador	C. America	1985
M 90361	Centa Oriental	El Salvador	C. America	1987
M 90362 (Male parent)	AGROCONSA1	El Salvador	C. America	1987

...continued

Table 7.7. *Continued*

Origin	Released name	Country	Region	Year
ICSV LM 90502 (M 36285 x 77 C3-1) bk-5-1-2-3-1-bk	Soberano	El Salvador	C. America	1996
ICSV LM 90503 (M 35585 x CS 3541) -31 -bk-5-2-2-3-1 -1 -7-bk	RCV	El Salvador	C. America	1996
ICSV LM 90508 (PP 290 x 852-2235) bk-4-6-3-1-bk	Jocoro	El Salvador	C. America	1997
ICSV 210	Bushuka	Eritrea	E.Africa	2000
PP 290 (INTSORMIL)	Shambuko	Eritrea	E.Africa	2000
89 MW 5003	Shieb	Eritrea	E. Africa	2000
89 MW 5056	Laba	Eritrea	E.Africa	2000
IS 29415	Shiketi	Eritrea	E. Africa	2000
E 35-1	Gambella-1107	Ethiopia	E. Africa	1980
76 TI #23	76 TI #23	Ethiopia	E.Africa	1980
M 36121	M 36121	Ethiopia	E.Africa	1980
IS 9302	IS 9302	Ethiopia	E.Africa	1980
IS 9323	ESIP 12	Ethiopia	E.Africa	
1984ICSV 1	Dinkmash	Ethiopia	E. Africa	1988
Diallel Pop 7-682	Melkamash	Ethiopia	E. Africa	1988
-	Seredo	Ethiopia	E. Africa	1990
	Framida	Ghana	W. Africa	1986
ICSV 111	Kaapala	Ghana	W.Africa	1997
M 90975	ICTAMILTAN85(ICTAC-21)	Guatemala	C. America	1985
IS 18484 (CS 3541)	Tortillero 1	Honduras	C. America	1984
ATX 623 x Tortiller	Catracho	Honduras	C. America	1984
M 62650	Sureno	Honduras	C. America	1985
E 1966 (IS 30468)	NTJ 2	India	Asia	1980
ICSV 1	CSV 11	India	Asia	1982
ICSV 112	CSV 13	India	Asia	1984
ICSH 153	CSH 11	India	Asia	1986
ICSV 145	SAR 1	India	Asia	1988
ICSV 239	BSR 1	India	Asia	1989
ICSV 745	DSV 3	India	Asia	1993
ICSV 197	ICSV 197	India	Asia	1993
Parent source	CSH 14	India	Asia	1993
Parent source	PJH 55	India	Asia	1993
Parent source	PJH 58	India	Asia	1993
Parent source	PKH 400	India	Asia	1993
Parent source	PSH 8340	India	Asia	1993
Parent source	CSV 15	India	Asia	1994
Parent Source	MLSH 36	India	Asia	1994
ICSA 91001 x ICSR 90017	ASH 1	India	Asia	1997
Parent source	JKSH 22	India	Asia	1999
ICSH 86686	PSH 1	India	Asia	1999
PVK 400	PVK 400	India	Asia	1999
Parent source	SPH 840	India	Asia	2000
GD 34553	PVK 801	India	Asia	2000
GD 31-4-2-3	Parbhani Moti (SPV 1411)	India	Asia	2002

...continued

Table 7.7. *Continued*

Origin	Released name	Country	Region	Year
ICSV 112	CSV 13	Kenya	E. Africa	1988
KAT 83/369	Kari Mtama I	Kenya	E. Africa	1994
IS 8193	Kari Mtama 2	Kenya	E. Africa	2001
PGRC/E216740	Kari Mtama 3	Kenya	E. Africa	2001
IS 76 T1#23	IS 76	Kenya	E. Africa	2001
ICSV 1	Pirira 1	Malawi	E. Africa	1993
ICSV 112	Pirira 2	Malawi	E. Africa	1993
Malisor-1	Malisor-1	Mali	W. Africa	1987
Malisor-4	Malisor-4	Meli	W. Africa	1987
Malisor-5	Malisor-5	Mali	W. Africa	1987
Malisor-7	Malisor-7	Mali	W. Africa	1987
	ICSV 1095 BF	Mali	W. Africa	1991
ICSV 1063 BF	ICSV 1063 BF	Mali	W. Africa	1993
ICSV 1079 BF	ICSV 1079 BF	Mali	W. Africa	1993
ICSV 401	ICSV 401	Mali	W. Africa	1994
CSM 335	Tieble	Mali	W. Africa	2001
CSM 485	Kossa	Mali	W. Africa	2001
CSM 660	Ngolofing	Mali	W. Africa	2001
Nazongola Anthocyane	Nazomble	Mali	W. Africa	2001
Nazongola Tan	Nazondje	Mali	W. Africa	2001
IS 15401	Soumalemba	Mali	W. Africa	2001
CGM 19/9-1-1 (Pedigree: 87-38 x 57-26)	Marakanio	Mali	W. Africa	2001
CIRAD 406	Soumba	Mali	W. Africa	2001
ICSV 1079 (Framida x E 35-1)	Yagare	Mali	W. Africa	2001
Sel from crosses from E. Africa	Valles Altos 110	Mexico	N. America	1978
-	Variadad 110	Mexico	N. America	1978
ICSV LM 89510	Blanco 86	Mexico	N. America	1986
ICSV 112	UANL-1-187	Mexico	N. America	1987
M 90362	UANL-1-287	Mexico	N. America	1987
M 62641	Costeno 201	Mexico	N. America	1989
ICSV 112	Pacifico 301	Mexico	N. America	1990
M 91057	Istmeno	Mexico	N. America	1991
PP 290	Perlita	Mexico	N. America	1991
M 90812	Tropical 401	Mexico	N. America	1991
IS 9468	Maravilla, No. SOF-043-201092	Mexico	N. America	2000
SDS 3220	Macia	Mozambique	E. Africa	1989
IS 8571	Mamonhe	Mozambique	E. Africa	1989
ICSV 112	Chokwe	Mozambique	E. Africa	1993
IS 8965	Shwe ni 1	Myanmar	Asia	1980
IS 2940	Shwe ni 2	Myanmar	Asia	1981
M 90906	Yezin 1 (Schwe phyu 1)	Myanmar	Asia	1984
M 36335	Yezin 3 (Schwe phyu 3)	Myanmar	Asia	1984
M 36248	Yezin 2 (Schwe phyu 2)	Myanmar	Asia	1984
M 36172	Yezin 4 (Schwe phyu 4)	Myanmar	Asia	1984
ICSV 735	Yezin 6	Myanmar	Asia	1996
ICSV 758	Yezin 7	Myanmar	Asia	1996
ICSV 804	Yezin 5	Myanmar	Asia	1996

...continued

Table 7.7. *Continued*

Origin	Released name	Country	Region	Year
SDS 3220	Macia	Namibia	S. Africa	1998
Sepon 77	NICA-SOR (T43)	Nicaragua	C. America	1985
ICSV 112	Pinollero 1	Nicaragua	C. America	1990
M 90038	Sepon 82	Niger	W. Africa	1993
ICSV 1007 BF	SRN 39	Niger	W. Africa	1993
ICSH 89002 (NG)	ICSH 89002(NG)	Nigeria	W. Africa	1995
ICSH 89009 (NG)	ICSH 89009(NG)	Nigeria	W. Africa	1995
ICSV 111	ICSV 111	Nigeria	W. Africa	1995
ICSV 400	ICSV 400	Nigeria	W. Africa	1997
NR 71176	NR 71176	Nigeria	W.Africa	1997
NR 71182	NR 71182	Nigeria	W. Africa	1997
NSSH 91001	NSSH 91001	Nigeria	W.Africa	1997
NSSH 91002	NSSH 91002	Nigeria	W. Africa	1997
ICSV 107	PARC-SS 1	Pakistan	Asia	1991
IRAT 408	PARC-SS 2	Pakistan	Asia	1991
-	Alanje Blanquito	Panama	C. America	1991
ISIAP DORADO	Dorado	Paraguay	S. America	
ICSV 126 (PSB Sg 93-20)	IES Sor 1	Phillipines	Asia	1993
PSB Sg 94-02	IES Sor 4	Phillipines	Asia	1994
-	5Dx160	Rwanda	C. Africa	1980
-	1 Kinyamka	Rwanda	C. Africa	1980
IS 25395		Rwanda	C. Africa	2001
IS 21219		Rwanda	C. Africa	2001
IS 8193		Rwanda	C. Africa	2001
-	IRAT 204	Senegal	W. Africa	1980
IESV 92043 DL		Somalia	E. Africa	2001
CR 35:5		Somalia	E. Africa	2001
Gedam el Hammam		Somalia	E. Africa	2001
Tx623AxK1597(Karper-1597)	Hageen Durra	Sudan	E. Africa	1983
ICSV 1007 HV	Mugawim Buda 1	Sudan	E.Africa	1991
IS 9830	Mugawim Buda 2	Sudan	E.Africa	1991
ICSV 1001 BF	Framida (SRN 39)	Sudan	E. Africa	1991
M 90393	INGAZI(M 90393)	Sudan	E. Africa	1992
IS 13444	Aroos Elrimal	Sudan	E. Africa	2000
SDSV 1513	MRS 13	Swaziland	S. Africa	1989
SDSV 1594-1	MRS 94	Swaziland	S.Africa	1989
ICSV 112	MRS 12	Swaziland	S. Africa	1992
2Kx17	Tegemeo	Tanzania	E. Africa	1988
	Pato	Tanzania	E. Africa	1995
SDS 3220	Macia	Tanzania	E. Africa	1999
	Suphanburi-1	Thailand	Asia	1996
ICSV 1001 BF	Framida	Togo	W.Africa	1986
Sepon 82 x S34	Sorvato 1	Togo	W.Africa	1998
Framida x S 34	Sorvato 28	Togo	W.Africa	1998
-	Seredo	Uganda	C. Africa	1980
	Epuripur (Tegemeo)	Uganda	C. Africa	1995

...continued

Table 7.7. *Continued*

Origin	Released name	Country	Region	Year
(GPR148 x E 35-1)4-1 x CS3541	Isiap Dorado	Venezuela	C America	1985
ICSV 2	ZSV 1	Zambia	S. Africa	1983
-	WSH 287	Zambia	S. Africa	1987
WSV 387	KUYUMA (MR4/4606 T11)	Zambia	S.Africa	1989
IS 23520	SIMA	Zambia	S. Africa	1989
ICSA 104(SPL 177A)	MMSH 413	Zambia	S.Africa	1990
-	MMSH 375	Zambia	S. Africa	1990
	ZSV 12	Zambia	S. Africa	1995
ICSV 112	SV 1	Zimbabwe	S. Africa	1985
ICSV 88060	SV 2	Zimbabwe	S. Africa	1987
-	ZWSH 1	Zimbabwe	S. Africa	1992
SDS 3220	Macia	Zimbabwe	S. Africa	1998
	SV 3	Zimbabwe	S. Africa	1998
	SV 4	Zimbabwe	S. Africa	1998

Table 7.8. Details of formal training programs carried out at ICRISAT Patancheru, 1989-1998

	Number of participants as					
Country	Visiting Scholars	Research Scholars	Research Fellows	Apprentices	In-service trainees	Total
Brazil	2					2
China					1	
Columbia	1					
Egypt	4					
Eritrea		2			1	
Ethiopia	1					
Germany		1		2		
Holland				3		
India	1	4				
Iran					1	
Ivory Coast			1			
Kenya	1					
Mali	1					
Mexico	1					
Myanmar	1					
Namibia	2					
Niger	1					
Nigeria	1					
Philippines	1					
Spain				2		
Sudan	2	2				
Syria	4	1				
Thailand	1					
Venezuela	1					
Yemen	5					5
Total	31	10	1	7	3	52

Table 7.9. Details of formal academic and informal (in-service) training programs carried out at Matopos (Zimbabwe), Patancheru (India) and USA/Brazil by SADC/ICRISAT SMIP and INTSORMIL, 1983-94.

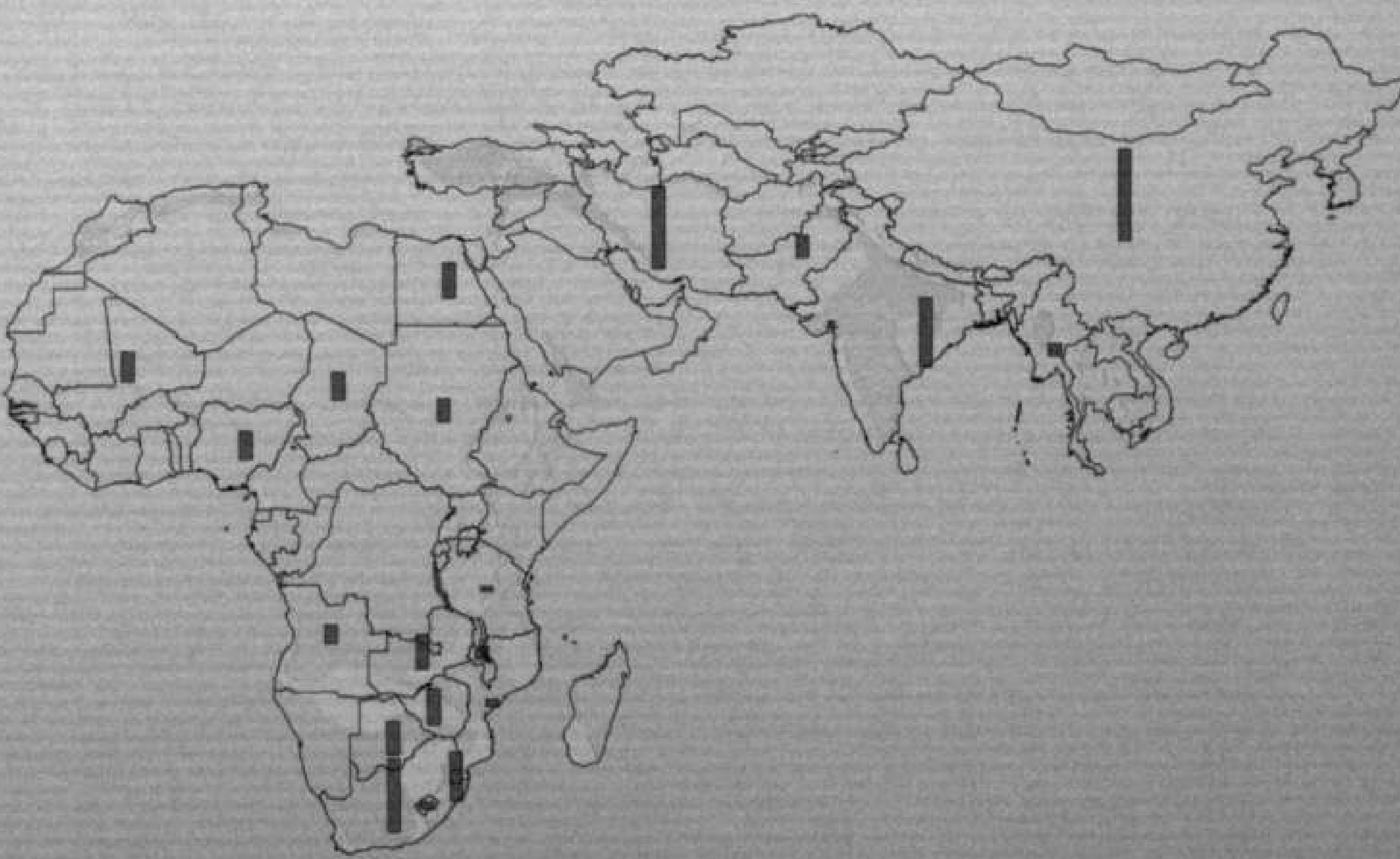
	Academic training				In-service training			
Country	PhD	MS	BS	Total	Matopos	Regional locations	ICRISAT-Patancheru	Total
Angola	-	4	-	4	4	2	1	7
Botswana	4	5	2	11	8	14	14	36
Lesotho	2	6	2	10	11	6	-	17
Malawi	7	5		12	15	11	13	39
Mozambique	2	5	-	7	3	1	13	17
Namibia	-	-	-	0	4	2	3	9
Swaziland	4	2	-	6	12	10	6	28
Tanzania	6	10	2	18	29	9	25	63
Zambia	3	10	3	16	20	11	25	56
Zimbabwe	6	7	-	13	24	18	22	64
Total	34	54	9	97	130	84	122	336

Table 7.10. Details of special training courses organized on sorghum.

Title	Countries	Participants (no.)	Duration	Location
Grain and food quality evaluation of sorghum	Burundi, Ghana, Niger, Nigeria, Tanzania and Zambia	7	1 Jul 1988 to 30 Sep 1988	Patancheru
East Africa sorghum pathology (EARSAM)	Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania s and Uganda	15	16 Sep 1988 to 30 Sep 1989	Patancheru
Maintenance of male-sterile lines and open-pollinated varieties and their use in seed multiplication	Egypt, Kenya, Mali, Myanmar, Namibia, Niger, Nigeria, and Syria	8	6 Mar 1995 to 17 Mar 1995	Patancheru
Screening for host resistance to insects	Afghanistan, Egypt, Ethiopia, India, Iran, Kenya, Mali, Myanmar, Nigeria, Pakistan, Sudan, Syria, Tanzania, Thailand and Yemen	22	24 Oct 1995 to 3 Nov 1995	Patancheru
In-country training course on sorghum improvement and production techniques	All from Egypt	26	18 Sep 1995 to 30 Sep 1995	Egypt
In-country training course on insect, pest survey and management	Eritrea	9	29 Sep 1997 to 11 Oct 1997	Eritrea
In-country training course on sorghum seed parents and hybrid development and multiplication	Myanmar	7	30 Dec 1997 to 7 Jan 1998	Myanmar
Technology exchange and training workshop on advances in sorghum anthracnose research	India and Thailand	5	23 Sep 1998 to 25 Sep 1998	Patancheru
Training workshop in on-farm research	9 SADC countries	24	11 Jul 1984 to 15 Jul 1984	Maseru, Lesotho
Regional seed production training course	Botswana, Lesotho, Malawi, Namibia, Swaziland, Tanzania, Zambia and Zimbabwe	28	22 Sep 1994 to 24 Sep 1994	Muzarabani, Zimbabwe
On-farm research methodology training workshop for extension	9 SADC countries	49	28 Sep 1994 to 29 Sep 1994	Dodoma,Tanzania
Training in the design, implementation and analysis of informal diagnostic surveys	Mozambique	7	13 Feb 1995 to 21 Feb 1995	Tete
Training in pollination techniques and seed production	Botswana and Zimbabwe	8	Feb 1995	Aisleby, Zimbabwe

Adoption of Improved Sorghum Cultivars

UK Deb, MCS Bantilan, CT Hash and J Ndjeunga



Adoption of Improved Sorghum Cultivars

UK Deb[1], MCS Bantilan[2], CT Hash[2] and J Ndjeunga[3]

8.1. Introduction

Successful development of appropriate improved crop cultivars paves the way for their adoption by farmers. Adoption of improved cultivars is a necessary precondition for plant breeding creating favorable impacts on farm households. Impacts may be obtained through yield increases, quality improvement, reduction in unit cost of production and reduced production risks. This chapter is a compilation of information about the level of adoption of improved sorghum cultivars and factors influencing it.

Adoption of improved sorghum cultivars was measured as a percentage of improved sorghum area in the total sorghum area. Based on their origin, adoption levels of improved sorghum cultivars were divided into four groups: (i) percentage of area sown to ICRISAT-bred cultivars; (ii) percentage of area sown to cultivars having ICRISAT parents; (iii) percentage of area sown to ICRISAT network cultivars; and (iv) percentage of area sown to non-ICRISAT (other) cultivars.

Information on adoption levels of improved sorghum cultivars were obtained from:(i) adoption and impact monitoring surveys carried out by ICRISAT; (ii) a literature survey; (iii) state and district level secondary data for India published in Fertilizer Statistics, State Crop Reports and Statistical Abstracts; and (iv) a rapid appraisal conducted during 1998/99 to estimate cultivar-specific adoption levels in several states of India.

Cultivar-specific adoption data for different sorghum cultivars are not available in published statistics. Cultivar-specific areas and adoption levels have been estimated using Delphi techniques and on the basis of available data on HYV sorghum area for major sorghum-producing states. In India, data on the total area under sorghum crop and HYV sorghum were available in crop statistics published by different states, but data on the area under different cultivars were not available. In order to generate this data, interviews were conducted of specialists working in state seed certification agencies, the National Seed Corporation, state seed development corporations, agricultural research institutes, the directorates of agriculture of major sorghum-producing states, extension personnel of Training and Visit (T&V) offices, private seed companies, seed dealers in different districts of major sorghum-growing states about their perceptions on the popularity of different cultivars in different districts at different points in time. The individuals involved in this process were asked to rank the popular cultivars and mention the likely percentage share of each in the total areas under HYV sorghum. Based on their responses and frank discussions, concrete figures were arrived at for the market share of different sorghum cultivars in the total HYV sorghum area in each region. This information was verified with available data on HYV sorghum area reported in the statistical bulletins published by different states.

1 Centre for Policy Dialogue, House 40/C, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.
2 International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh India.
3 International Crops Research Institute for the Semi-Arid Tropics, BP 12404, Niamey, Niger.

Deb UK, Bantilan MCS, Hash CT and Ndjeunga J. 2004. Adoption of improved sorghum cultivars. Pages 181-198 in Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

This chapter also discusses technology adoption levels in Asia, Africa and Latin America, the critical factors influencing adoption levels and constraints to adoption of improved cultivars as reported by farmers. Finally, the lessons learned from sorghum cultivar adoption studies conducted in Asia, Africa and Latin America are described.

8.2. Technology Adoption in Asia

Table 8.1 shows the level of adoption of improved sorghum cultivars in several sorghum-producing countries in Asia. China has the highest level of adoption of improved cultivars (98% of sorghum area) in Asia followed by Iran (87%) and India (73%). A description of country-specific adoption follows.

India. The level of adoption of improved sorghum cultivars in major sorghum-producing states of India is shown in Figure 8.1. Significant increases in the level of adoption were observed in all major sorghum-growing states (Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh and Gujarat) except Rajasthan. In 1996/97, the highest level of adoption of improved sorghum cultivars was found in Madhya Pradesh (85% of sorghum area), followed by Maharashtra (84%) and Tamil Nadu (77%). Adoption levels in Andhra Pradesh and Karnataka were about 70% while they reached 52% in Gujarat. On the other hand, the observed adoption level in Rajasthan was only 2%.

Similar analyses were conducted on district-level data from these major sorghum-producing states in India. The level of adoption of improved sorghum cultivars across all districts of India for four periods (1966-68, 1974-76, 1984-86 and 1992-94) are shown in Figure 8.2. The early and rapid levels of adoption in Tamil Nadu, Karnataka and Maharashtra states are evident while a very slow level of adoption was observed in Rajasthan. Levels of adoption were highest (more than 80%) in a majority of sorghum-producing districts of Maharashtra and in some districts of neighboring Andhra Pradesh. In 1992-94, farmers of 28 districts adopted improved cultivars on more than 80% of their sorghum areas. These districts were Nanded, Jalgaon, Nagpur, Yeotmal, Akola, Amravati, Wardha, Kolhapur, Buldhana, Sangli, Nasik, Osmanabad and Dhulia in Maharashtra; Indore, Dhar, Betul and Morena in Madhya Pradesh; Aligarh, Allahabad and Buduan in Uttar Pradesh; East Godavari, Khammam and Karimnagar in Andhra Pradesh; Shimoga and Hassan in Karnataka; Ganganagar in Rajasthan; Tirunelveli Kattabomman in Tamil Nadu; and Rajkot in Gujarat. Another 16 districts had adoption levels ranging between 70 and 80%: Beed, Chandrapur and Parbhani in Maharashtra; Shivpuri, Khargone, Sehore, Raisen, Chindwara, Khandwa, Shajapur and Narsimhapur in Madhya Pradesh; Cuddapah in Andhra

Table 8.1. Adoption level (% area) of improved sorghum cultivars in Asia.

Country	Year	Percent area sown to				
		ICRISAT cross	ICRISAT parent	ICRISAT network	Others	All improved
China	1998	·	9	-	69	98
India	1999	1	10	3	59	73
Iran	1995-96	-	-	-	87	87
Myanmar	1995-96	10	-	-	-	10
Pakistan	1995-96	-	-	-	21	21
Thailand	1995-96	-	10	-	-	10

Source: ICRISAT Impact Monitoring Survey, 1997-2000.

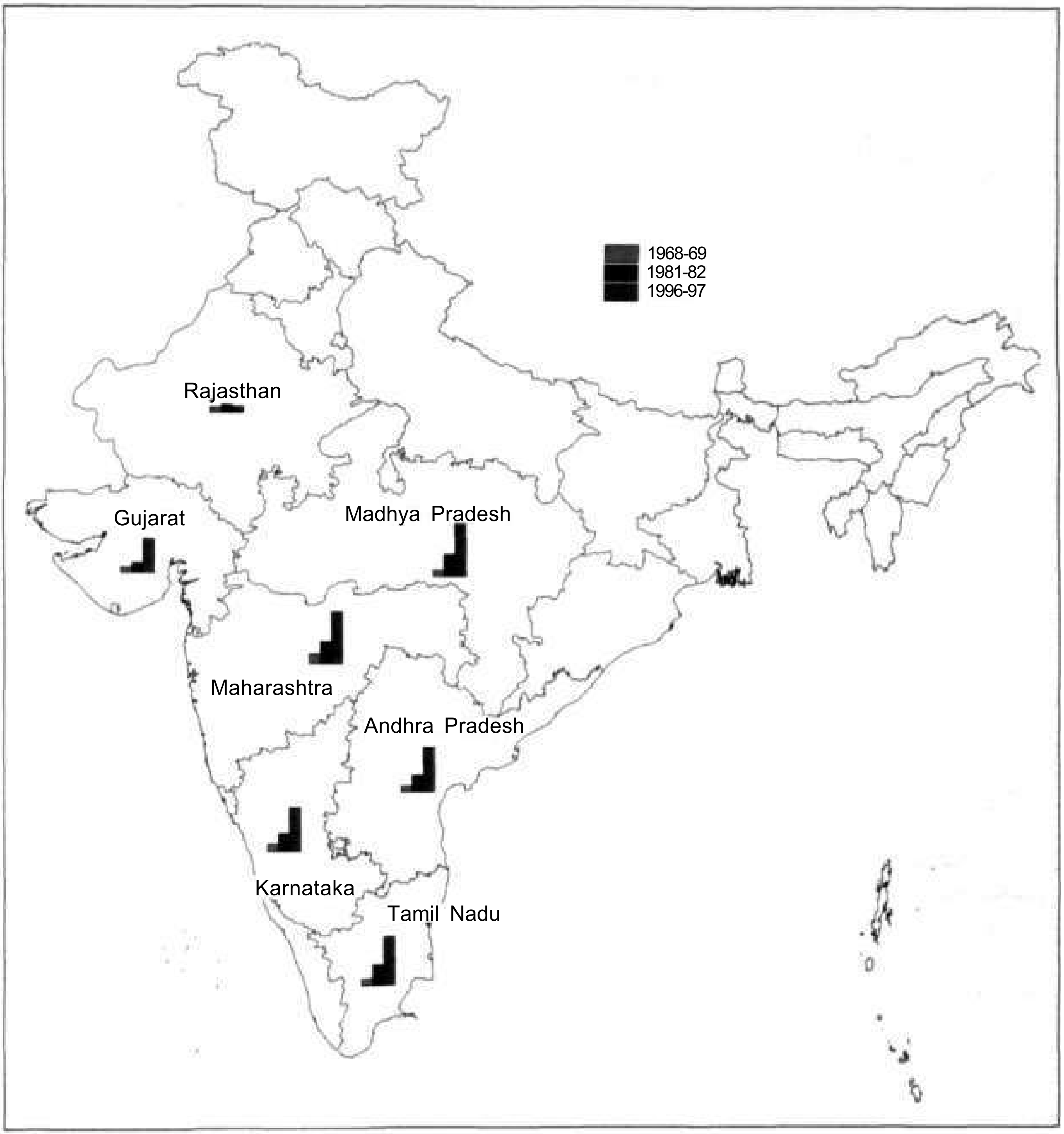


Figure 8.1. Trends in adoption levels (% of total sorghum area) of improved sorghum cultivars in major sorghum-producing states of India, 1968-97.

Pradesh; Chickmagalur and Bellary in Karnataka; North Arcot in Tamil Nadu and Bulandshar in Uttar Pradesh.

The trends in adoption of specific, popular sorghum hybrids in India are shown in Figure 8.3. The slow and limited adoption of CSH 1 is evident, as is the subsequent more rapid and widespread adoption of CSH 5, CSH 6 and CSH 9. The farmers have recently adopted MSH 51, popularly known as Mahyco 51, a cultivar from the private sector. JKSH 22, another cultivar from the private sector, is also gaining its ground. Improved open-pollinated varieties have been less

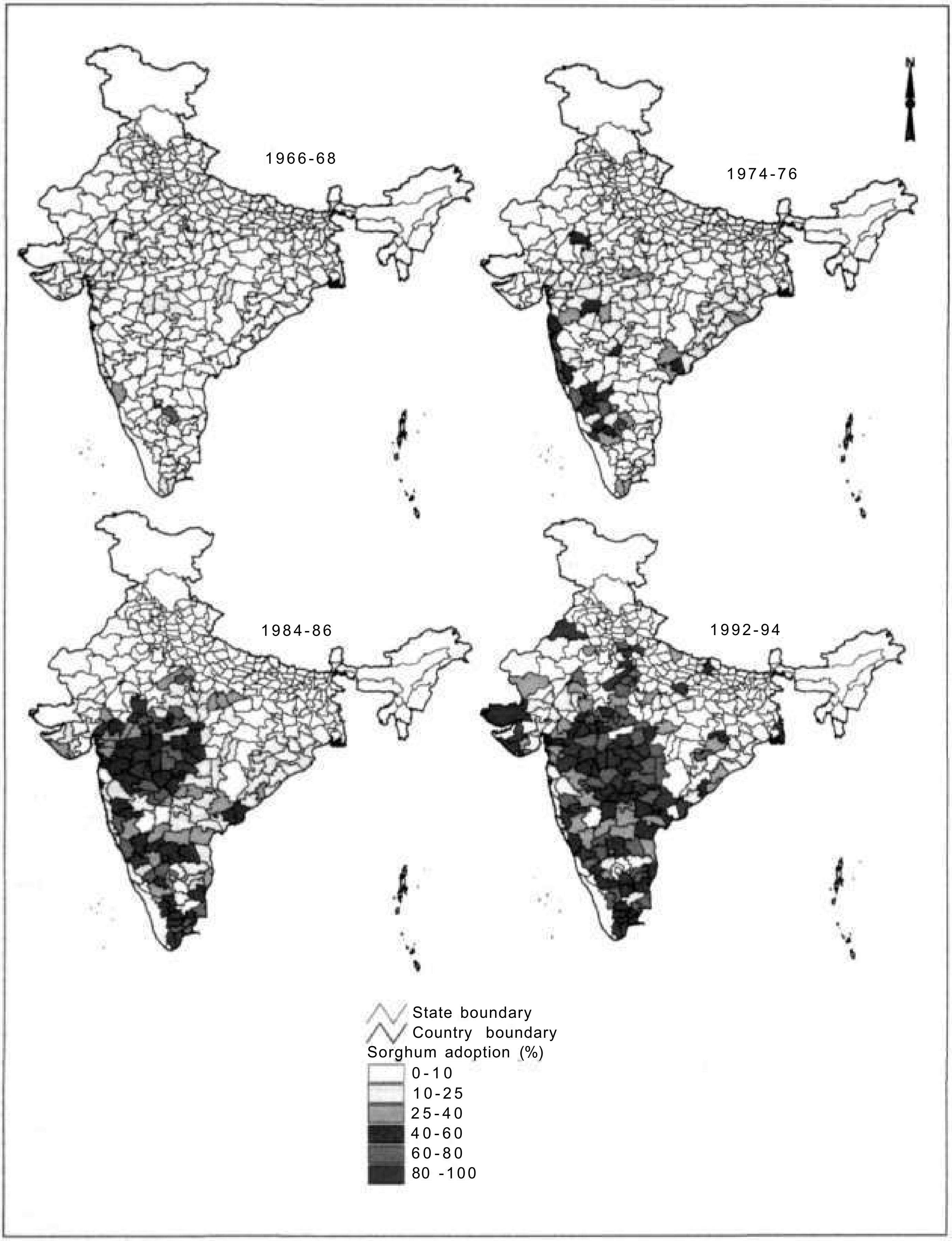


Figure 8.2. Rate of adoption (%) of improved sorghum cultivars in India.

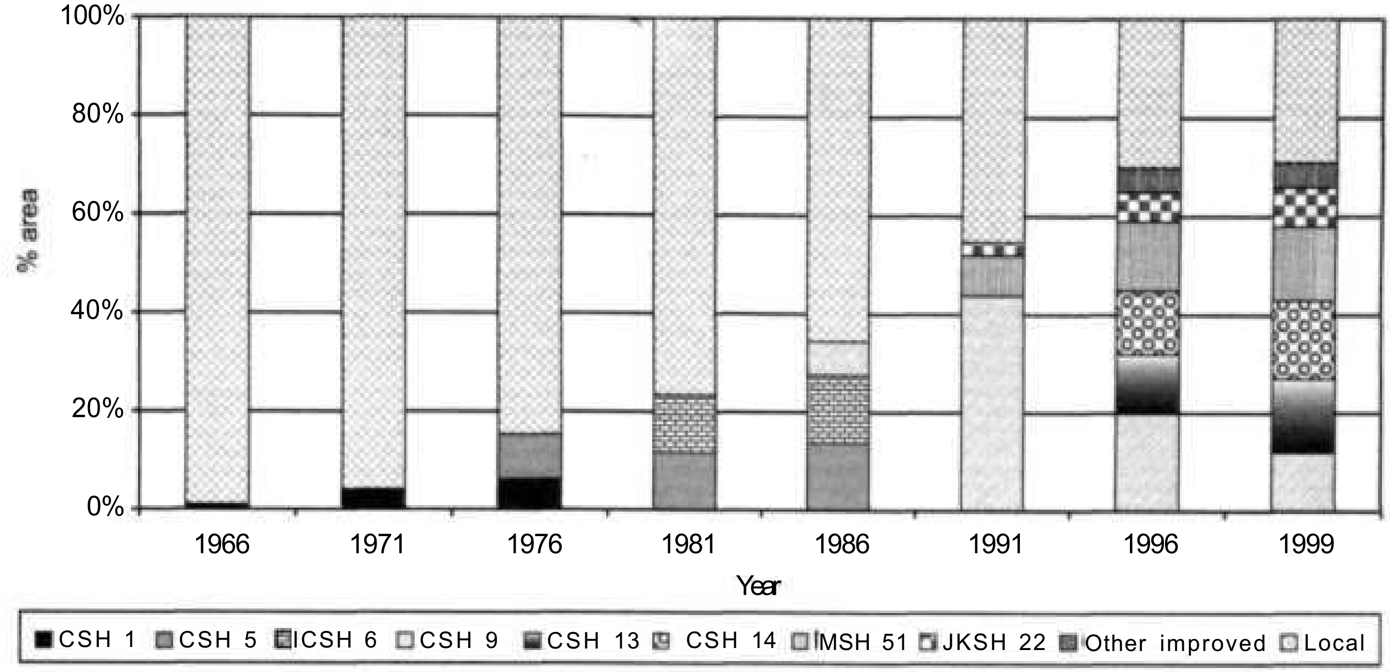


Figure 8.3. Trends in the adoption of different sorghum cultivars in India, 1966-99.

popular than the hybrids from the time these first became available (Rana et al. 1997). Since hybrids provide higher yields and their seed is readily available from a large number of private and public seed companies, adoption of hybrids took off readily. Three phases in the spread of improved sorghum cultivars have been observed in India. The first phase lasted until 1975, when CSH 1 was the only improved cultivar adopted to any extent. During this period, improved sorghum cultivars (CSH 1) mainly replaced traditional local cultivars. The second phase occurred between 1976 and 1986, when the dominant improved sorghum cultivars were CSH 5 and CSH 6. This phase was characterized by the replacement of traditional local cultivars and the initial group of hybrids (CSH 1, CSH 2 and CSH 4) with new hybrids (CSH 5 and CSH 6). The third phase started after 1986, when these second cycle hybrids were replaced by CSH 9, MSH 51, JKSH 22, CSH 13 and CSH 14, which as a group were adopted rapidly and more widely than earlier improved sorghum cultivars. During this period, Indian farmers began to be acquainted with a large number of private-sector bred hybrids in the market. The three phases of adoption are evident in Figure 8.4, which depicts the trends in adoption of improved cultivars in Andhra Pradesh, Gujarat and Maharashtra between 1972 and 1997.

Deb and Bantilan (1998) documented cultivar-specific adoption levels of improved sorghum cultivars in different states of India. A summary of their results (Figs. 8.5a and b) shows that CSH 9 was the most popular cultivar in almost all the major sorghum-growing states in 1993. However, there were regional variations in the popularity of other cultivars. For example, Mahyco 51 was popular in Gujarat, Maharashtra, Madhya Pradesh, Tamil Nadu and Andhra Pradesh. Mahyco had strong distribution and marketing networks in these states.

China. The levels of adoption of improved sorghum cultivars in China are the highest among all Asian countries. A series of generations of new cultivars consistently replaced old cultivars over time (Table 8.2). In 1994, 99% of the total sorghum area in China was sown to improved cultivars. Hybrids are more popular than varieties. Even in 1975-76, the level of adoption of improved sorghum cultivars in China was 90%. The popularity of different hybrids in China varied over time.

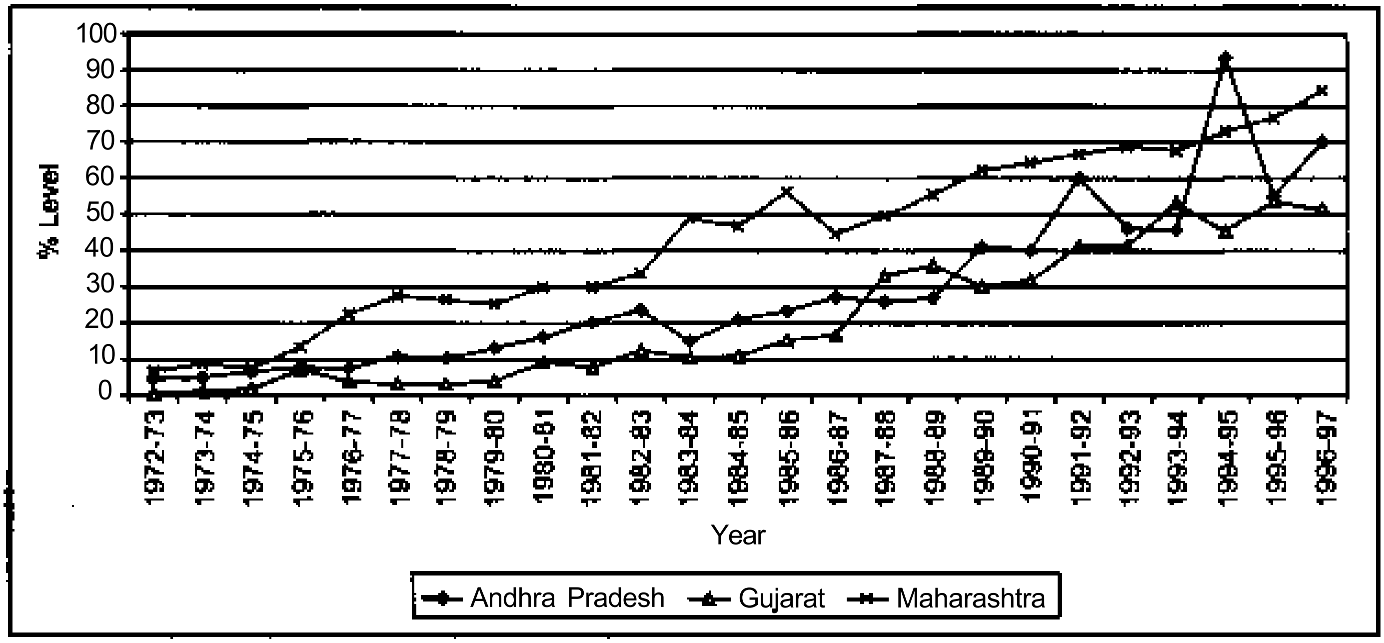


Figure 8.4. Trends in the adoption level (%) of improved sorghum cultivars in selected states of India, 1972-97.

In 1975-76, six sorghum hybrids (Jin Za No. 1, Xin Za No. 52, Jin Za No. 4, Jin Za No. 5, Ji Za No. 11 and Ji Za No. 26) occupied more than 60% of the total sorghum area. Jin Za No. 5 covered about 19% of the sorghum area in China in 1975-76. In 1980-81, the two most popular cultivars were Liao Za No. 1 and Zin Za No. 83 which covered 22% of the total sorghum area. Four other cultivars (Liao Za No. 2, Shen Za No.4, Tie Za No. 6 and Tie Za No. 7) covered about 11% of the total area. Only 5% of the total sorghum area in China was under local cultivars 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, which together covered about 20% of the total sorghum area in China. In 1990-91, the level 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 the most popular. By 1994, 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 the most popular. In 1999, 9% of sorghum area in China was sown to cultivars having ICRISAT parents. As shown in Table 8.2, the popularity of new generations of improved sorghum cultivars, speedy turnover of new cultivars and dominance of hybrids over OPVs were the features of adoption of improved sorghum cultivars in China during this 20-year period.

Myanmar. Adoption levels of improved sorghum varieties were low in Myanmar. In 1975-76, only local sorghums were in cultivation while in the mid 90s, all area under improved cultivars (9.73%) was sown to ICRISAT-bred varieties (Table 8.3). In 1980-81, the level of adoption of improved cultivars was 28% and the popular cultivars were (Shwe Ni 1, Shwe Ni 2, Shwe Ni 3, Shwe Ni 4, Shwe Ni 5, and Shwe Ni 9). The level of adoption fell to only 9% in 1985-86 and the popular cultivars at that time were Shwe Ni 1, Yezin White Grain 1 and Yezin White Grain 2. By 1990-91, the level of adoption fell further to 6% and the popular improved cultivars were Shwe Ni 1, Shwe Ni 4, Yezin White Grain 1, Yezin White Grain 2 and Yezin White Grain 3. The fluctuation in adoption has been influenced by the weakening public sector seed multiplication, distribution and extension programs compared to two decades ago. By the mid-90s, the adoption level of improved cultivars had returned to 9.73% and the most popular cultivars were Yezin White Grain 1, Yezin White Grain 2 and Yezin White Grain 3.

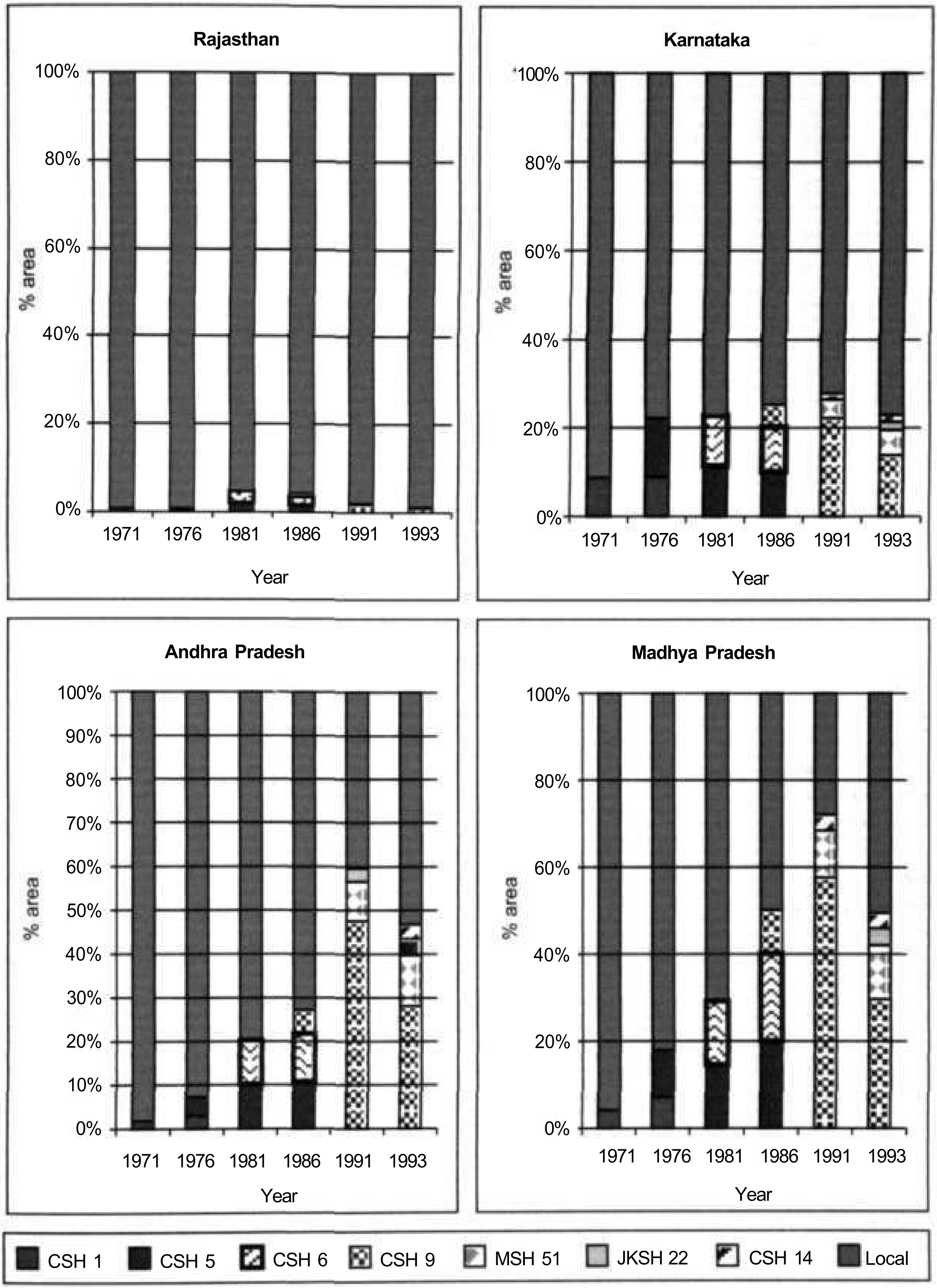


Figure 8.5a. Trends in the adoption rate of different sorghum cultivars in selected states of India, 1971-1993.

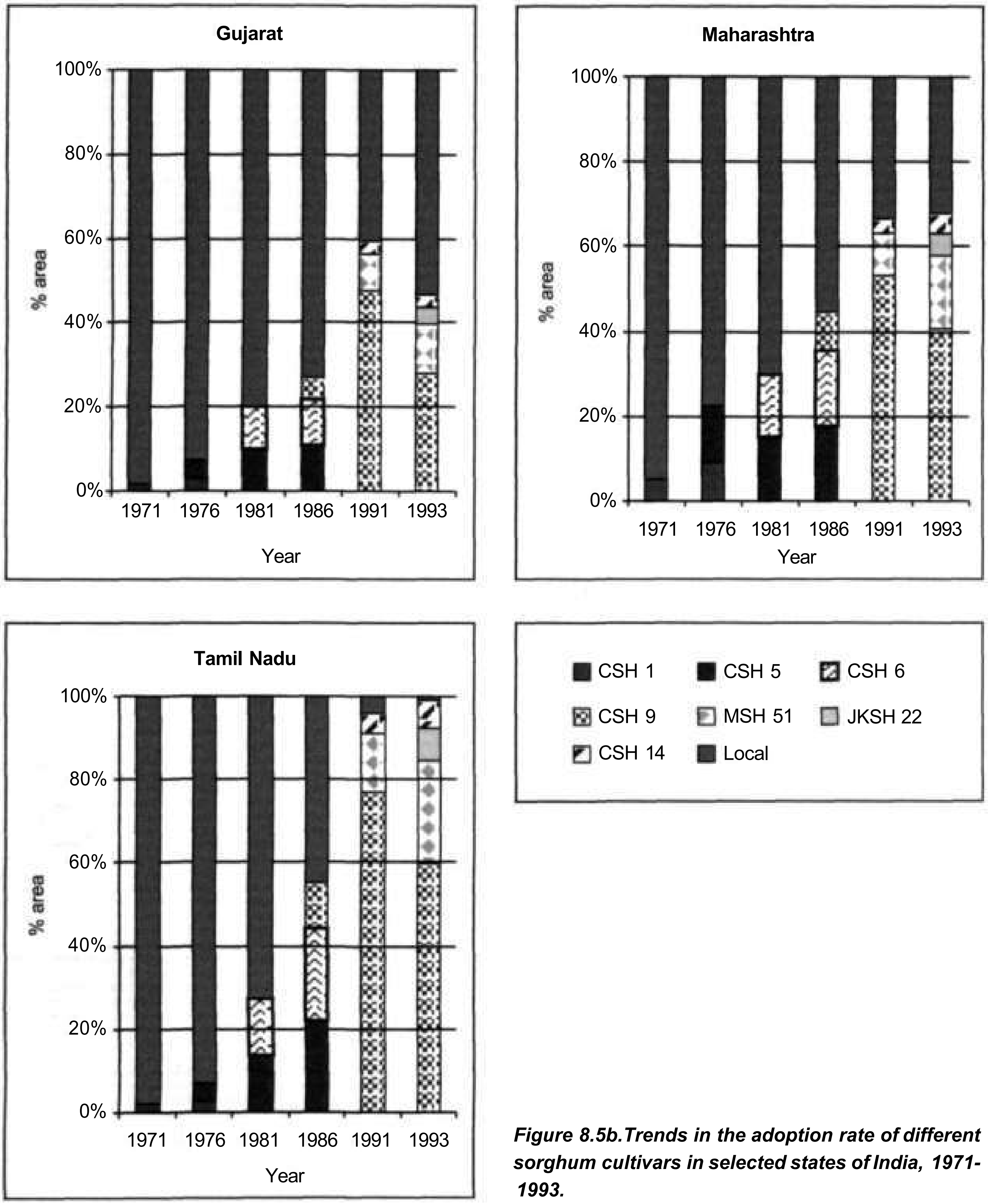


Figure 8.5b. Trends in the adoption rate of different sorghum cultivars in selected states of India, 1971-1993.

Pakistan. Local cultivars have always dominated sorghum cultivation in Pakistan. In the mid-70s, only 7% of the total sorghum area in Pakistan was sown to improved cultivars, but this increased to 21% by the mid-90s (Table 8.4). However, as of 1995-96, no ICRISAT cultivars were grown in Pakistan.

Table 8.2 . Trends in the adoption level (%) of improved sorghum cultivars in China, 1976-94.

Cultivar	1976	1981	1986	1991	1994
Jin Za No. 1 (hybrid)	6.22				
Xin Za No. 52 (hybrid)	6.38				
Jin Za No. 4 (hybrid)	12.42				
Jin Za No. 5 (hybrid)	18.90				
Ji Za No. 11 (hybrid)	7.94				
Ji Za No. 26 (hybrid)	8.38				
Tie Za No. 6 (hybrid)		2.34			
Liao Za No. 1 (hybrid)		10.50			
Liao Za No. 2 (hybrid)		2.34			
Jin Za No. 83 (hybrid)		10.59			
Shen Za No. 4(hybrid)		3.51			
Tie Za No. 7 (hybrid)		2.34			
Shen Za No. 5 (hybrid)			6.72		
Qiao Za No. 2 (hybrid)			4.48		
Liao Za No. 4 (hybrid)			4.48		
Jin Za No. 94 (hybrid)			4.47		
Jin Za No. 12 (hybrid)				8.86	
Tie Za No. 10 (hybrid)				5.18	
Liao Za No. 5 (hybrid)				6.21	
Long Si Za No. 1 (hybrid)				3.13	
Long Za No. 3 (hybrid)					7.29
Liao Za No. 6 (hybrid)					4.28
Liao Za No. 7 (hybrid)					2.45
Liao Za No. 10 (hybrid)					1.64
Other improved	29.74	63.39	77.86	74.61	83.35
Local	10.00	5.00	2.00	2.00	1.00
All	100.00	100.00	100.00	100.00	100.00
Total sorghum area	**4333.50**	**2613.10**	**1898.69**	**1414.10**	**1392.97**

Source: ICRISAT Impact Monitoring Survey (1997). Total sorghum area-units ('000 ha) (FAOSTAT 2003).

Table 8.3. Trends in the adoption level (%) of improved sorghum cultivars in Myanmar, 1981-94.

Varieties	1981	1986	1991	1994
Shwe Ni 1	10.41	2.40	1.31	
Shwe Ni 2	1.37			
Shwe Ni 3	1.83			
Shwe Ni 4	1.26		0.65	
Shwe Ni 5	4.46			
Shwe Ni 9	8.41			
Yezin White Grain 1		1.60	2.97	3.89
Yezin White Grain 2		5.29	1.07	1.95
Yezin White Grain 3			0.30	3.89
Local	72.25	90.72	93.70	87.73
Total	**100.00**	**100.00**	**100.00**	**97.46**

Source: ICRISAT Impact Monitoring Survey (1997).

Table 8.4. Trends in the adoption level (%) of improved sorghum cultivars in Pakistan, 1976-94.

Cultivars	1976	1981	1986	1991	1994
All improved	7	8	13	16	21
Local	93	92	87	84	79
Total	100	100	100	100	100
Total sorghum area ('000 ha)	446.94	392.50	399.20	382.70	438.20

Source: ICRISAT Impact Monitoring Survey (1997); FAOSTAT (2003).

Thailand. In Thailand, improved cultivars having at least one ICRISAT parent covered 10% of the country's total sorghum area in 1995-96. Thailand has released seven improved cultivars. Two varieties (Early Hegari and Late Hegari) were introduced in the early 1960s from USA. Hegari is still popular in Thailand. The other five improved cultivars are materials developed by the national breeding program. One of the cultivars (Suphan Buri 1, released in 1993] had ICRISAT-supplied germplasm as a parent.

Iran. All sorghum grown in Iran up to 1985-86 were local varieties. However, by 1995-96, 87% of the sorghum growing area in Iran was under improved cultivars. None of this area was sown to ICRISAT cultivars. It may be noted that the total area under sorghum in Iran is low, but it has been increasing over time, from 4 000 ha in 1980-81 to 30 000 ha in 1995-96.

8.3. Technology Adoption in Africa

Table 8.5 shows the levels of adoption of improved sorghum cultivars in African countries. South Africa had the highest adoption level (77%) in Africa followed by Swaziland (50%), Zimbabwe (36%) and Zambia (35%). Country-specific adoption situations are discussed below.

Southern and Eastern Africa. Phofu is the most popular improved variety in Botswana. Its adoption level in 1997/98 was 21% (Rohrbach et al. 1999). Levels of adoption of ICRISAT-bred varieties in Sudan, Malawi, Zambia and Zimbabwe in 1997 were 3%, 10%, 35% and 36%, respectively (Table 8.5). The level of adoption of improved sorghum cultivars in South Africa in 1997 was 77% but all were non-ICRISAT cultivars. It may be mentioned here that South Africa began receiving ICRISAT sorghum materials only in 1994/95, due to which ICRISAT cultivars have not yet been released in that country.

Egypt. Most of the sorghum area in Egypt is sown to local varieties. In 1975-76, only 5% of Egypt's sorghum area was under improved cultivars. However, this increased to 35% (including 15% of the area under OPV selections from ICRISAT crosses and hybrids having ICRISAT parents) in 1993-94 (Table 8.6). In 1975-76, Giza 114 was the only improved cultivar grown in Egypt; it covered 5% of the sorghum area.In 1980-81 two cultivars—Giza 114 (4.4%) and Giza 15 (10.6%)—covered 15% of the country's total sorghum area. By 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. Two other improved cultivars, ISIAP Dorado and NES 1007, were also grown at that time and jointly covered about 5% of Egypt's sorghum area. By 1990-91, Giza 15 covered about 20% of the total sorghum area while ISIAP Dorado, NES 1007 and Giza 113 had a share of 8%, 1% and 1%, respectively. Giza 15 is still popular in Egypt and covered about 17% of the sorghum area in 1993-94. The other

Table 8.5. Level of adoption (% area) of different improved sorghum cultivars in Africa.

Country	Region	Year	Percent area planted to				
			ICRISAT cross	ICRISAT parent	ICRISAT network	Others	All improved
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 Baguirmi	1995	27				27
	Guera	1995	38				
	Mayo Kebbi	1995	27				
	Chari Baguirmi	1995	24				
Egypt		1995/96		5		30	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
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. (1998) for Nigeria; Rohrbach and Makhwaje (1999) for Botswana; SMIP (1999) for Angola, Lesotho, South Africa, Swaziland and Tanzania; Yapi et al. (1998) for Mali; and Yapi et al. (1999) for Cameroon and Chad.

Table 8.6. Trends in the adoption level (%) of improved sorghum cultivars in Egypt, 1976-94.

Cultivars	1976	1981	1986	1991	1994
Giza 114	4.82	4.39			
Giza 15		10.53	15.00	19.92	17.00
ISIAP Dorado			2.02	7.99	10.00
NES 1007			2.98	0.96	
Giza 113				0.96	3.00
Hybrids					5.00
Locals	95.18	85.00	80.00	70.01	65.00
Total	100.00	100.00	100.00	100.00	100.00
Total sorghum area ('000 ha)	199.39	173.38	155.68	136.02	158.03

Source: ICRISAT Impact Monitoring Survey, 1997-2000 for cultivar-specific adoption level; FAOSTAT (2003) for the sorghum area in Egypt.

popular improved cultivars were Giza 113 and ISIAP Dorado. The case of ISIAP Dorado is particularly interesting as this short-statured, large- and hard-grained, high-yielding, white-grained/ tan plant OPV was selected from breeders' nurseries at ICRISAT-Patancheru by an in-service trainee from El Salvador in 1979/80. Following its release in El Salvador (as ISIAP Dorado), it has been widely used and distributed by both ICRISAT and INTSORMIL. It is now cultivated in El Salvador, Mexico, Honduras, Panama and Paraguay, in addition to Egypt.

Nigeria. Local sorghum 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 in 1996 to determine the nature, extent and determinants of adoption of ICSV 111 and ICSV 400. A survey was conducted in 27 villages (9 in Kano, 9 in Katsina, 6 in Kaduna and 3 in Jigawa). A total of 219 farmers from these four states were interviewed. Levels of adoption of improved cultivars (ICSV 111 and ICSV 400) were 28% in Kano, 10% in Katsina, 29% in Kaduna and 3% in Jigawa.

Chad. Yapi et al. (1999) studied the adoption and benefits of ICRISAT-bred improved sorghum variety S 35 in Chad, based on farm survey data collected from 152 farmers in 17 districts in 28 villages for 1994/95. This study was conducted in three zones, Guera, Mayo Kebbi and Chari Baguirmi, which are located in the Sahelian and the Sahelian-Sudanian zones, where short rainy seasons with erratic rainfall patterns necessitate the use of short-cycle crop varieties such as S 35. These zones were the target and distribution zones for S 35 in Chad. The adoption level for S 35 was higher in Guera (38%) than in Mayo Kebbi (27%)) and Chari Baguirmi (24%). This is because Guera is the zone most suited to S 35 cultivation, and most of the S 35 seed produced at Gassi Research Station between 1987 and 1989 was distributed in this zone. In Chari Baguirmi, adoption only began in 1992 and reached 24% in 1995. This lower adoption level can be explained by farmers' preference for local red sorghum (*djigari*) compared to white sorghums such as S 35; the favorable climate for cultivation of other crops and the nonavailability of S 35 seed.

Cameroon. Ndjomaha et al. (1998) studied the adoption and impact of improved sorghum variety S 35 in northern Cameroon. S 35 was bred at ICRISAT-Patancheru (India) and introduced to this area in 1986. This area is popularly called the cotton belt of north-central Cameroon and is divided into three zones: Mayo Sava, Mayo Danay and Diamare. Thirty-four villages were selected (8 in Mayo Sava, 14 in Diamare and 12 in Mayo Danay) and a total of 571 farmers (136 from Mayo Sava, 250 from Diamare and 185 from Mayo Danay) were interviewed. Ten years after its introduction, S 35 was being grown on 50% of the rainfed sorghum area by 85% of the farmers in the Mayo Sava zone, but was much less popular in the Diamare (14% area) and Mayo Danay (12% area) zones.

Kamuanga and Fobasso (1994) conducted a similar study of S 35 adoption in north-central Cameroon in 1990. The study found that 13% of farmers adopted S 35, with 8.7% of the area covered by rainfed sorghum.

Mali. Yapi et al. (1998) studied the adoption of improved sorghum cultivars in three regions - Koulikoro, Segou and Mopti - of Mali. The study locations were at elevations between 400 and 900 m, but each occupied a different ecological niche. Data were collected from 300 units of agricultural production (UAP) spread over 43 villages in Mopti, Segou and Koulikoro in 1995 following a three-stage sampling procedure.

There were 213 adopters from 300 UAPs, with adoption levels in terms of cultivated area ranging from 17 to 29% between 1990 and 1995 across all three regions. During this period, adoption levels rose from 20 to 30% in Koulikoro, 14 to 29% in Segou and 14 to 23% in Mopti. The marginally higher levels in Koulikoro can be explained by the importance of sorghum in the local diet and favorable conditions for sorghum cultivation. Adoption levels in the other two regions are relatively high considering that sorghum is a secondary crop in local diets there.

8.4. Technology Adoption in Latin America

CGIAR (1996) reported that more than a fifth of the sorghum area in 1993 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 INTSORMIL and NARS). This included almost half the sorghum area in Guatemala, a third in Honduras and a fifth in Nicaragua and El Salvador (Table 8.7).

Table 8.7. Level of adoption (% of sorghum area) of improved sorghum cultivars in Central America.

		Percent area planted to	
Country	Year	Cultivars released through ICRISAT program	Others
Central American countries	1993	>20	NA
Guatemala	1993	49	NA
Honduras	1993	33	NA
Nicaragua	1993	20	NA
El Salvador	1993	20	NA
Honduras (southern region)	1990	-	15

Source: Lopez-Pereira et al. (1994) for Honduras; and CGIAR (1996) for other countries.

Lopez-Pereira et al. (1994) and Lopez-Pereira and Sanders (1992) reported that approximately 15% of the sorghum area in Honduras was covered by two improved sorghum cultivars (the hybrid Catracho and the variety Sureno) developed by the Ministry of Natural Resources' National Sorghum Program and INTSORMIL. These cultivars were adopted in the southern region of Honduras, which produces approximately 56% of the nation's sorghum. These high-yielding cultivars have good tortilla quality and respond well to chemical fertilizers, especially under improved soil and moisture conditions (Clara 2000).

8.5. Critical Factors Influencing Adoption

Surveys conducted in Nigeria, Chad, Cameroon and Mali collected information on reasons for the adoption of improved sorghum cultivars and the constraints to adoption faced by farmers (Table 8.8). Ogungbile et al. (1998) mentioned farmers' reasons for growing and not growing improved sorghum varieties (ICSV 111 and ICSV 400) in Nigeria. Early maturity topped the list of reasons for growing these new varieties while high yield ranked second. Good food quality, ease of threshing and processing ranked third, fourth and fifth, respectively.

Farmers of Chad had a number of reasons for adopting S 35. The three most common were early maturity, high yield and good taste (Yapi et al. 1999). Early maturity is more important to farmers in Guera than in the other two regions because end-of-season drought stress is a serious problem in that region. Early maturity is equally important in Mayo Kebbi (73%) and Chari Baguirmi (75%). Contrary to common belief, however, early maturity is not always associated with drought tolerance — it does provide a mechanism to escape more readily predictable end-of-season drought stress but can actually increase vulnerability to mid-season drought stress. The percentage of farmers citing high yield as an important factor in all three study zones confirms the importance of this criterion independent of agroclimatic zones. Good taste was an important trait for adoption in Guera because dietary habits in this region favor white sorghum; in fact, there is a price difference between the two types of sorghums in Chad, especially in Guera. It is surprising that such a high percentage of farmers (53% in Mayo Kebbi and 38% in Chari Baguirmi) adopted S 35 for its taste, especially in Chari Baguirmi where red sorghum is preferred. Less commonly cited reasons for adoption by the farmers included drought tolerance, a higher selling price and the 'sweetness' of the sorghum stalk.

Higher grain yield and tolerance to late sowing of S 35 and extension services from PNVFA (Program national de vulgarisation et de formation agricoles) were key factors influencing adoption of S 35 in Cameroon. Mayo Sava benefited from PNVFA services since 1989, while Diamare and Mayo Danay were covered only in 1992 and 1994. These extension efforts certainly have contributed to the higher adoption level of S 35 in Mayo Sava. Over the 10-year period (1986-95), S 35's yield advantage over the local variety was 432 kg in Mayo Sava, 89 kg in Diamare and 52 kg in Mayo Danay. These differences indicate a better genetic potential for S 35 in Mayo Sava than in the other two areas, probably because rainfall there is more congruent with the 300-800 mm research target regime. During the same period, average rainfall in Mayo Sava was 687 mm, while Diamare and Mayo Danay received 819 mm and 811 mm rainfall, respectively. Local sorghum varieties are usually

Table 8.8. Factors influencing adoption of improved sorghum cultivars in African countries.

Country	Region	Year	Cultivar	Factors influencing adoption
Botswana	National	1997	SDS 3320 (Phofu)	Broad acceptability of the variety for early maturity, large head and large white grain and strong stem resistant to lodging.
Cameroon	Mayo Sava, Diamare, Mayo Danay	1995	S 35	Yield gain (600 kg ha^{-1}) maximum during drought years when landrace yields are almost nil. Widely adopted for early maturity.
Chad	Guera, Mayo Kebbi, Chari Baguirmi	1995	S 35	Widely adopted for early maturity and fodder/food quality.
Malawi	National		SPV 351	Widely accepted for early maturity.
Mali	Segou, Koulikoro, Mopti	1995	All improved	Reasons for adoption of new sorghum varieties for all the three regions of Mali were earliness (85% farmers cited this), productivity (67%) and food quality (34%). These reasons varied in order and in importance in the three regions, perhaps due to rainfall differences.
Mozambique			ICSV 88060	Drought relief program distribution.
Nigeria	Kano, Katsina, Kaduna, Jigawa	1996-97	ICSV 111, ICSV 400	High yield and early maturity are the major reasons for adoption. Farmers cited good food quality, ease of threshing and processing, insect and disease resistance and lower labor requirement as reasons for adoption.

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

sown in June, but S 35 can be sown up to 15 July. Thus, when June rainfall is weak, S 35 fares better. Farmers of Cameroon cited several reasons for adopting S 35 - earliness, and food and feed quality. In addition, fanners in Mayo Sava and Diamare appreciate S 35 for its high productivity and grain color. In Mayo Sava, 27% of those interviewed adopted the variety for its high market price, which was 22-40% higher than the local variety. In Diamare, the stem of S 35 is consumed like sugarcane, a characteristic that was mentioned by nearly 20% of the farmers (Ndjomaha et al. 1998).

Kamuanga and Fobasso (1994) conducted a similar study of S 35 adoption in north-central Cameroon in 1990. Reasons for adoption cited by farmers were similar in the two studies. The study determined that adopters of S 35 cultivate relatively large areas, and have more plows and draft animals than the non-adopters. They also have more contact with extension agents and seem to exploit new technologies more readily. Factors such as education and age do not seem to affect adoption, but most of the adopters belong to the Mafa, Toupouri and Guiziga groups. On the other hand, the Foulbe, Moundang and Masa cultivate smaller amounts of S 35. This can be explained by the wide availability of the local red-grained variety Djagari, which is a good substitute for S 35 in the zones where the non-adopters live.

Yapi et al. (1998) mentioned that the main reasons for adoption of new sorghum varieties for all the three regions of Mali were earliness (85%), productivity (67%) and food quality (34%). These reasons varied in order and in importance in the three regions, perhaps due to rainfall differences.

8.6. Constraints to Adoption as Reported by Farmers

Low soil fertility was a constraint to adoption of improved sorghum cultivars generally mentioned by all Nigerian farmers. Farmers felt that the improved cultivars (ICSV 111 and ICSV 400) would not do well on marginal land without adequate fertilizer application. Another important constraint mentioned was insect damage. The improved 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. While people in Katsina and Jigawa who produce at subsistence level were concerned about the taste and texture of food prepared from grain of improved cultivars, farmers in Kaduna and Kano who produce grain for sale were not concerned about organoleptic characteristics of the grain (Ogungbile et al. 1998).

Lack of seeds was the major reason mentioned by most of the respondents in the Nigerian study for not growing the improved varieties. It was noted that breeders and other researchers had provided seeds as part of on-farm trials but it was not possible for everybody to take part in the on-farm trials. Seed companies were not producing these seeds to sell to farmers. Furthermore, seed companies are not likely to be interested in producing OPVs. Farmers' response - lack of knowledge - could be interpreted to indicate ineffectiveness of extension communications regarding these cultivars. 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 necessary inputs (Ogungbile et al. 1998).

Constraints to adoption of S 35 in Chad, as mentioned by farmers, included vulnerability to bird damage (due to early maturity), poor soil fertility, nonavailability of seed and seed cost (Yapi et al. 1999).

There were many reasons for non-adoption in Cameroon. The most important reasons cited by farmers there included losses due to birds, grain mold, high price of milling, light food, regermination of seed, need for fertile soil, poor quality of beer, small stalks for construction, dislike of stalks by animals and lack of seed (Ndjomaha et al. 1998). Several reasons such as losses due to birds, grain mold and regermination of seed are due to the early maturity of S 35, which although helpful when rains cease early, results in increased vulnerability to damage by rain during grain maturation.

The most significant constraints to adoption of improved sorghum cultivars cited by Malian farmers were lack of information about the existence and utility of new varieties (58%), lack of seed (50%) and poor soil (13%). Lack of information and seed were the most important constraints in all three regions, while poor soil was a problem only in Mopti. In Segou, there was a strong preference for local varieties. In Koulikoro, the need to use fertilizer on improved varieties, their greater vulnerability to bird damage, labor shortages and storage characteristics were cited by farmers as adoption constraints (Yapi et al. 1998).

Based on a farm-level survey conducted across 119 households in southern Honduras in 1990, Lopez-Pereira and Sanders (1992) reported that development of soil conservation technologies would be a necessary precondition for increasing the adoption of improved sorghum cultivars in hillside farming areas of southern Honduras. Another major constraint to adoption was the limited working capital of small farmers. The study suggested that greater access to official credit and better credit conditions for small farmers would be necessary for the adoption of new sorghum cultivars and soil erosion control technologies.

8.7. Lessons from Adoption Studies

Adoption levels of improved sorghum cultivars are high in Asian countries, but comparatively low in African countries. Inter-country comparisons of adoption show that ICRISAT crosses are popular in several African countries. Adoption studies conducted at the farm-, district- and state-levels revealed that adoption of cultivars is related to: (i) the presence of farmers' preferred traits in the new cultivars, (ii) the ease of access to seeds of specific cultivars and/or management options made available when specific cultivars are grown, and (iii) the availability of seeds and the profitability of new cultivars. These have important implications for breeding strategy and for seed delivery systems. The participation of farmers and NARS in all stages of variety selection and development would help ensure that farmers have access to improved varieties with farmer preferred traits. Availability of seed of improved open-pollinated cultivars should be ensured through the participation of farmer cooperatives and public sector seed companies. The involvement of private sector seed companies will be economically attractive and substantial only when hybrid cultivars that provide a reliable and recurring market for seed are available. Therefore, promotion of sorghum hybrids in Asian countries may be possible through broader partnerships and innovative institutional arrangements of public breeding programs with the private sector. On the other hand, promoting OPVs may require stronger involvement of public sector companies and community-level seed production. Availability of source seed (breeder's seed) is a necessary precondition for producing foundation seed and certified seed and their equivalents. It is essential that ICRISAT and its partners lay greater emphasis on the supply of breeder's seed to public and private sector seed companies, and producers of community-level seed.

8.8. References

CGIAR (Consultative Group on International Agricultural Research). 1996. CGIAR Newsletter, March 1996 (http://www.worldbank.org/html/cgiar/newsletter/Mar96/4sorghla.htm).

Clara VR. 2000. Sorghum (*Maicillo*) in El Salvador, Central America. Pages 26-28 *in* International Sorghum and Millet Newsletter, Vol. 41. Texas, USA: Sorghum Improvement Conference of North America, and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Deb UK and Bantilan MCS. 1998. Impact on genetic diversity and yield stability. Chapter 7 *in* Spillover impacts of sorghum germplasm research (Deb UK and Bantilan MCS, eds.). Andhra Pradesh, India: Socio-Economics and Policy Program, ICRISAT. Mimeo.

Kamuanga ML and Fobasso M. 1994. Role of farmers in the evaluation of an improved variety: The case of S 35 in northern Cameroon. Journal for Farming System Research and Extension 4(2):93-110.

Lopez-Pereira MA and Sanders JH. 1992. Market factors, government policies and adoption of new technology by small Honduran farmers: A stochastic programming application. Quarterly Journal of International Agriculture 31:55-73.

Lopez-Pereira MA, Sanders JH, Baker TG and Preckel PV. 1994. Economics of erosion-control and seed-fertilizer technologies for hillside farming in Honduras. Agricultural Economics 11:271-288.

Ndjomaha C, Yapi A and Adamou A. 1998. Impact of sorghum S 35 in extreme north Cameroon. Pages 26-37 *in* Assessing joint impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT, 2-4 Dec 1996, ICRISAT, Patancheru, India, (Bantilan MCS and Joshi PK, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Obilana AB, Monyo ES and Gupta SC. 1997. Impact of genetic improvement in sorghum and pearl millet: Developing country experiences. Pages 119-141 *in* Proceedings of the International Conference on Genetic improvement of sorghum and pearl millet, 22-27 Sep 1996, Holiday Inn Plaza, Lubbock, Texas. INTSORMIL and ICRISAT.

Ogungbile et al. 1998. Factors influencing awareness and adoption of ICSV 111 and ICSV 400 sorghum varieties. Socio-economics and Policy Program, ICRISAT, Patancheru 502 324, Andhra Pradesh, India. Mimeo.

Rana BS, Swarnalata Kaul and Rao MH 1997. Impact of genetic improvement on sorghum productivity in India. Pages 141-165 *in* Proceedings of the International Conference on Genetic improvement of sorghum and pearl millet, 22-27 Sep 1996, Holiday Inn Plaza, Lubbock, Texas. INTSORMIL and ICRISAT.

Rohrbach DD and Makhwaje E. 1999. Adoption and impact of new sorghum varieties in Botswana. PO Box 776, Bulawayo, Zimbabwe: Southern African Development Community/International Crops Research Institute for the Semi-Arid Tropics, Sorghum and Millet Improvement Program (SMIP) (Semiformal publication).

Sanders JH, Bezuneh T and Schroeder TC. 1994. Impact assessment of the SAFGRAD commodity networks. Mimeo.

Yapi A, Kergna AO, Debrah SK, Sidibe A and Sanogo O. 1998. Impact of sorghum and millet research in Mali. Pages 76-93 *in* Assessing joint impacts: proceedings of an International Workshop on Joint impact assessment of NARS/ICRISAT, 2-4 Dec 1996, ICRISAT, Patancheru, India (Bantilan MCS and Joshi PK, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

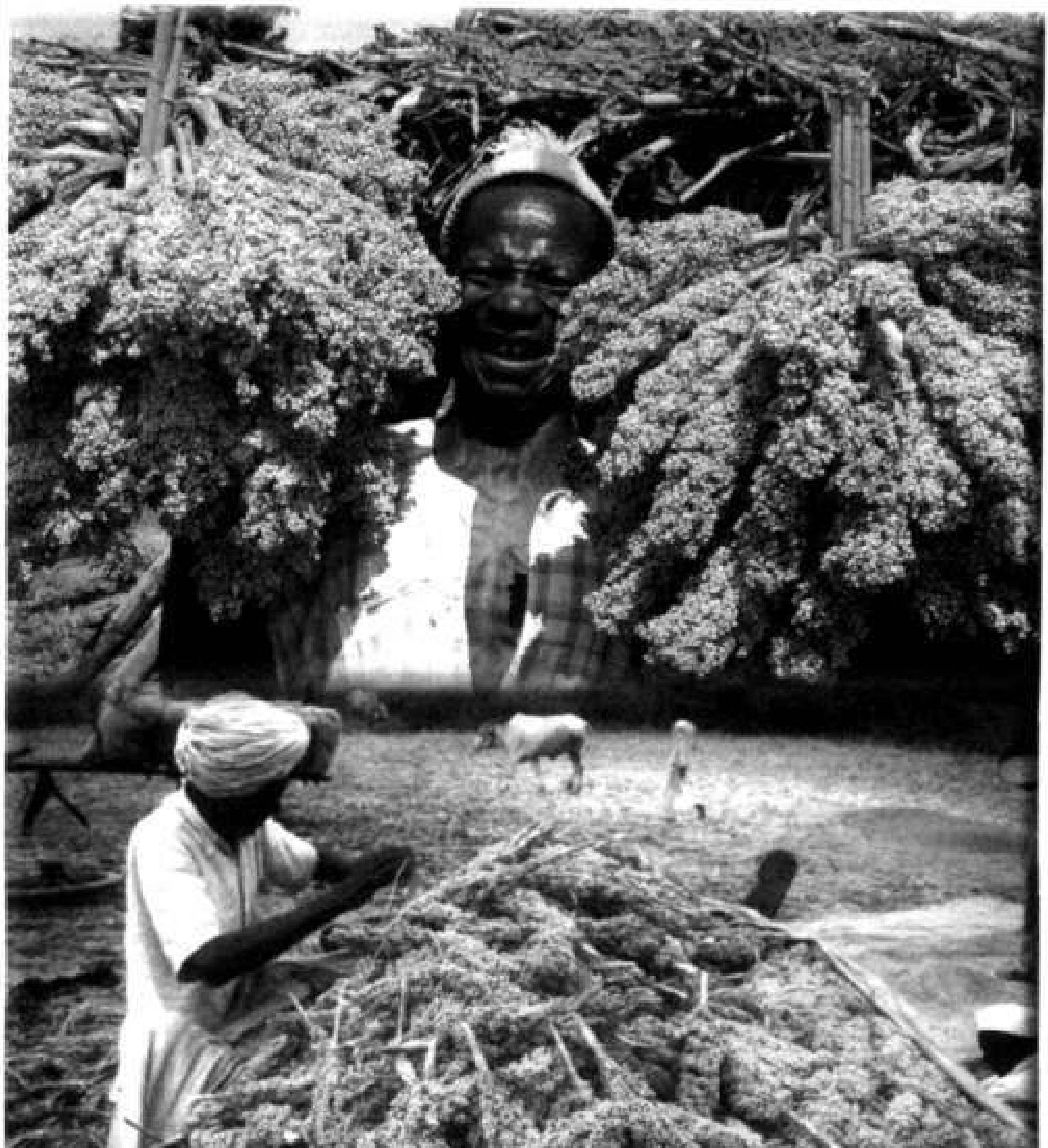
Yapi A , Debrah SK, Dehala G and Njomaha C. 1999. Impact of germplasm research spillovers: The case of sorghum variety S 35 in Cameroon and Chad. Impact Series No. 3. ICRISAT, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 30 pp.

PART IV: Impacts of Improved Cultivars and Future Directions

Productivity Impacts of Improved Sorghum Cultivars

9

UK Deb, MCS Bantilan, RE Evenson and AD Roy



Productivity Impacts of Improved Sorghum Cultivars

UK Deb[1], MCS Bantilan[2], RE Evenson[3] and AD Roy[4]

9.1. Introduction

The ultimate goal of sorghum breeding is to create impacts in farmers' fields. Impacts from improved sorghum cultivars may be obtained through increase in yield, reduction in per unit cost of production or increase in stability of yield. This chapter analyzes all these aspects based on data collected from different sources.

9.2. Methodology

The indicators used in measuring productivity impacts are reduction in per unit cost of production, yield gains and yield variability. Variability in yield of sorghum has been measured in relative terms using the Cuddy-Delia Valle Index, used in recent years as a measure of variability in time series data [Weber and Sievers 1985; Singh and Byerlee 1990). The simple coefficient of variation (CV) overestimates the level of instability in time series data characterized by long-term trends, whereas the Cuddy-Delia Valle Index corrects the coefficient of variation by:

$$CV = (CV^*)\ (1-R^2)^{0.5} \qquad \ldots(9.1)$$

where

CV is the Cuddy-Delia Valle Index, ie, the corrected CV. Henceforth, any mention of CV would refer to the Cuddy-Delia Valle Index.

CV^* is the simple estimate of the CV (%)

R^2 is the coefficient of determination from time trend regression adjusted by the number of degrees of freedom.

Some authors have estimated CV around trend as the standard error of regression divided by the mean. After estimating CV both ways from the same set of data, Singh and Byerlee (1990) found identical results whichever method was used. In their case, the correlation between the instability indices of two methods was 0.9998. Since both methods provide similar results, here we have estimated instability index using the Cuddy-Delia Valle Index.

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

Deb UK, Bantilan MCS, Evenson RE and Roy AD. 2004. Productivity impacts of improved sorghum cultivars. Pages 203-222 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

9.3. Impact on Sorghum Yield

9.3.1. Global Yield Scenario

Figure 9.1 depicts sorghum yields and yield gains in different countries of the world in 1999-2001 compared to 1971-73. In the early 1970s, yield levels were very low in a majority of the developing countries. However, in the mid-1990s yields rose in Asia (China, India, Pakistan and Korean Republic). Per hectare yield increased by more than 3 t (3213 kg) in China and by 320 kg (65%) in India. By 1998, hybrid adoption in China had exceeded 98% and the adoption of improved cultivars in India was about 73%. Yields increased in Pakistan by 21% and doubled in North Korea. In Thailand, sorghum yield decreased. In the 1960s, Thailand used to grow sorghum for grain purposes but since the 1980s, a large area under the crop is being used for fodder, and the dried fodder is exported to Japan. FAO data do not record this fact since only area harvested and grain production are reported.

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. There has been no significant change in other African countries. In many southern African countries, yields declined in the 1990s compared to the early 1960s. This decline could have been due to low fertilizer use and a shift in sorghum cultivation to poorer land. Moreover, breeders have laid emphasis on developing improved cultivars with early maturity and yield stability rather than high yield. A thorough analysis is required to identify the reasons for the decline in yield in many African countries.

Sorghum yield in European countries has increased substantially. It has doubled in Italy and France, tripled in Greece and increased fivefold in Spain. There was a notable increase in yield in the Americas (Colombia, Mexico and USA). Yield doubled in Argentina, Nicaragua, Albania, Guatemala and Peru.

A comparison of trends in average yield in Africa and India for the last four decades indicates that sorghum yield in India has consistently gone up and has already crossed the average yield of Africa, though the yield of sorghum in Africa in the 1960s was much higher than that of India (Figure 9.2). As is known, this happened due to the development of improved sorghum cultivars by scientists and the uptake of these cultivars by farmers in India, given the more favorable infrastructure and policy environment supporting technology uptake. Regression analyses of the same sorghum data confirm the significance of several factors influencing yield. Important among these are high yielding varieties (HYVs), agroecological factors and infrastructure variables (market density, road infrastructure and irrigation) (Bantilan 2003).

9.3.2. District-level Yield in India

Figures 9.3 and 9.4 portray the yields in different sorghum-growing districts of India for rainy-season sorghum and postrainy-season sorghum. Figure 9.3 shows that the yield gains from rainy-season sorghum in Maharashtra and Andhra Pradesh were high where adoption rates too were high. Yield per hectare increased by at least 750 kg in the districts in these states and by more than one ton in many districts. It may be noted here that India's research focus has been mainly on rainy-season sorghum. There was less research on postrainy-season sorghum; so fewer improved cultivars were developed and yield increases were lower (Figure 9.4).

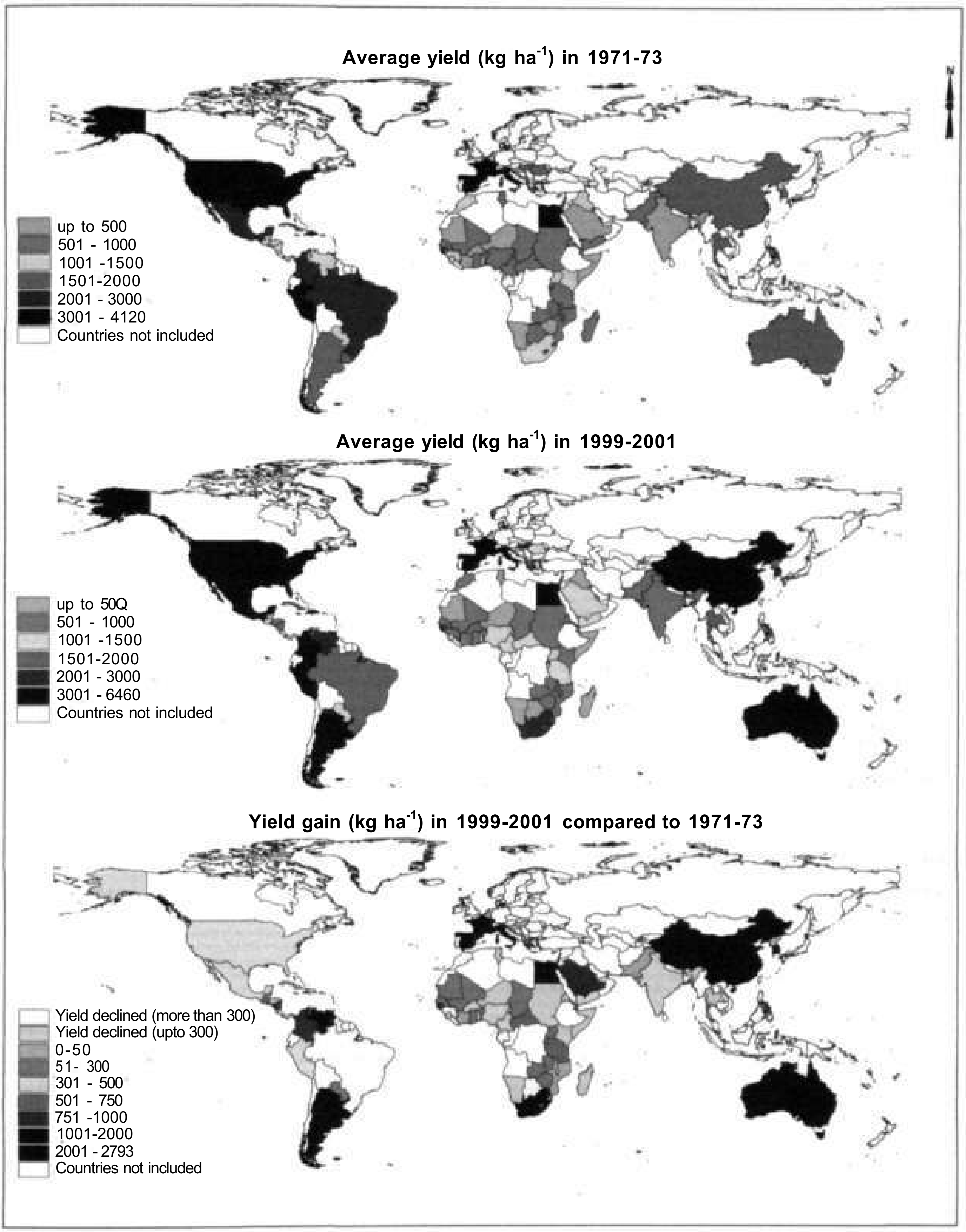


Figure. 9.1. Average yield and yield gain in sorghum in different countries.

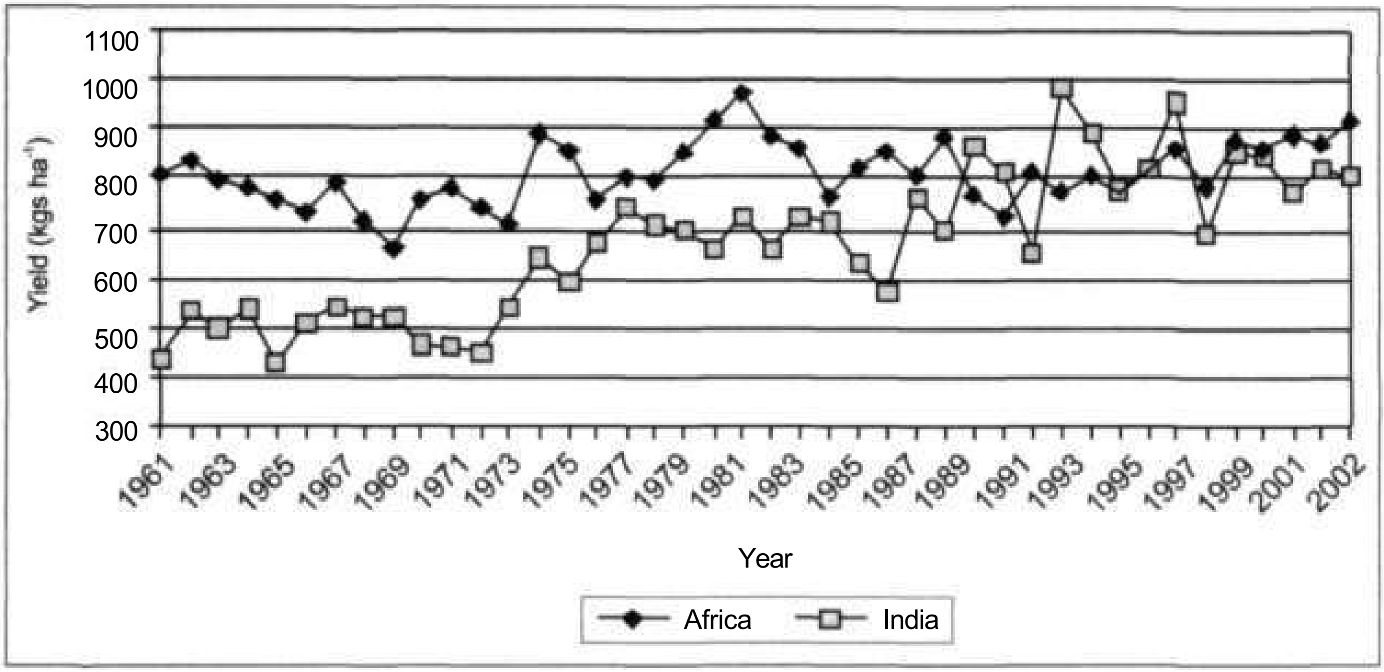


Figure. 9.2. Trends in sorghum yields in Africa and India, 1961-2002.

9.3.3. Yield Gain at the Farm Level

Table 9.1 summarizes farm-level yield gains from different studies conducted in Africa. Yields of improved cultivars were 7-63% higher than the best local cultivars in Nigeria. Improved sorghum variety S 35 had a 51% yield advantage in Chad and 14% in Cameroon. Ndjomaha et al. (1998) reported that during 1986-95, the per hectare difference in productivity between S 35 and the local variety was 432 kg in Mayo Sava, 89 kg in Diamare and 52 kg in Mayo Danay regions of Cameroon. 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 profits increased by 51% (Yapi et al. 1998). These yields are consistent with those found in previous studies. Shetty et al. (1991) noted that sorghum yields in Mali were about 600 kg ha^{-1} compared to 2,000-3,000 kg ha^{-1} on research stations.

9.4. Impact on Cost of Production

An analysis of the cost of cultivation data based on farm-household surveys conducted by the Government of India shows that real cost of production per ton of sorghum in India decreased in the 1980s and the 1990s compared to the early 1970s. In Maharashtra, it fell by 40% in the 1990s compared to the 1970s. In Rajasthan this figure was 37% (Table 9.2).

The farm-level impact of improved sorghum cultivars on per unit cost of production is presented in Table 9.3. S 35 had a cost advantage of 12% in Cameroon and 25% in Chad (Yapi et al. 1999). Using improved sorghum varieties in Mali reduced production cost by as much as 25% (US$34 t^{-1}), compared to local varieties. 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 for either the market or their own consumption.

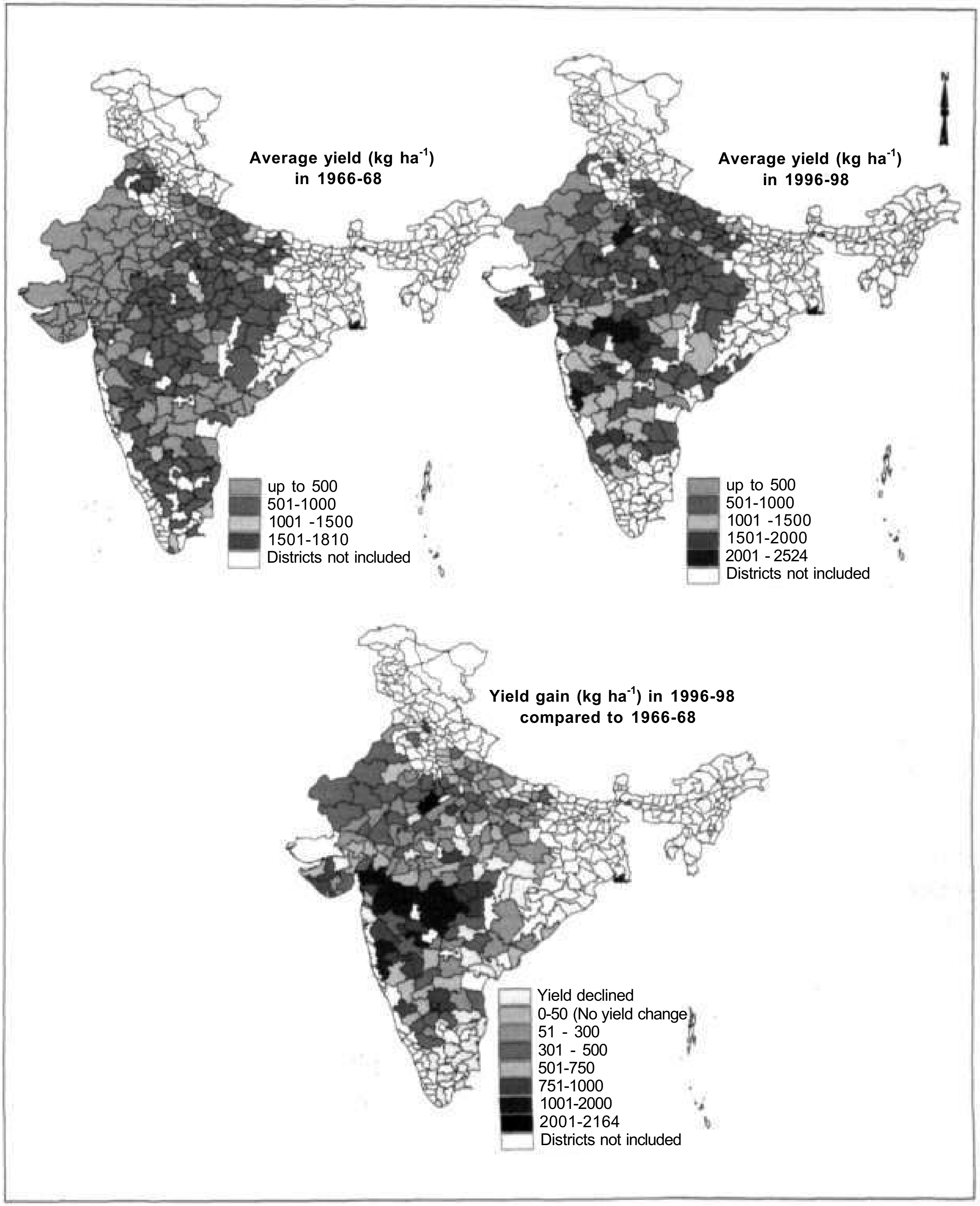


Figure. 9.3. Average yield and yield gain in rainy-season sorghum in India.

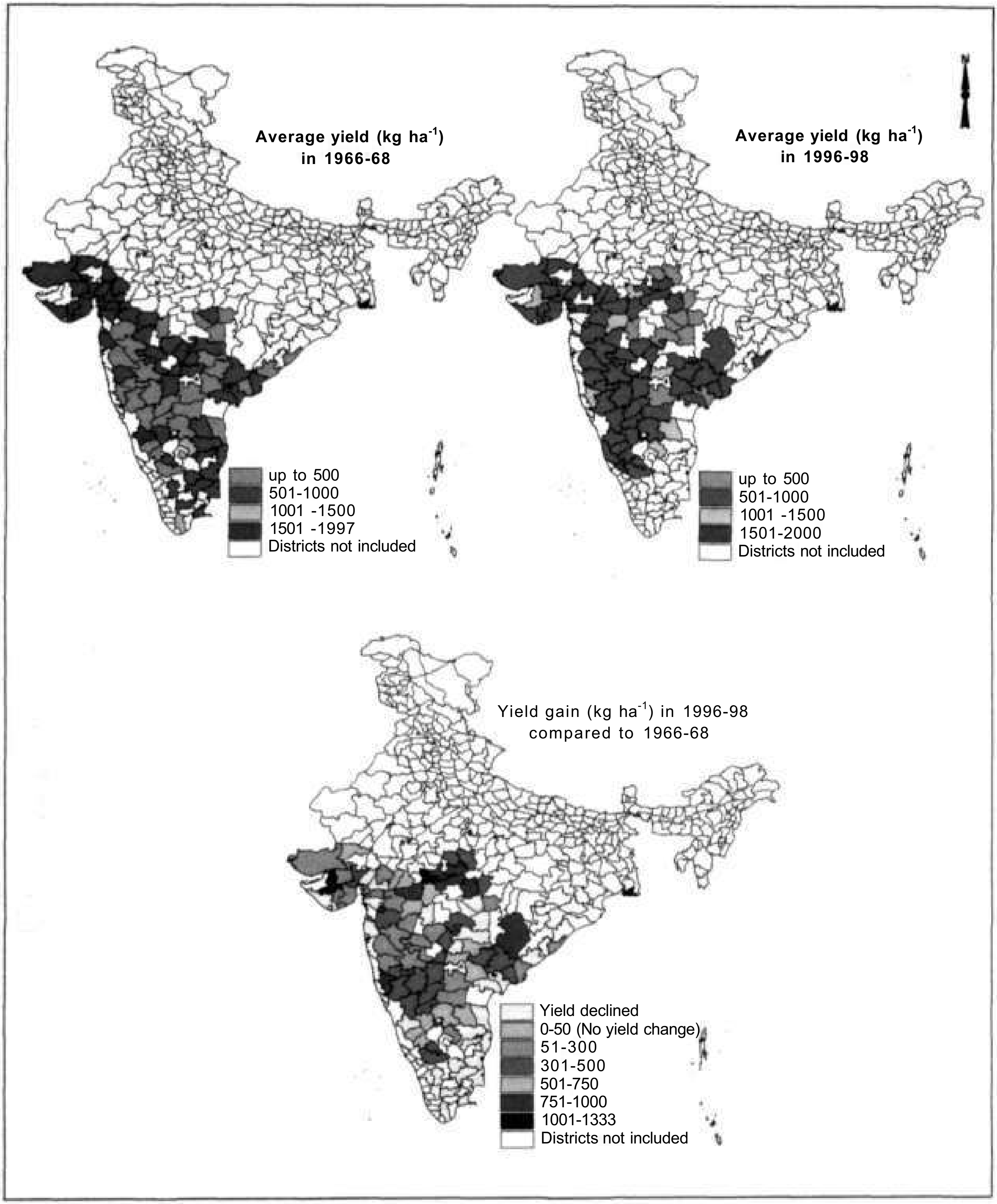


Figure. 9.4. Average yield and yield gain in postrainy-season sorghum in India.

Table 9.1. 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. 1998.

Table 9.2. Impact of improved sorghum cultivars on per ton production cost[1] in India, 1971-95.

States	Average cost (Rs t^{-1}) Early 1970s[2]	Average cost (Rs t^{-1}) Early 1980s[3]	Average cost (Rs t^{-1}) Early 1990s[4]	Cost reduction (%) compared to the early 1970s: Early 1980s	Cost reduction (%) compared to the early 1970s: Early 1990s
Andhra Pradesh	270	NA[5]	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

1. All costs are real costs of production. For Rajasthan, the real cost is computed on the basis of 1992 prices and for all the other states it is based on 1989 prices.
2. Early 1970s indicate for Andhra Pradesh (average of 1973-74), Karnataka (average of 1972-74), Madhya Pradesh (1976), Maharashtra (average of 1972-74) and Rajasthan (average of 1972-74).
3. Early 1980s indicate for Karnataka (average of 1981-83), Madhya Pradesh (average of 1981-83), Maharashtra (average of 1982-83) and Rajasthan (average of 1981-83).
4. Early 1990s indicate for Andhra Pradesh (average of 1994-95), Karnataka (1991), Madhya Pradesh (average of 1994-95), Maharashtra (1995) and Rajasthan (1992).
5. NA = Not available.

Source: Calculated from various reports of the Commission for Agricultural Costs and Prices, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.

9.5. Impact on Yield Stability

9.5.1. Asia

Relative variability in yield is an important indicator of stability in the productivity of a given crop in a given region. Table 9.4 shows the relative variability in sorghum yield in different countries and the changes (%) in the index in the 1980s (1981-90) and the 1990s (1991-99) compared to the 1970s (1971-80). This relative variability is the Cuddy-Delia Valle Index explained earlier. An increase in variability in area, production and yield is not desirable since it indicates instability in the system.

Table 9.3. Impacts of improved sorghum cultivar S 35 on per unit cost of production in Cameroon and Chad, 1995.

Country	Region	Unit variable costs (CFA Francs t^{-1})		Unit cost reduction (%)
		Local	Improved	
Cameroon	Mayo-Sava	77500	57700	26
Cameroon	Diamare	63500	58900	7
Cameroon	Mayo Danay	50000	49300	1
Cameroon		63161	55607	12
Chad	Guera	89296	65825	26
Chad	Mayo-Kebbi	45994	37903	18
Chad	Chari-Baguirmi	67765	49947	26
Chad		80805	60817	25

Source: Yapi et al. 1999.

There was an increase in variability in sorghum yield in five out of the nine study countries of Asia during the 1990s. In both India and China, relative variability in yield increased during this period. In the 1990s, both countries had a relative variability in yield of around 12.3%, though China had a much lower yield variability in the 1970s (4.23%) compared to India (8.72%). On the other hand, Pakistan was the only major sorghum-producing country which showed a decline in relative variability in yield in all the time periods, except for the 1980s compared to the 1970s.

Tables 9.5, 9.6 and 9.7 show the association between yield and instability in sorghum yield during the 1990s compared to earlier decades (ie, the 1970s and 1980s); and the 1980s compared to the 1970s, respectively. The types of association were split into four categories: AA - increase in yield with decrease in variability; AB - increase in yield with increase in variability; BA - decrease in yield with decrease in variability; and BB - decrease in yield with increase in variability. AA is the most ideal type of association while BB is the undesired type of association (Fig. 9.5).

Pakistan, Saudi Arabia and Thailand were the three countries under AA association during the 1990s compared to the 1970s (Table 9.5). China, India, the Korean Republic and Yemen fell under AB type. None of the countries fell under type BA in the 1990s compared to the 1970s, while only Korea DPR was in type BB association.

In the 1990s compared to the 1980s (Table 9.6), as many as 4 countries - Saudi Arabia, Yemen, Thailand and Pakistan - out of the 8 studied were under AA type of association. Among these, except for Pakistan and Yemen, the other two countries were minor producers of sorghum. China and India were in AB type; the Korean Republic in BA type and Korea DPR slid to the most undesirable BB type. Pakistan was the only major sorghum-producing country in the region that experienced type AA association in the 1990s compared to the 1980s and the 1970s. India and China on the other hand exhibited an increase in yield as well as an increase in variability in yield.

Comparing the 1970s and the 1980s (Table 9.7), there was an AA type of association in only one country (Korea DPR) out of the eight studied. India, China, the Korean Republic and Saudi Arabia showed AB type of association, and Pakistan and Thailand the BA type.

9.5.2. Africa

It is noted that 17 of the 24 countries in WCA saw a decline in variability in yield (Table 9.8). The countries that showed the greatest decline in yield variability were Guinea-Bissau (-88.1%), Nigeria

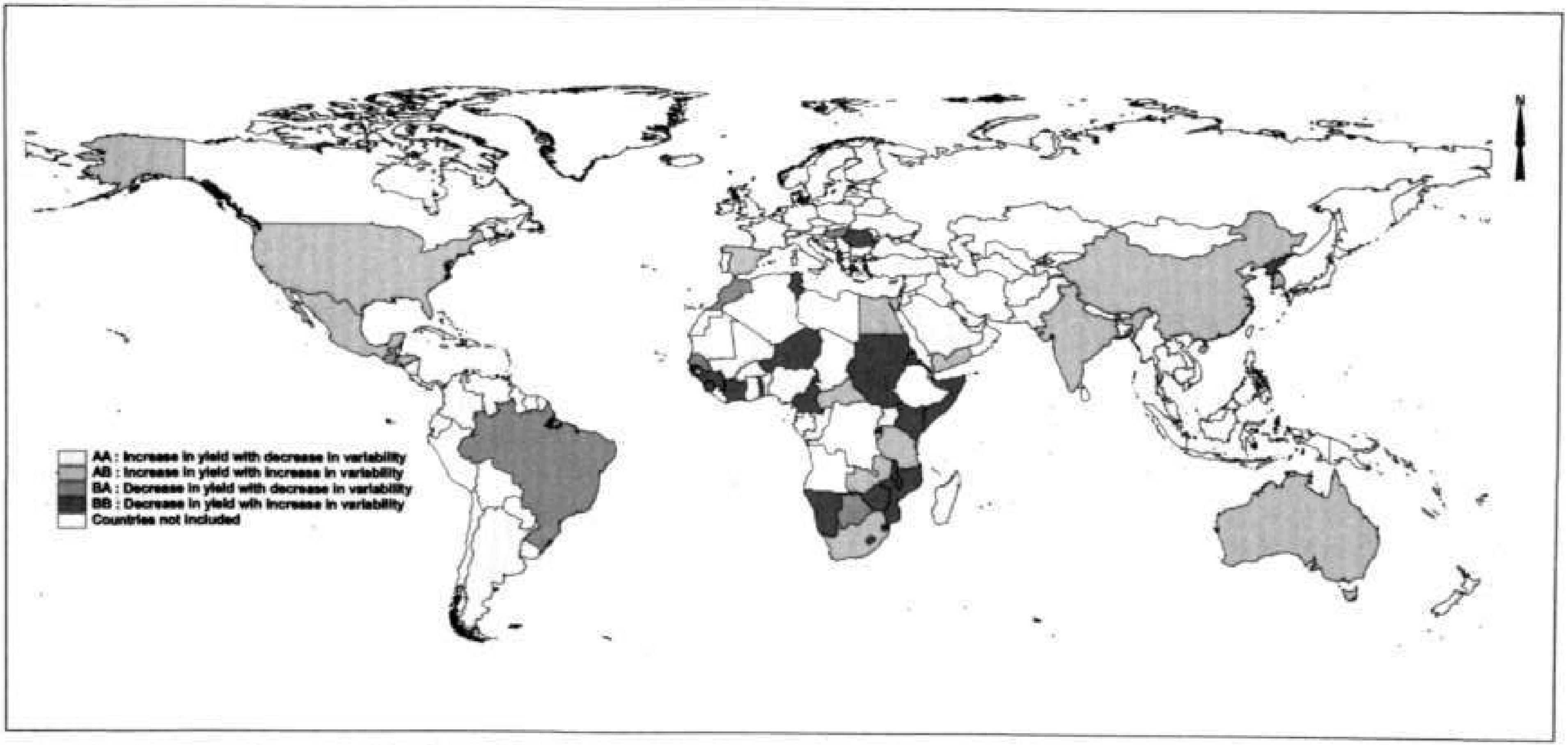


Figure. 9.5. Association between yield and instability in yield of sorghum.

Table 9.4. Relative variability in sorghum yield in different countries.

Country	Relative variability (CV) 1971-80	1981-90	1991-99	Change compared to 1971-80 (%) 1981-90	1991-99
Albania	6.15	2.81	9.62	-54.38	56.40
Argentina	13.81	9.06	8.49	-34.38	-38.49
Australia	15.19	16.45	19.71	8.25	29.74
Benin	11.79	8.87	3.03	-24.79	-74.33
Botswana	60.35	33.36	31.00	-44.71	-48.63
Brazil	16.94	10.40	8.78	-38.63	-48.16
Burkina Faso	8.12	11.13	5.31	37.04	-34.59
Burundi	3.09	9.03	5.69	192.12	83.96
Cameroon	5.67	16.52	5.81	191.43	2.42
Central African Rep	9.62	16.97	16.15	76.36	67.80
Chad	11.47	13.00	8.61	13.34	-24.93
China	4.23	8.70	12.34	105.70	191.68
Colombia	7.02	5.76	3.57	-17.92	-49.21
Egypt	1.97	3.87	9.33	96.62	373.74
El Salvador	7.60	28.97	8.13	281.26	6.97
Eritrea	4.99	7.62	35.20	52.84	605.62
France	13.59	13.74	6.32	1.12	-53.50
Gambia	20.99	13.59	10.38	-35.26	-50.54
Ghana	10.46	23.19	7.82	121.79	-25.18
Guatemala	16.31	18.68	1.12	14.51	-93.15
Guinea	3.68	11.41	16.41	210.48	346.40
Guinea-Bissau	7.97	27.90	3.32	249.84	-58.41
Haiti	12.10	4.38	2.69	-63.79	-77.72
Honduras	17.91	12.37	19.12	-30.93	6.74
Hungary	26.67	42.87	25.12	60.73	-5.83
India	8.72	10.68	12.39	22.45	42.09
Italy	8.96	17.49	4.03	95.22	-55.07
Ivory Coast	9.87	6.04	11.10	-38.81	12.50
Kenya	4.27	27.27	10.65	538.02	149.09
Korea DPR	3.45	2.83	10.25	-18.03	197.19
Korea Rep.	4.65	24.67	8.43	430.42	81.23
Lesotho	29.06	20.01	30.46	-31.16	4.82
Madagascar	47.23	21.02	6.27	-55.50	-86.72
Malawi	10.05	21.16	31.44	110.52	212.78
Mali	18.63	15.06	13.40	-19.18	-28.05
Mauritania	33.67	23.40	7.41	-30.49	-78.01
Mexico	6.20	7.21	9.02	16.38	45.54
Morocco	46.20	19.17	36.22	-58.51	-21.59
Mozambique	14.10	13.62	19.96	-3.44	41.53
Namibia	10.12	4.20	57.88	-58.45	471.90
Nicaragua	15.81	13.70	15.37	-13.40	-2.82
Niger	14.70	22.06	17.00	50.05	15.66
Nigeria	21.33	12.07	2.67	-43.43	-87.50

...continued

Table 9.4. *Continued*

	Relative variability (CV)			Change compared to 1971-80 (%)	
Country	1971-80	1981-90	1991-99	1981-90	1991-99
Pakistan	**3.97**	**1,72**	1.22	-56.61	-69.16
Peru	**7.95**	**9.93**	15.05	24.98	89.45
Romania	26.55	16.48	39.41	-37.92	48.47
Rwanda	6.48	10.40	23.15	60.56	257.30
Saudi Arabia	27.85	31.97	5.10	14.80	-81.70
Senegal	21.28	9.73	10.67	-54.29	-49.85
Sierra Leone	5.66	25.12	9.02	344.05	59.40
Somalia	5.12	5.52	14.27	7.77	178.71
South Africa	20.76	22.40	26.42	7.92	27.28
Spain	5.79	5.18	12.75	-10.44	120.31
Sudan	7.06	30.67	13.56	334.33	92.06
Swaziland	25.72	57.18	39.56	122.28	53.80
Tanzania, United Rep.	17.93	32.02	20.63	78.56	15.06
Thailand	16.93	8.91	5.04	-47.34	-70.24
Togo	5.18	17.55	13.11	238.54	152.91
Tunisia	8.37	12.26	17.96	46.43	114.49
Uganda	15.91	14.82	13.28	-6.79	-16.49
Uruguay	20.07	13.94	5.57	-30.57	-72.25
USA	11.26	10.20	12.76	-9.46	13.33
Venezuela	11.11	4.43	5.20	-60.08	-53.19
Yemen	7.81	32.17	14.86	311.93	90.26
Zambia	14.00	15.60	17.74	11.36	26.64
Zimbabwe	13.67	37.73	26.41	176.08	93.24

Source: Authors' calculation is based on FAO (2002).

(-77.9%) and Mauritania (-68.4%). In all these countries except Nigeria, absolute sorghum yield was quite low, lower than even the regional average yield in both the 1980s and the 1990s. On the other hand, there has been an increase in variability in yield in Egypt, a country with the highest yield among those studied in the WCA and SEA regions. Therefore, though there has been a decline in variability in yield in a majority of the countries in WCA, this has been truer in the case of countries with low absolute yield than those with high absolute yield.

The SEA region presented a different picture. There was an increase in relative variability in both area and production of sorghum during the 1980s and the 1990s. There has been a decline in variability in area in only 5 (Madagascar, Tanzania, Zambia, Somalia and Mozambique) of the 14 countries studied. The rest of the countries saw an increase in variability in area. A similar trend was noticed in SEA, where only 6 (Madagascar, Swaziland, Kenya, Zambia, Botswana and Zimbabwe) of the 14 countries studied witnessed a decline in variability in production. Among all these countries, except for Kenya, the rest contributed a minor share in the region's production of sorghum. Tanzania and South Africa, the major sorghum producers in the region, on the other hand witnessed an increase in variability in production in the 1990s compared to the 1980s. In terms of variability in yield in SEA, there has been a decline in variability in only 6 countries - Madagascar, Kenya, Tanzania, Swaziland, Zimbabwe and Botswana (listed in the order of decline). Among these countries, except for Tanzania and Kenya, which showed high absolute yields, the rest fared poorly.

Table 9.5. Association between yield and instability in yield of sorghum in different countries in the 1990s (1991-99) compared to the 1970s (1971-80).

Region	Types of association			
	AA: Increase in yield with decrease in variability	AB: Increase in yield with increase in variability	BA: Decrease in yield with decrease in variability	BB: Decrease in yield with increase in variability
Asia	Saudi Arabia, Pakistan, Thailand	India, Korea Rep, Yemen, China	-	Korea DPR
Others	Italy, France	USA, Australia, Spain	Hungary	Albania, Romania
Latin America	Uruguay, Venezuela, Colombia, Argentina, Nicaragua	Honduras, El Salvador, Mexico, Peru	Haiti, Guatemala, Brazil	
Southern and Eastern Africa	Madagascar	Tanzania, Zambia, South Africa	Botswana	Lesotho, Mozambique, Swaziland, Zimbabwe, Kenya, Somalia, Malawi, Namibia, Eritrea
Western, Central and Northern Africa	Nigeria, Mauritania, Benin, Guinea-Bissau, Gambia, Burkina Faso, Mali, Ghana, Chad, Uganda	Central African Rep, Burundi, Egypt	Senegal, Morocco	Cameroon, Ivory Coast, Niger, Sierra Leone, Sudan, Tunisia, Togo, Rwanda, Guinea

Source: Authors' calculation based on FAO Agricultural Statistics (http://www.fao.org).

Table 9.6. Association between yield and instability in yield of sorghum in different countries in the 1990s (1991-99) compared to the 1980s (1981-90).

Region	Types of association			
	AA: Increase in yield with decrease in variability	AB: Increase in yield with increase in variability	BA: Decrease in yield with decrease in variability	BB: Decrease in yield with increase in variability
Asia	Saudi Arabia, Yemen, Thailand, Pakistan	China, India	Korea Rep	Korea DPR
Others	Italy, France	Australia, Romania, Spain	Hungary	USA, Albania
Latin America	El Salvador, Uruguay, Colombia, Argentina	Venezuela, Peru, Honduras	Guatemala, Haiti, Brazil	Nicaragua, Mexico
Southern and Eastern Africa	Madagascar, Kenya, Zimbabwe, Botswana	South Africa, Lesotho	Tanzania, Swaziland	Zambia, Mozambique, Malawi, Somalia, Eritrea, Namibia
Western, Central and Northern Africa	Guinea-Bissau, Mauritania, Ghana, Benin, Cameroon, Sudan, Burkina Faso, Burundi, Chad, Gambia	Egypt	Nigeria, Sierra Leone, Togo, Niger, Mali, Uganda, Central African Rep	Senegal, Guinea, Tunisia, Ivory Coast, Morocco, Rwanda

Source: Authors' calculation based on FAO Agricultural Statistics (http://www.fao.org).

Table 9.7. Association between yield and instability in yield of sorghum in different countries in the 1980s (1981-90) compared to the 1970s (1971-80).

	Types of association			
Region	AA: Increase in yield with decrease in variability	AB: Increase in yield with increase in variability	BA: Decrease in yield with decrease in variability	BB: Decrease in yield with increase in variability
Asia	Korea DPR	Saudi Arabia, India, China, Korea Rep	Pakistan, Thailand	Yemen
Others	Albania, Spain, USA	Australia, France, Hungary, Italy	Romania	
Latin America	Venezuela, Argentina, Honduras, Uruguay, Colombia, Nicaragua	Guatemala, Mexico, Peru	Brazil, Haiti	El Salvador
Southern and Eastern Africa	Namibia, Madagascar	Somalia, Zambia, Eritrea, Tanzania United Rep, Swaziland	Botswana, Lesotho, Mozambique	South Africa, Malawi, Zimbabwe, Kenya
Western, Central and Northern Africa	Senegal, Nigeria, Ivory Coast, Gambia, Mauritania, Benin, Mali, Uganda	Chad, Burkina Faso, Rwanda, Central African Rep, Egypt, Burundi, Guinea, Togo, Guinea-Bissau	Morocco	Tunisia, Niger, Ghana, Cameroon, Sudan, Sierra Leone

Source: Authors' calculation based on FAO Agricultural Statistics (http://www.fao.org).

Table 9.9 shows the association between sorghum yield and instability in yield in different African countries. As many as 10 of the 24 countries in WCA fell under type AA association (increase in yield with a decline in variability). This is a positive sign as far as sorghum production is concerned. In SEA on the other hand, many of the countries fell under type BB (decrease in yield with increase in variability). This speaks unfavorably for the region as a whole. As many as 6 countries out of 14 in SEA were in BB type, while in WCA only 6 countries out of the 24 came under this type. On the whole, it can be said that sorghum production in terms of yield and stability in yield has been better in WCA than in SEA.

Table 9.10 classifies the sorghum area of countries by changes in the CV in sorghum yield between the 1970s and the 1990s. Majority of the countries in WCA (16 out of 24) experienced a decline in variability in yield of 10% or more. These countries account for 97% of the total area under sorghum. On the other hand, 8 countries of the 14 in SEA recorded increases in yield variability of 10% or more. These countries account for 57% of the total area under sorghum. This therefore reaffirms our earlier observation that WCA on the whole has performed better than SEA in terms of sorghum production stability in Africa.

9.6. Relationship between Adoption of Improved Cultivars,Yield and Variability in Yield

Table 9.11 shows the association between percentage change in yield and adoption of improved sorghum cultivars in Africa in the 1980s and the 1990s. In WCA, 5 of the 6 countries for which we have adoption data saw an increase in yield between the early eighties (1981-83) and the late nineties

(1997-99) (46% in Egypt to 9% in Sudan). Nigeria was the only exception among the countries in WCA, where in spite of low to moderate levels of adoption (3-29%), there was a sharp decline in yield (32%). Nigeria seems not to have benefited from the adoption of improved cultivars in terms of increments in average yield. In WCA, 5 of the 6 countries for which adoption data was available witnessed a decline in relative variability in yield (77.9% in Nigeria to 10.9% in Mali). The only exception was Egypt, though this country is one of the highest adopters of improved cultivars in the region. In fact, Egypt has the highest yield level among all the countries studied in Africa.

Table 9.8. Relative variability in sorghum yield in African countries.

		Relative variability (CV) in yield		Change in yield CV (%)
Country	Region	1981-90	1991-99	1981-90 to 1991-99
Benin	WCA	8.87	3.03	-65.86
Burkina Faso	WCA	**11.13**	**5.31**	-52.27
Burundi	WCA	**9.03**	**5.69**	-37.03
Cameroon	WCA	**16.52**	**5.81**	-64.86
Central African Rep.	WCA	**16.97**	**16.15**	-4.85
Chad	WCA	**13.00**	**8.61**	-33.77
Ivory Coast	WCA	**6.04**	**11.10**	83.86
Egypt	WCA	**3.87**	**9.33**	140.94
Gambia	WCA	**13.59**	**10.38**	-23.60
Ghana	WCA	**23.19**	**7.82**	-66.27
Guinea	WCA	**11.41**	**16.41**	43.78
Guinea-Bissau	WCA	**27.90**	**3.32**	-88.11
Mali	WCA	**15.06**	**13.40**	-10.98
Mauritania	WCA	**23.40**	**7.41**	-68.36
Morocco	WCA	**19.17**	**36.22**	89.00
Niger	WCA	**22.06**	**17.00**	-22.92
Nigeria	WCA	**12.07**	**2.67**	-77.90
Rwanda	WCA	**10.40**	**23.15**	122.53
Senegal	WCA	**9.73**	**10.67**	9.70
Sierra Leone	WCA	**25.12**	**9.02**	-64.10
Sudan	WCA	**30.67**	**13.56**	-55.78
Togo	WCA	**17.55**	**13.11**	-25.30
Tunisia	WCA	**12.26**	**17.96**	46.48
Uganda	WCA	**14.82**	**13.28**	-10.40
Botswana	SEA	**33.36**	**31.00**	-7.08
Eritrea	SEA	**7.62**	**35.20**	361.68
Kenya	SEA	**27.27**	**10.65**	-60.96
Lesotho	SEA	**20.01**	**30.46**	52.26
Madagascar	SEA	**21.02**	**6.27**	-70.16
Malawi	SEA	**21.16**	**31.44**	48.58
Mozambique	SEA	**13.62**	**19.96**	46.58
Namibia	SEA	**4.20**	**57.88**	276.55
Somalia	SEA	**5.52**	**14.27**	158.61
South Africa	SEA	**22.40**	**26.42**	**17.94**
Swaziland	SEA	**57.18**	**39.56**	**-30.81**
Tanzania, United Rep	SEA	**32.02**	**20.63**	**-35.58**
Zambia	SEA	**15.60**	**17.74**	**13.72**
Zimbabwe	SEA	37.73	26.41	-30.01

Source: Authors' calculation based on FAO Agricultural Statistics (http://www.fao.org).

Table 9.9. Association between yield and instability in yield of sorghum in different African countries in the 1990s (1991-99) compared to the 1980s (1981-90).

	Types of association			
Region	AA: Increase in yield with decrease in variability	AB: Increase in yield with increase in variability	BA: Decrease in yield with decrease in variability	BB: Decrease in yield with increase in variability
Southern and Eastern Africa	Madagascar, Kenya, Zimbabwe, Botswana	South Africa, Lesotho	Tanzania United Rep, Swaziland	Zambia, Mozambique, Malawi, Somalia, Eritrea, Namibia
Western, Central and North Africa	Guinea-Bissau, Mauritania, Ghana, Benin, Cameroon, Sudan, Burkina Faso, Burundi, Chad	Egypt	Nigeria, Sierra Leone, Togo, Gambia, Niger, Mali, Uganda, Central African Rep	Senegal, Guinea, Tunisia, Ivory Coast, Morocco, Rwanda

Source: Authors' calculation based on FAO Agricultural Statistics (http://www.fao.org).

In SEA, 8 of the 9 countries for which we have adoption data saw an increase in yield between the early eighties (1981-83) and the late nineties (1997-99), the exception being Tanzania which saw a 16% reduction in yield. However the adoption level in Tanzania was very low, only 2%. The highest yield gain was recorded in Swaziland (91%), which has an adoption level of 50%. The other notable countries in terms of yield gains were Zimbabwe with a 46% yield gain and 36% adoption and South Africa with a yield gain of 38% and 77% adoption. However, a dismal picture emerges when we compare relative variability in yield with adoption of improved cultivars in SEA. There was an increase in relative variability in yield in 5 of the 9 countries for which we have yield data. The rest of the countries saw a decline between the 1980s and the 1990s. These countries (in the order of magnitude of decline) were Tanzania, Swaziland, Zimbabwe and Botswana. However as noted earlier, since Tanzania has a very low rate of adoption, the decline cannot be solely attributed to rates of adoption. On the other hand, South Africa which has a very high adoption rate of 77%, witnessed an increase in the variability of yield. Therefore, no consistent relationship emerges between adoption of improved cultivars and its effect on decline in yield variability for Africa as a whole and for countries in SEA in particular.

9.6.1. South America

Yield variability is one of the most important indicators of stability in the farming system of a region. In terms of variability in yield of sorghum, there has been a decline in eight countries in South America, which includes Argentina (the second largest producer of sorghum in the region). The other countries where yield variability declined were Brazil, Colombia, Guatemala, Haiti, Nicaragua, Uruguay and Venezuela. Yield variability increased in Mexico, Peru, El Salvador and Honduras. All these countries except Mexico and Peru had absolute yield levels below the regional average. In spite of their high absolute yields, Peru and Mexico experienced increases in yield variability. Argentina and Uruguay, which had high absolute yields, recorded a decline in yield variability. This is a positive sign as far as the production of sorghum in the region is concerned.

In the 1980s compared to the 1970s, 6 (Venezuela, Argentina, Honduras, Uruguay, Colombia and Nicaragua) of the 12 countries studied fell under type AA association (increase in yield and decline in variability). Of these, the absolute yield levels in Argentina, Uruguay and Colombia were higher than the regional average. Mexico, Peru and Guatemala (type AB association with increase

Table 9.10. Classification of countries and sorghum area by changes in coefficients of variation of sorghum yields.

Periods	Change in CV Decrease of 10% or more	 Less than + 10% change	 Increase of 10% or more
In the 1980s, compared to the 1970s	Haiti, Venezuela, Morocco, Namibia, Pakistan, Madagascar, Albania, Senegal, Thailand, Botswana, Nigeria, Ivory Coast, Brazil, Romania, Gambia, Argentina, Lesotho, Honduras, Uruguay, Mauritania, Benin, Mali, Korea DPR, Colombia, Nicaragua, Spain (26)	USA, Uganda, Mozambique, France, Somalia, South Africa, Australia (7)	Zambia, Chad, Guatemala, Saudi Arabia, Mexico, India, Peru, Burkina Faso, Tunisia, Niger, Eritrea, Rwanda, Hungary, Central African Rep, Tanzania United Rep, Italy, Egypt, China, Malawi, Ghana, Swaziland, Zimbabwe, Cameroon, Burundi, Guinea, Togo, Guinea-Bissau, El Salvador, Yemen, Sudan, Sierra Leone, Korea Rep, Kenya (33)
Percentage of countries	39.4	10.6	50.0
Percentage of sorghum area	17.4	15.9	66.7
In the 1990s compared to the 1970s	Guatemala, Nigeria, Madagascar, Saudi Arabia, Mauritania, Haiti, Benin, Uruguay, Thailand, Pakistan, Guinea-Bissau, Italy, France, Venezuela, Gambia, Colombia, Botswana, Brazil, Argentina, Burkina Faso, Mali, Ghana, Chad, Morocco, Uganda (26)	Hungary, Nicaragua, Cameroon, Lesotho, Honduras, El Salvador (6)	Ivory Coast, USA, Tanzania United Rep, Niger, Zambia, South Africa, Australia, Mozambique, India, Mexico, Romania, Swaziland, Albania, Sierra Leone, Central African Rep, Korea Rep, Burundi, Peru, Yemen, Sudan, Zimbabwe, Tunisia, Spain, Kenya, Togo, Somalia, China, Korea DPR, Malawi, Rwanda, Guinea, Egypt, Namibia, Eritrea (34)
Percentage of countries	39.4	9.1	51.5
Percentage of area under sorghum	28.4	1.9	69.7
In the 1990s compared to the 1980s	Guatemala, Guinea-Bissau, Saudi Arabia, Nigeria, Italy, El Salvador, Madagascar, Mauritania, Ghana, Benin, Korea Rep., Cameroon, Sierra Leone, Kenya, Uruguay, Sudan, France, Yemen, Burkina Faso, Thailand, Hungary, Haiti, Colombia, Burundi, Tanzania United Rep, Chad, Swaziland, Zimbabwe, Pakistan, Togo, Gambia, Niger, Brazil, Mali, Uganda (35)	Botswana, Argentina, Central African Rep, Senegal (4)	Nicaragua, Zambia, India, Venezuela, South Africa, Australia, Mexico, USA, China, Guinea, Tunisia, Mozambique, Malawi, Peru, Lesotho, Honduras, Ivory Coast, Morocco, Rwanda, Romania, Egypt, Spain, Somalia, Albania, Korea DPR, Eritrea, Namibia (27)
Percentage of countries	53.0	6.1	40.9
Percentage of area under sorghum	49.0	2.2	48.7

Source: Authors' calculation based on FAO Agricultural Statistics (http://www.fao.org).

Table 9.11. Association between relative variability in yield and adoption of improved cultivars of sorghum in Africa.

Country	Relative variability (CV) in yield 1981-90	Relative variability (CV) in yield 1991-99	Change in yield CV (%) 1981-90 to 1991-99	Adoption of IC (%)
Western and Central Africa				
Benin	8.87	3.03	-65.86	
Burkina Faso	11.13	5.31	-52.27	
Burundi	9.03	5.69	-37.03	
Cameroon	16.52	5.81	-64.86	12 to 49
Central African Rep.	16.97	16.15	-4.85	
Chad	13.00	8.61	-33.77	24 to 38
Egypt	3.87	9.33	140.94	35
Gambia	13.59	10.38	-23.60	
Ghana	23.19	7.82	-66.27	
Guinea	11.41	16.41	43.78	
Guinea-Bissau	27.90	3.32	-88.11	
Ivory Coast	6.04	11.10	83.86	
Mali	15.06	13.40	-10.98	29
Mauritania	23.40	7.41	-68.36	
Morocco	19.17	36.22	89.00	
Niger	22.06	17.00	-22.92	
Nigeria	12.07	2.67	-77.90	3 to 29
Rwanda	10.40	23.15	122.53	
Senegal	9.73	10.67	9.70	
Sierra Leone	25.12	9.02	-64.10	
Sudan	30.67	13.56	-55.78	22
Togo	17.55	13.11	-25.30	
Tunisia	12.26	17.96	46.48	
Uganda	14.82	13.28	-10.40	
Southern and Eastern Africa				
Botswana	33.36	31.00	-7.08	33
Eritrea	7.62	35.20	361.68	
Kenya	27.27	10.65	-60.96	
Lesotho	20.01	30.46	52.26	4
Madagascar	21.02	6.27	-70.16	
Malawi	21.16	31.44	48.58	10
Mozambique	13.62	19.96	46.58	5
Namibia	4.20	57.88	1276.55	
Somalia	5.52	14.27	158.61	
South Africa	22.40	26.42	17.94	77
Swaziland	57.18	39.56	-30.81	50
Tanzania, United Rep.	32.02	20.63	-35.56	2
Zambia	15.60	17.74	13.72	35
Zimbabwe	37.73	26.41	-30.01	36

Source: Authors' calculation based on FAO Agricultural Statistics (http://www.fao.org). Adoption data is from Chapter 8 of this book.

in yield and increase in variability) saw increases in absolute yield levels; but this was not accompanied by a corresponding decline in yield variability. Both Mexico and Peru have very high absolute yield levels, the highest among South American countries. Guatemala showed a low level of absolute yield. Brazil and Haiti (type BA with decrease in yield and decrease in variability), had very low levels of absolute yield. The average yield in Haiti was only 768 kg ha^{-1} in the 1990s. El Salvador was the only country during this period to fall under type BB association with decrease in yield and increase in variability.

In the 1990s compared to the 1970s, Uruguay, Venezuela, Colombia, Argentina and Nicaragua were in type AA association. All these countries except Venezuela and Nicaragua had high levels of absolute yield, higher than the average for the continent as a whole. El Salvador, Mexico, Peru and Honduras fell under AB type association. Haiti, Guatemala and Brazil were in type BA during this period. During this period, it is noted that all the countries with high levels of absolute yield also witnessed a decline in relative variability in yield. The only exceptions were Mexico and Peru.

The association between yield and relative variability of yield in the 1990s compared to the 1980s shows a slightly different trend. Mexico, the largest producer of sorghum in the region, fell under type BB association. However, Argentina, the second largest producer, recorded an increase in yield and a decline in yield variability during this period.

9.7. Conclusions

This chapter discussed three dimensions of productivity impact derived from the adoption of improved sorghum cultivars.

The yield trends demonstrated varying scenarios of yield gains across countries, regions and continents. In addition, the synthesis of available farm-level survey studies confirmed the measurable decline in unit cost of producing sorghum in Asia and Africa. Countries with higher level of adoption of improved cultivars were shown to have achieved higher yield gains as in the case of China, India and South Africa. In particular, the yield trends revealed different scenarios of yield impact in India and Africa. The data covering four decades from 1961 to 2002 clearly show that India has progressed tremendously in terms of sorghum yield, while most countries in Africa are lagging behind. As elucidated in Section 9.3, improved cultivars along with infrastructure variables and policy, played a key role in this differential growth in sorghum yield.

The global and country-level analysis attempted to establish a link between adoption, yield gain and reduction in yield variability. The types of association relating sorghum yield and instability in yield facilitated the identification of country scenarios where the ideal outcome of increase in yield and reduced variability (eg, type AA) are shown, as in the case of Pakistan during the period from the 1970s to the 1990s. In both India and China, relative variability in yield increased in the 1990s compared to the 1970s. Both countries experienced increased yield with adoption of improved cultivars, along with increased yield variability. This analysis based on aggregate data for India does not corroborate the results found earlier using district-level data (Deb et al. 1999). The earlier results indicate that the expansion of area under improved cultivars helped to increase sorghum yield as well as reduce its relative variability in India. In Africa, no consistent relationship emerged between adoption of improved cultivars and decline in yield variability.

9.8. References

Bantilan MCS. 2003. Agricultural transformation in Asia and Africa. Paper presented at the International Workshop on Transferability of Green Revolution to Africa, Aug 2003, Durban, South Africa.

Deb UK, Joshi PK and Bantilan MCS. 1999. Impact of modern cultivars on growth and relative variability in sorghum yields in India. Agricultural Economics Research Review 12(2):84-106.

FAO (Food and Agriculture Organization). 2002. FAO Statistical Database.

Ndjomaha C, Yapi A and Adamou A. 1998. Impact of sorghum S 35 in extreme north Cameroon. Pages 26-37 *in* Assessing joint impacts: proceedings of an International Workshop on Joint impact assessment of NARS/ICRISAT, 2-4 Dec 1996,ICRISAT, Patancheru, India (Bantilan MCS and Joshi PK, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Ogungbile et al. 1998. Factors influencing awareness and adoption of ICSV 111 and ICSV 400 sorghum varieties. Socio-economics and Policy Program, ICRISAT, Patancheru 502 324, Andhra Pradesh, India. Mimeo.

Shetty SVR, Beninati NF and Beckerman SR. 1991. Strengthening sorghum and pearl millet research in Mali. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (Limited distribution).

Singh AJ and Byerlee D. 1990. Relative variability in wheat yields across countries and over time. Journal of Agricultural Economics 41(1):21-32.

Weber A and Sievers M. 1985. Observations on the geography of wheat production instability. Quarterly Journal of International Agriculture 24(3):201-211.

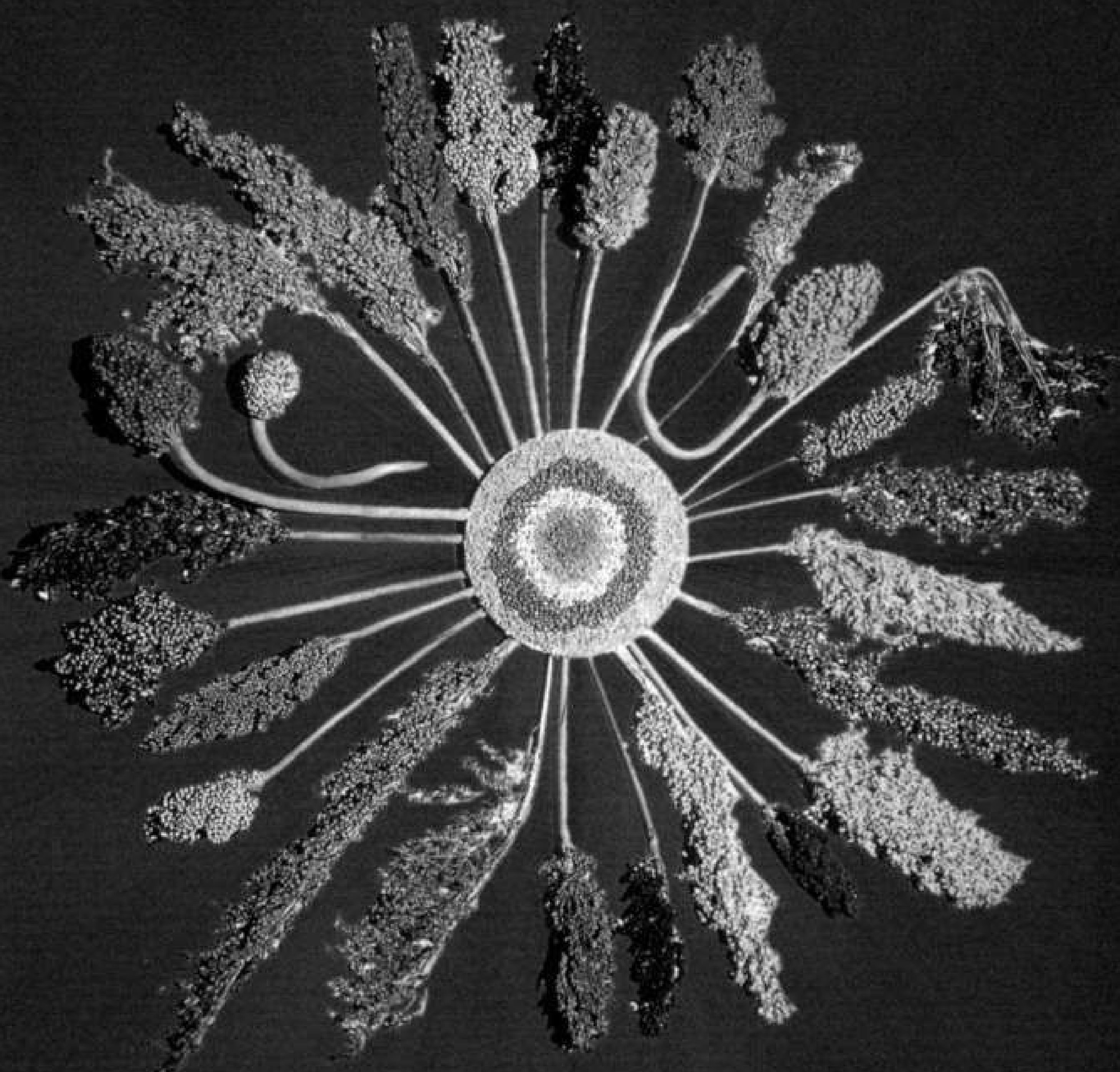
Yapi A, Kergna AO, Debrah SK, Sidibe A and Sanogo O. 1998. Impact of sorghum and millet research in Mali. Pages 76-93 *in* Assessing joint impacts: proceedings of an International Workshop on Joint impact assessment of NARS/ICRISAT, 2-4 Dec 1996, ICRISAT, Patancheru, India (Bantilan MCS and Joshi PK, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Yapi A, Debrah SK, Dehala G and Njomaha C. 1999. Impact of germplasm research spillovers: the case of sorghum variety S 35 in Cameroon and Chad. Impact Series No. 3. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 33 pp.

Impact of Improved Sorghum Cultivars on Genetic Diversity and Yield Stability

10

UK Deb, MCS Bantilan, BVS Reddy, PJ Bramel and N Kameswara Rao



Impact of Improved Sorghum Cultivars on Genetic Diversity and Yield Stability

UK Deb[1], MCS Bantilan[2], BVS Reddy[2], PJ Bramel[3] and N Kameswara Rao[3]

10.1. Introduction

The genetic diversity of a crop species is fundamental to its improvement and survival. Low levels of genetic diversity in cultivars increasingly render them vulnerable to unexpected pests and diseases, resulting in major production losses. History has been witness to numerous epidemics caused by low levels of nuclear and cytoplasmic genetic diversity. These include the blight that affected temperate potatoes in the northern hemisphere in the 1840s and the southern corn leaf blight epidemic of maize in the USA in 1970 (McIntyre et al. 1997).

It is largely believed that the Green Revolution led to a reduction in genetic diversity. For example, Pretty (1995) states "the introduction of modern varieties and breeds has almost always displaced traditional varieties and breeds". Cooper et al. (1992) inferred that the Green Revolution not only destroyed diversity, but as new seeds replaced old traditional varieties and their wild relatives, the future raw material for plant breeding programs was lost. High-yielding cultivars developed by national and international breeding programs and multinationals are reported to be the major cause of genetic erosion (Fowler and Mooney 1990; FAO 1996). Shiva (1991) states that the food supplies of millions are today "precariously perched" on the "narrow and alien genetic base" of the semi-dwarf wheat, and that "science and politics were wedded together in the very inception of the Green Revolution" which left the Punjab of India "ravaged by violence and ecological scarcity". Some researchers believe that the Green Revolution has increased variability in crop production (Hazell 1989; Mehra 1981; Barker et al. 1981; Griffin 1988) and thereby increased threats to food security. If this is the case, then it has serious consequences for sustainability in production and food security.

This chapter quantifies and estimates different types of genetic diversity indices—average, weighted and recommended - and the impact of germplasm research on yield increase and yield instability. Finally, it determines the relationship between adoption of improved cultivars, genetic diversity and yield instability.

10.2. Analytical Techniques

10.2.1. Quantification of Genetic Diversity

Genetic diversity in a crop can be measured in different ways such as pedigree analysis and molecular markers (for example, restriction fragment length polymorphosis - RFLPs).

[1] Centre for Policy Dialogue, House 40/c, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.
[2] International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
[3] Formerly of the Internationa] Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Deb UK, Bantilan MCS, Reddy BVS, Bramel PJ and Kameswara Rao N. 2004. Impact of improved sorghum cultivars on genetic diversity and yield stability. Pages 225-234 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Determining genetic diversity through molecular markers is prohibitively expensive and is only done by biotechnologists.

One way of determining genetic diversity in a crop is to analyze its parentage (Cox et al. 1985; Souza et al. 1994). Souza et al. (1994) distinguished between latent and apparent genetic diversity. Latent genetic diversity within a crop may influence disease vulnerability and stability across variable environmental stresses, while apparent genetic diversity is shown by the development of specific resistance genes. A narrow genetic base may increase a crop's latent vulnerability to disease and pest epidemics, especially those to which a crop or cropping region has been newly or increasingly exposed.

A Coefficient of Parentage (COP) summarizes genealogical similarities between pairs of cultivars. According to St Martin (1982) and Souza et al. (1994), each cultivar has a COP of 1 within itself, and each pair of cultivar without any common parentage has a COP of 0. Assuming each parent contributes equally to the progeny, then with unrelated parents the COP between parent and offspring is 0.5.

The pedigree of all varieties and hybrids was traced in this study to compute genetic diversity. However, this was not possible in the case of privately researched sorghum hybrids. Of the 122 notified cultivars, the pedigree of 77 cultivars could be traced. Since, this analysis is based only on these 77 cultivars, the estimates underestimate the level of diversity. To overcome this limitation, a further analysis was done for all the 182 cultivars under a restricted assumption that a cultivar with unknown parentage is not related to any other cultivar, ie, it has no common parentage. Since this would overestimate the actual level of diversity prevailing in farmers' fields, the actual level of diversity would be somewhere between the two estimates.

A matrix (77 x 77) of COPs between each of 77 important Indian cultivars (varieties and hybrids) was prepared.

The converse of genealogical similarity is diversity. Souza et al. (1994) define Coefficient of Diversity (COD) as (1-COP), whereby the higher the COD value, the greater is the genetic diversity within the cropping system. The COD indicates the degree to which a single cultivar and its related germplasm dominate a cropping region.

Souza et al. (1994) distinguished between various types of diversity:

- Average annual diversity within particular years
- Temporal diversity (comparing diversity at the start and end of periods)
- Recommended diversity based on variety recommendations from local research systems.

This analysis examines all these types of diversities:

- Average diversity: Based on the average COD of each variety grown in a given region in a given year
- Weighted diversity: 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: Based on the average COD of each cultivar recommended by either the public or private research system or notified by the seed certification agency, that can be grown in a given region in a given year.

Algebraically, if P is the matrix of the COP values between each of the cultivars, then the average diversity is calculated as:

$$d = 1 - G_i P G_i' \qquad \ldots(10.1)$$

where,

G. is a row vector of weighting values and G_i' is its transpose. Any cultivar grown in a region in year i receives a weight of n^{-1} (where n is the number of cultivars grown in that year), while other cultivars receive a weight of 0.

The weighted diversity value d_w, is calculated as:

$d_w = 1 - A_iPA_i'$ ...(10.2)

where,

A is a row vector of the proportion of the area sown to each cultivar in year i and A_i' is its transpose.

The recommended or notified diversity value d is calculated as:

$d = 1 - R_iPR_i'$ ...(10.3)

where,

R is a row vector of weighting values and R' is its transpose. Any cultivar recommended in a region in year i receives a weight of n^{-1} (where n is the number of cultivars grown in that year), while other cultivars receive a weight of 0.

10.2.2. Estimation of Instability in Sorghum Yield

Production variability (instability)[4] may arise due to variability in area, yield and/or interaction between area and yield. Since variability in yield is the main source of production instability (Weber and Sievers 1985; Hazell 1985), this analysis focuses exclusively on yield variability and instability in sorghum yield during two periods - 1966/67 to 1980/81 and 1981/82 to 1993/94. Critics opine that HYVs have decreased genetic diversity and increased variability in production. The objective was to test this hypothesis.

Instability in sorghum yield has been measured using the Cuddy-Delia Valle index, referred in equation 9.1 in Chapter 9, adopted in recent years as a measure of variability in time-series data.

To test the differences in CV between two time periods, Z statistics was computed[5].

$Z = (CV, -CV,) \{[(1 + 2CV_1)/2](1/n_1 -1/n_2)\}^{0.5}/CV_1$ ...(10.4)

where,

CV_2 and CV_1 are the CVs of periods 2 and 1, respectively

n_1 and n_2 represent the number of years during period 1 and period 2, respectively.

The change in CV for each district was tested using the Central Limit Theorem to compute

$Z^* = \sum Z_i/m^{0.5}$ ...(10.5)

where,

Z. are the standard normal test statistics for each observation of equation and m is the number of observations in the sample.

10.3. Improved Sorghum Cultivars Released

Table 10.1 shows the total number of improved sorghum cultivars released in select countries in Asia and Africa. A complete list of all these cultivars (varieties/hybrids) along with their pedigree, yield potential, year and purpose of release are given in Appendixes I and II.

---

4 Variability and instability are extensively used as synonyms in this study.

5 For details, see Kendal and Start (1969) and Anderson and Hazell (1989).

India. The first sorghum hybrid CSH 1 was released in 1964. Today, about 182 improved cultivars of sorghum are available for cultivation for grain, forage or dual purpose. Of these, 122 are notified either by the National Seed Release Committee or by the State Seed Release Committees. The rest are products of private seed companies, sold as "truthfully labeled seed".

Table 10.1. Number of sorghum cultivars recommended for release in select countries in Asia and Africa.

Country	Up to	Varieties	Hybrids	Total
India	1998 (April)	101	81	182
China	1997	0	24	24
Indonesia	1997	13	0	13
Pakistan	1997	7+(4)[1]	0	11
Thailand	1997	7	0	7
Iran	1997	3	3	6
Myanmar	1997	21	0	21
Nigeria	1998	4	0	4
Egypt	1998	5	3	8

1. Figure in parenthesis is the number of cultivars submitted to the seed release committee for recommendation.

Of the 122 notified cultivars, 16 are derived from ICR1SAT supplied materials. It is difficult to know the parentage of private hybrids due to proprietary reasons. However, private seed companies in India have collaborations with ICRISAT, and have acknowledged that their hybrids contain part of the genome from ICRISAT material. Details of collaborations with private seed companies in India are discussed in Chapters 4 and 7.

China. China has released 24 improved sorghum cultivars, of which 7 are ICRISAT-derived ones. After 1987, China released 10 cultivars, of which 7 were derived from ICRISAT-supplied materials. This indicates the potential of ICRISAT material in the future development of sorghum hybrids in China.

Pakistan. Pakistan has recommended a total of 11 improved cultivars for release. Four varieties (D.G. Pearl, Sarokarthuho, Red Janpur and Bagdar) are pure line selections from local landraces. Two of them (PARC SS1 and PARC SV1) are ICRISAT-derived varieties, two (Pak SSII and DS 75) are from Purdue University's germplasm collection and one (Jowar 86) is from national program breeding materials. Variety PARC SH1 was directly introduced from India (CSH 6) through international trials. PARC SS2 too was directly introduced (IRAT 204) from ICRISAT through international trials.

Thailand. Thailand has released seven improved cultivars. Two varieties (Early Hegari and Late Hegari) were introduced in the early 1960s from USA. Hegari is still popular in Thailand. The other five cultivars are from materials derived from the national breeding program. Suphan Buri 1 released in 1993 had ICRISAT-supplied germplasm as a parent in the crosses.

Myanmar. Myanmar has released 21 varieties, of which 11 are directly from ICRISAT-supplied breeding lines (seven varieties) or direct germplasm introductions from ICRISAT (four varieties). After 1982, all the 7 varieties released were direct introductions from ICRISAT breeding lines.

Indonesia. Indonesia has released 13 improved sorghum varieties - two are pure line selections from local landraces and the others direct introductions. Pedigrees of these cultivars could not be traced. However, ICRISAT has had substantial collaboration with Indonesia since 1980.

Iran. Iran has six recommended sorghum varieties - Speed Feed, Jumbo, Sugar grace, Payam, Kimia and Sepeeden. The first three, originating in Australia, have been released for forage while the other three (local selections) are used for grain.

Egypt. Egypt has eight recommended cultivars (5 varieties and 3 hybrids). These are Giza 114 (released in 1962), Giza 15 (1978), Giza 113 (1994), Dorado (1993), NES 1007, Hybrid 1, Hybrid 2 and Hybrid 3 (1996). Giza 114 and Giza 15 are pure line selections from local varieties, while Giza 113 is derived from a cross between a local and an exotic variety. The three varieties have been released for grain purposes and the hybrids for dual purpose. None of these is from ICRISAT materials.

Nigeria. After 1995, Nigeria released four improved cultivars (ICSH 89002NG, ICSH 89009 NG, ICSV 111 and ICSV 400) from collaborative research with ICRISAT. All were direct selections from ICRISAT breeding lines after adaptive research trials. Before 1995, several other varieties and hybrids were developed and released by the Nigeria NARS. The first two were hybrids developed in Nigeria in a partnership program, based on ICRISAT-bred parents developed at Patancheru, India. The other two were developed by ICRISAT-Patancheru.

10.4. Genetic Diversity in Sorghum in India

Various types of genetic diversity indices - average, recommended and weighted - were quantified based on the data and analytical methods discussed in the earlier section. The results of estimated genetic diversity for India are reported in Tables 10.2 and 10.3. The results are presented in five-year intervals from 1966 to 1994. The recommended diversity and average diversity among improved sorghum cultivars in India has increased remarkably over time. The numerical values of the average and recommended diversities of sorghum in India was the same since all the recommended sorghum cultivars are grown in India, even though the area under a majority of them is very limited. Since the estimation of average and recommended diversities does not consider the area covered by the cultivars, these are to some extent overestimates of the actual diversity in the farmer's field. Therefore, the study calculated the weighted diversity in sorghum cultivation in India as a whole and for seven major sorghum-growing states (Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Madhya Pradesh, Rajasthan and Tamil Nadu). Estimates of the weighted COD are given in Table 10.3. The level of weighted diversity was much higher in 1994 than in the early 1970s in all the 7 states.In the absence of information about parentage, and thereby genetic diversity, one can try to understand the level of diveristy in any crop cultivation by counting the number of cultivars grown by the farmers. The number

Table 10.2. Coefficient of diversity (average and recommended) in sorghum in different states of India.

Year	Diversity index[1]
1966	0.25
1971	**0.92**
1976	**0.95**
1981	**0.97**
1986	**0.98**
1991	0.99
1994	0.99

1. The Diversity index here is based on 182 cultivars.

Source: Based on authors'calculation.

of recommended sorghum cultivars grown in a country can also be an indicator of this purpose. Table 10.4 reports the diversity in sorghum cultivation (measured as the total number of improved cultivars) in important sorghum-growing countries of Africa and Asia. It is evident that the number of improved cultivars has increased over time. The number of improved cultivars are generally high in those contries where adoption is relatively high.

Table 10.3. Coefficient of diversity (weighted) in sorghum in different states of India.

States	1966	1971	1976	1981	1986	1991	1994
Results based on 77 cultivars							
Andhra Pradesh	0.00	0.00	0.48	0.25	0.32	0.36	0.74
Gujarat	0.00	0.00	0.34	0.56	0.25	0.27	0.28
Karnataka	0.00	0.00	0.41	0.45	0.47	0.60	0.69
Madhya Pradesh	0.00	0.00	0.46	0.46	0.44	0.55	0.64
Maharashtra	0.00	0.00	0.46	0.52	0.48	0.45	0.50
Rajasthan	0.00	0.00	0.34	0.56	0.25	0.27	0.36
Tamil Nadu	0.00	0.00	0.32	0.38	0.50	0.63	0.69
India	0.00	0.00	0.47	0.48	0.45	0.55	0.72
Results based on 182 cultivars							
Andhra Pradesh	0.00	0.00	0.84	1.00	1.00	1.00	1.00
Gujarat	0.00	0.00	0.36	0.94	1.00	1.00	1.00
Karnataka	0.00	0.00	0.49	0.91	0.99	0.99	1.00
Madhya Pradesh	0.00	0.00	0.53	0.94	0.98	1.00	1.00
Maharashtra	0.00	0.00	0.54	0.92	0.98	1.00	1.00
Rajasthan	0.00	0.00	0.36	0.94	1.00	1.00	1.00
Tamil Nadu	0.00	0.00	0.36	0.94	1.00	1.00	1.00
India	0.00	0.00	0.56	0.94	0.99	1.00	1.00

Source: Based on authors' calculation.

Table 10.4. Diversity in sorghum cultivation (measured as the total number of improved cultivars).

	Number of improved cultivars				Number of improved cultivars		
Country	1980	1990	1998	Country	1980	1990	1998
Africa				**Asia**			
Botswana	7	7	11	China	7	16	24
Burkina Faso	2	4	5	India	50	111	182
Egypt	3	3	8	Indonesia	9	11	13
Ethiopia	1	5	7	Myanmar	10	18	21
Kenya	4	8	10	Pakistan	6	7	11
Malawi	-	1	3	Thailand	2	4	7
Mali	-	-	4				
Mozambique	3	8	9	**Latin America**			
Niger	-	-	2	El Salvador	2	4	4
Nigeria	-	-	4	Mexico	1	6	9
Senegal	1	1	1	Nicaragua	-	2	2
Sudan	-	1	6				
Swaziland	-	2	3				
Tanzania	4	5	6				
Uganda	8	8	10				
Zambia	1	7	9				
Zimbabwe	-	2	6				

10.5. Instability in Yield

The impact of sorghum germplasm research on yield increase (productivity) and instability (variability over years) in yield in India was calculated using the mean yield of sorghum and instability indices (using the Cuddy-Delia Valle Index). During period 1 (1966/67-1980/81), the percentage of HYV sorghum area to the total sorghum area in India was less than 20% while during period 2 (1981/82-1993/94) it was above 20%, indicating that HYV sorghum cultivation was less intensive during period 1 compared to period 2. Therefore, these two periods can be called the early HYV period and late HYV period, respectively. The coefficient of genetic diversity among the improved cultivars was very low during period 1; it increased significantly during period 2. Therefore, period 1 can also be treated as a period of low genetic diversity while period 2 was a period of genetically diversified sorghum cultivation.

Table 10.5 compares the level of and changes in average yield and relative variability in sorghum yield between the two periods in different states of India. During period 1, the highest productivity was recorded in Karnataka (985 kg ha^{-1}) followed by Tamil Nadu (943 kg ha^{-1}) and Madhya Pradesh (729 kg ha^{-1}), while yield was low in Gujarat (499 kg ha^{-1}) and Rajasthan (300 kg ha^{-1}). During period 2, the highest productivity was in Tamil Nadu (1113 kg ha^{-1}) followed by Karnataka (957 kg ha^{-1}) and Maharashtra (902 kg ha^{-1}). The lowest yield level was in Rajasthan (412 kg ha^{-1}) followed by Gujarat (551 kg ha^{-1}) and Andhra Pradesh (661 kg ha^{-1}). Yields levels in all the states except Karnataka (where productivity fell by 28 kg ha^{1}) increased during period 2 compared to period 1. Average yield in India during period 1 and 2 was 582 kg ha^{-1} and 748 kg ha^{-1}, respectively. The coefficient of variation in yield decreased in all the states except Gujarat. It may be mentioned here that the study districts of Gujarat contributed only 2.7% of total sorghum production and 4.9% of total sorghum area in India during 1991-1994. The coefficients of variation in sorghum yield in India during these two periods were 11% and 13%, respectively. This implies that food security has been strengthened over time through reduction in year-to-year yield fluctuations.

To examine the differences in changes in CV for yield between the two periods, the Z statistics was computed for each of the 146 study districts. A summary of the analysis (Table 10.6) shows that although 26% of the districts in India showed significant increases in CV, they comprised only 14% of the total sorghum area in India. On the other hand, 39% of the districts experienced significant decreases in CV; they comprised 42% of the total sorghum area in India. This implies that during period 2 (1981/82-1993/94), reduction in yield fluctuations ensured food security in most of the major sorghum-producing areas in India.

Table 10.5. Average yield and relative variability in sorghum yield in different states of India.

	Period 1(1966-80)		Period 2 (1981-93)		Change (%)	
States	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: Authors' calculations are based on data obtained from the Government of India.

Table 10.6. Districts and sorghum area (%) with a statistically significant change in yield variability according to the computed Z* statistics.

States	Districts (%)		Area (%)	
	Increased CV	Decreased CV	Increased CV	Decreased CV
Andhra Pradesh	25	30	20	43
Gujarat	69	6	76	0
Karnataka	7	36	1	29
Madhya Pradesh	14	50	10	51
Maharashtra	5	45	3	50
Rajasthan	48	43	64	20
Tamil Nadu	33	44	25	52
India	26	39	14	42

Source: Authors' calculations are based on data obtained from the Government of India.

10.6. Relationship between Improved Cultivars, Genetic Diversity and Yield Instability

The relationship between the spread of improved cultivars and weighted index of genetic diversity in different states of India are presented in Table 10.7. The rates of adoption and genetic diversity in all the states except Rajasthan have increased over time. Given this situation, improved cultivars were neither adopted at a significant rate, nor was there any increase in genetic diversity among improved sorghum cultivars. The overall situation with the exception of Rajasthan implies that sorghum breeders were using different parental materials to develop new improved cultivars rather than depending only on few parental materials. The breeders were successful in utilizing a large genetic pool to increase the diversity rather than counting on only few materials in a narrow genetic pool.

The relationship between genetic diversity and yield instability can be observed from Table 10.8. 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 periods 1 and 2 were almost similar. The variability situation was also similar during these two periods. In Rajasthan, genetic diversity as well as relative variability decreased. In other words, an increase in genetic diversity in all the major sorghum-producing states of India except Rajasthan has resulted in a decrease in variability in sorghum yield.

Table 10.7. Relationship between adoption of improved cultivars and coefficient of weighted diversity among sorghum cultivars.

States	Adoption rate (%)			Genetic Diversity Index (COD)		
	1968	1981	1993	1966	1981	1994
Andhra Pradesh	0.56	20.28	46.76	0.00	0.25	0.74
Gujarat	0.15	7.78	53.16	0.00	0.56	0.28
Karnataka	3.03	22.76	22.97	0.00	0.45	0.69
Madhya Pradesh	0.92	29.17	49.48	0.00	0.46	0.64
Maharashtra	8.47	30.02	68.09	0.00	0.52	0.50
Rajasthan	0.42	4.64	1.52	0.00	0.56	0.36
Tamil Nadu	1.35	27.65	99.31	0.00	0.38	0.69
India	3.68	23.39	52.42	0.00	0.48	0.72

Source: Authors' calculations are based on data obtained from the Government of India.

Table 10.8. Coefficient of weighted diversity and instability in sorghum yield in different states of India.

States	Genetic Diversity Index (COD) 1981	Genetic Diversity Index (COD) 1994	Change in COD (%)	Index of yield instability Period 1	Index of yield instability Period 2	Change in instability index (%)
Andhra Pradesh	0.25	0.74	196.00	23.02	21.66	-5.91
Gujarat	0.56	0.28	-50.00	31.55	42.51	34.76
Karnataka	0.45	0.69	53.33	26.65	23.08	-13.40
Madhya Pradesh	0.46	0.64	39.13	24.08	19.52	-18.96
Maharashtra	0.52	0.50	-3.85	29.50	26.51	-6.71
Rajasthan	0.56	0.36	-35.71	58.62	50.77	-13.40
Tamil Nadu	0.38	0.69	81.58	28.13	26.24	-6.71
India	0.48	0.72	50.00	10.59	13.02	22.97

Source: Authors' calculations are based on data obtained from the Government of India.

10.7. Conclusion

The number of improved sorghum cultivars and their rate of adoption in all the study countries have increased over time. Genetic diversity among improved sorghum cultivars in India has increased. This indicates that sorghum breeders in India were using different parental materials to develop new cultivars rather than relying on a few parental materials. The impact of sorghum germplasm research on yield instability measured for different states shows that instability in sorghum yield fell during period 2 compared to period 1. Period 1 saw the low adoption of HYVs accompanied by low genetic diversity among the improved sorghum cultivars. Period 2 was characterized by high adoption accompanied by high levels of genetic diversity among the improved sorghum cultivars. Therefore, it can be concluded that sorghum germplasm research in India has contributed to increases in genetic diversity, thereby helping reduce instability in sorghum yield.

10.8. References

Barker RE, Gabler E and Winckelmann D. 1981. Long-term consequences of technological change on crop yield stability: The case for cereal grains. *In* Food security for developing countries (Valdes A, ed.). Boulder, USA: Westview Press. 351 pp.

Cooper D, Vellve R and Hobbelink H. 1992. Growing diversity: Genetic resources and local food security. London, U.K.: Intermediate Technology Publications. 174 pp.

Cox TS, Kiang YT, Gorman MB and Rodgers DM. 1985. Relationships between coefficients of parentage and genetic similarity indices in soybean. Crop Science 25:529-32.

FAO (Food and Agricultural Organization of the United Nations). 1996. The state of the world's genetic resources for food and agriculture (background documentation for the International Technical Conference on Plant Genetic Resources, 17-23 Jun 1996, Leipzig, Germany. Rome, Italy: FAO. 336 pp.

Fowler FJ and Mooney P. 1990. The threatened gene: Food, policies and the loss of genetic diversity. Cambridge, U.K.: The Lutterworth Press. 278 pp.

Griffin K. 1988. Alternative strategies for economic development. Paris, France: Organization for Economic Cooperation and Development. 267 pp.

Hazell PBR. 1985. Sources of increased variability in world cereal production since the 1960s. Journal of Agricultural Economics 36(2): 145-159.

Hazell PBR. 1989. Changing patterns of variability in world cereal production. Pages 13-34 *in* Variability in grain yield (Anderson JR and Hazell PBR, eds.). Baltimore and London: The John Hopkins University Press.

McIntyre CL, Tao Y, Jordan DR and Hanzell RG. 1997. Application of molecular markers to sorghum breeding in Australia. International Sorghum and Millets Newsletter 38:11-14.

Mehra S. 1981. Instability in Indian agriculture in the context of the new technology. Research Report No. 25. Washington D.C. USA: International Food Policy Research Institute. 55 pp.

Pretty. 1995. Regenerating Agriculture. London: Earthscan Publications.

Shiva V. 1991. The violence of the Green Revolution. U.K., London: Zed Books.

St Martin SK. 1982. Effective population size for the soybean improvement program in maturity groups 00 to IV. Crop Science 22:151-152.

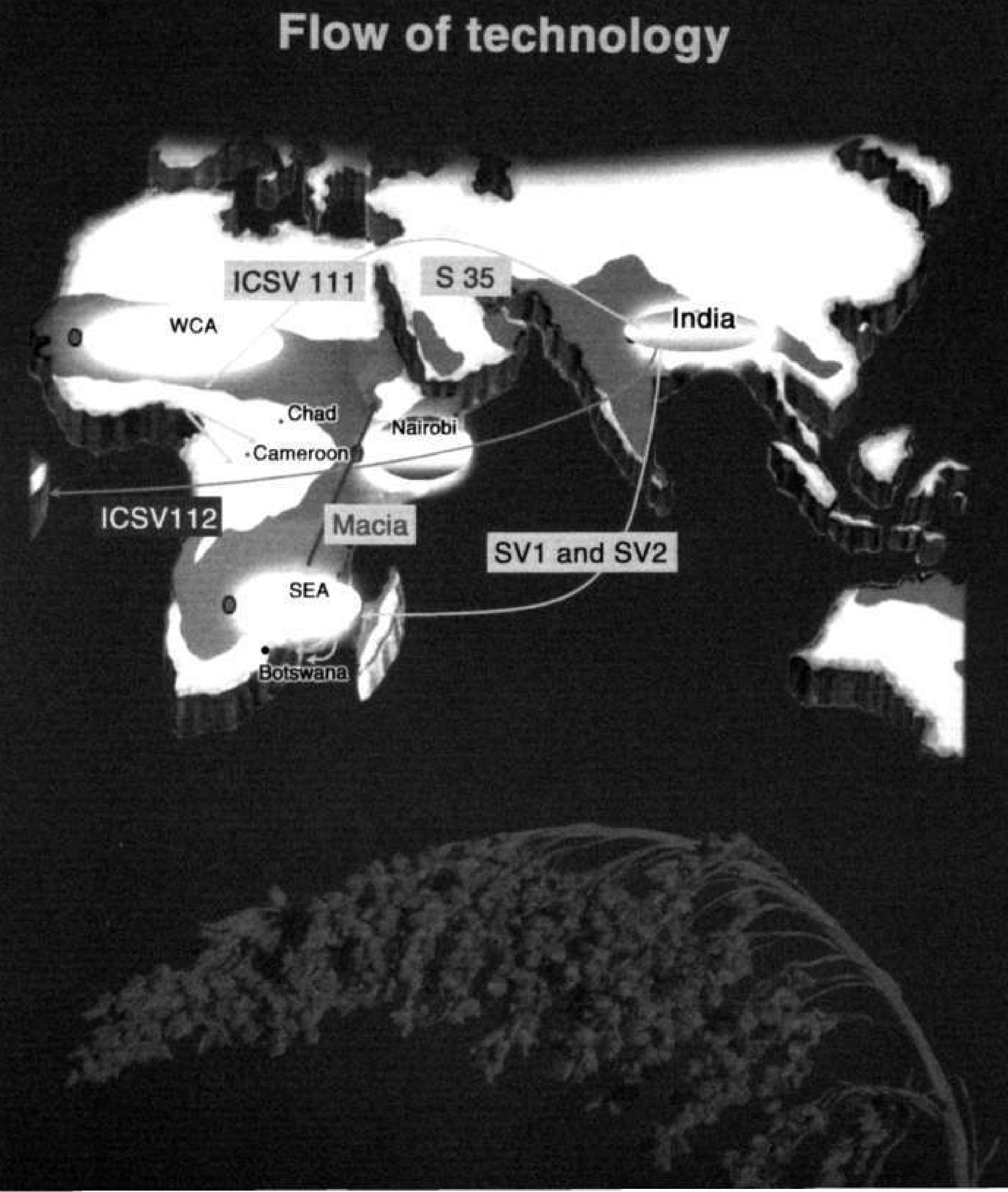
Souza E, Fox PN, Byerlee D and Skovmand B. 1994. Spring wheat diversity in irrigated areas of two developing countries. Crop Science 34:774-783.

Weber A and Sievers M. 1985. Observations on the geography of wheat production instability. Quarterly Journal of International Agriculture 24(3):201 -211.

Spillover Impacts of Sorghum Research

11

UK Deb, MCS Bantilan, FT Bantilan and CLL Gowda



Spillover Impacts of Sorghum Research

UK Deb[1], MCS Bantilan[2], FT Bantilan[3] and CLL Gowda[2]

11.1. Introduction

A technological breakthrough in agriculture often leads to increased yields, or improves the quality of output, or enhances the efficiency of input use. If the new technology has applicability beyond the confines of the location for which it was generated, or beyond the commodity for which it was developed, such an effect is commonly referred to as spillover effects. A review (Deb and Bantilan 2001) of the spillover impacts of agricultural research has covered the evolution of the concept over time, different types of spillovers dealt in literature and techniques to quantify spillover impacts by different studies on the subject.

Bantilan and Davis (1991) identified three types of spillover effects: across-location spillover, across-commodity spillover and price spillover. The first two types are direct effects and the last indirect.

Across-location or across-environment spillover effect refers to a situation where a technology developed for a specific location can be adapted and adopted to improve the production efficiency at other locations. However, the degree of applicability may vary across locations due to agronomic, climatic, ecological and socioeconomic differences in the production environments. Also known as technology spillover, an example of across-environment research spillover is the ICRISAT-developed sorghum variety ICSV 112 (SPV 475). Primarily intended for India, it was later released in India (CSV 13), Mexico (UNAL 1-87), Nicaragua (Pinoleso) and Zimbabwe (SV 1). This variety matures in 115-120 days and yields 3.4 t ha^{-1} at Patancheru, India (ICRISAT 1990).

Evenson (1989) described across-location spillover as interlocational spillover and explained it with a generalization of the role of geoclimatic inhibitors of spillover (Figure 11.1). The horizontal axis depicts an index of a particular set of geoclimatic factors such as water stress. The vertical axis indicates the variable cost of production per unit of product. Suppose that three research programs are located, respectively, in environments 1, 2 and 3. Environment 1 is the "best" suited for production. The technology employed there has been "targeted" to location 1. When this technology is used in environments other than 1, its performance is diminished by environmental interactions. The diminution in performance is greater for the program more tightly targeted to environment 1. Research programs in locations 2 and 3 similarly target technology to their respective environments.

The real cost advantage of the technology developed for environment 1 (relative to the technology for environments 2 or 3) declines when the technology is transferred to locations dissimilar to location 1. Its absolute advantage (over type 2 or 3 technology) is shown to be limited to the range E_{21} -E_{13} Now consider an improvement in technology produced by research in location

[1] Centre for Policy Dialogue, House 40/C, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.
[2] International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
[3] Formerly of the International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Deb UK, Bantilan MCS, Bantilan FT and Gowda CLL. 2004. Spillover impacts of sorghum reseach. Pages 237-260 in Sorghum genetic enhancement, research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

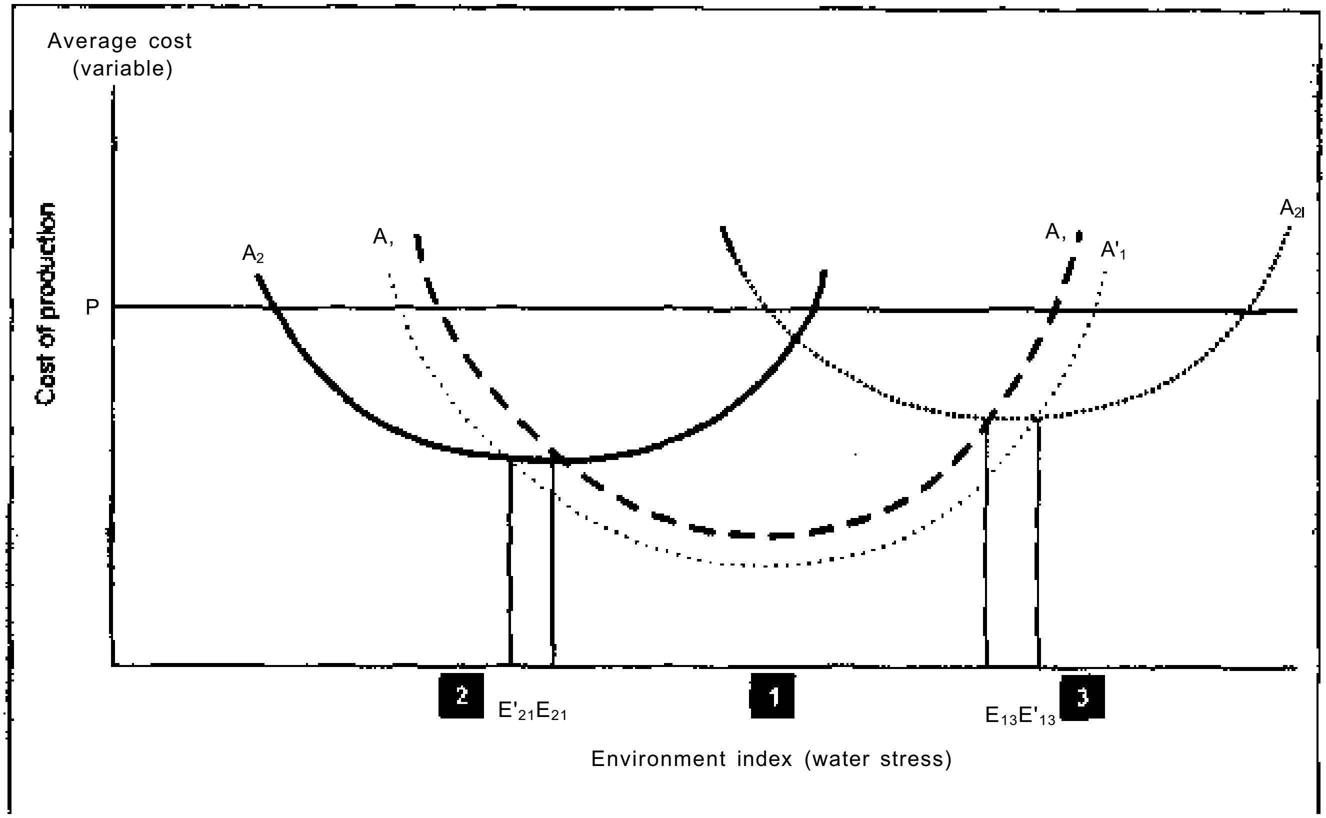


Figure 11.1. Generalization of the role of geoclimatic inhibitors of spillover effects (Evenson 1989).

1 (depicted as the A_1 curve). The direct spillover of this technology is limited to the environment range E'_{21} -E'_{13}. However, when comparable technology improvements occur in locations 2 and 3, the range of direct spillover from I to the other locations would be narrowed. If more locations were to build targeted research programs, the range of direct spillover would be further narrowed. Thus, the specification of direct spillover research requires consideration of the general research design of a system, including the range of locations in which the technology is applicable.

Evenson (1994) *defined* the potential spillover for a biological technology as $S_{ij} = Y_{ij}/Y_{jj}$, where Y_{jj}. is the yield in environment j of varieties developed for that environment and Y_{ij} is the yield of the same group of varieties in environment i. Byerlee (1997) reported that the extent of the spillover, ie, the size of S.. depends on various factors: agroecological similarity between the originating and receiving region, local food tastes and preferences, factor prices and institutional factors (land tenure and intellectual property rights). He also mentioned that realization of the potential spillover is influenced by other factors such as historical and cultural links between countries, geographical proximity, complexity of the problem and other institutional factors (the research networks and the level of intellectual property rights).

Across-commodity spillover effect occurs when the technology developed has applicability across commodities. For example, a cultural management technique specially developed for sorghum production may also have the potential of improving the efficiency of production of millets and other cereals. Across-commodity spillover has been termed by Evenson (1989) as intercommodity spillover. He mentioned that for some technologies the spillover mechanism would not be confined to a single commodity. Resource-or input-based technology may be relevant to several commodities. Pretechnology science findings may spill over across commodities because they enhance the invention potential of several commodity technology programs. For example, programs to control insects or correct a soil problem will spill over across commodities. A screening technology developed for sorghum may be equally useful for pearl millet screening. Research on biological control of *Helicoverpa* in chickpea and pigeonpea may be equally applicable in cotton and sorghum.

Price spillover occurs when the technological change for a particular commodity at a specific location increases supply and changes the price of that commodity in other locations through trade. It may also significantly affect the price of a related commodity in the same location. This is particularly relevant for products with low demand elasticity, and/or when the rate of product transformation among commodities is significant (Bantilan and Davis 1991).

Price spillovers can be seen as a case of intersectoral spillover as discussed by Evenson (1989). He elaborated that most private (and public) firms in an economy conduct two types of research programs. The first is directed toward process improvements in the sector itself (usually within the firm). Such research does not have spillover effects on another sector except by way of price. The second type of research is directed to product improvement. Such research can result in real and accounting spillovers because, when product quality changes, it is almost impossible to account for the quality change in terms of the price. When a manufacturer introduces a new machine and sells it at a price that is 10% higher than the price of an existing machine, accounting methods will measure the new machine as providing 10% more real services to the agricultural sector. However, there are at least two reasons why the new machine is likely to be providing 10% more real service. First, the manufacturer will have to provide a real discount to farmers to sell the new machine. Second, competition and expected competition from other manufacturers will lead him to give a real discount to farmers. Such real discounts associated with the introduction of new products from the farm-input supply sector constitute research spillovers to the agricultural sector.

Evenson (1989) also discusses another type of spillover: interfoci spillover. He defines it in the context of research system design, which is characterized by a set of hierarchical research foci. He relates this to most agricultural research programs where investment occurs in three stages: (a) pretechnology science; (b) technology invention and development; and (c) technology development and sub-invention. These stages correspond to specific specialization, which lead to locational specialization. Invention and development of new technology, ie, stage b, is the central objective of NARSs as well as IARCs. It is well-recognized that technology development rests on the twin pillars of science and technology which together define the invention potential of a national program. Almost all national and international research institutions invest in pretechnology science research programs, ie, stage a, to build invention potential. Genome mapping techniques (such as RFLP mapping and polymerase chain reaction) and genome transformation activities at ICRISAT are examples of pretechnology science research which immensely helps in technology generation and development for a group of crops rather than a single one. By enhancing invention potential, pretechnology science research has a spillover effect on programs within the given system as well as on other national and international research programs. Technology developed in one country may enhance the invention potential in another even if it is not directly transferable. Plant varieties, for example, may be valuable as germplasm in the breeding programs of another nation or state. Another example of interfoci spillover is the ongoing genome transformation activity at ICRISAT - which relates to research stage b - which is likely to make an immense contribution to prevention of fungal diseases in sorghum.

Most national research programs, especially those of small countries, concentrate on adaptive development and subinvention, ie, stage c. Typically, they are technologically dependent on international research institutes, and receive direct and indirect research spillin[4] from them. For example, Bangladesh has released six chickpea varieties; of these, four were drawn from ICRISAT crosses after screening and adaptive research trials. The other two were also from crosses provided by another international research center. Thus, Evenson's interfoci research spillover is really an indirect type of across-location spillover.

This chapter discusses the technology spillover potential from enhanced sorghum germplasm and its determinants. Actual/realized spillover from improved sorghum technologies generated by sorghum scientists are also documented.

11.2. Data and Research Methodology

11.2.1. Data

This study used data obtained from three different sources: International Sorghum Varietal and Hybrid Adaptation Trial (ISVHAT), All India Coordinated Sorghum Improvement Project (AICSIP) and NARS survey data obtained through ICRISAT's Impact Monitoring Survey.

ISVHAT Data

ICRISAT commenced international yield testing of sorghum cultivars in 1976. Several yield trials were distributed by individual breeders until 1988. From 1989 to 1993, the trial was conducted by the Cooperative Cereals Research Network. It contained 26 elite sorghum genotypes and materials from all ICRISAT centers in Asia and Africa. Materials from Egypt, India, Sudan and Syria too were incorporated. Once every two years, the trial was reconstituted with new genotypes. Each year data from 25-30 locations, ranging in latitudes from 20°S to 43°N, were obtained. Data on phonology, plant height, grain yield and response to important pests and diseases were collected. (Alagarswamy 1996).

The trial provided scientists from various disciplines an opportunity to collaborate in the systematic evaluation of sorghum cultivars, and to contribute to the identification of cultivars adapted to specific regions in the semi-arid tropics in order to facilitate sustainable sorghum production. The trial's main objectives were to:

- make available to sorghum scientists the world's elite breeding lines, varieties and hybrids either for direct use or as parents in crosses within their breeding programs
- provide sorghum scientists an opportunity to assess the performance of their advanced breeding lines and released cultivars over a wide range of climatic, soil, disease and insect conditions
- identify lines with stable resistance to major disease, insects and other stresses
- identify similarities and differences in the effects of test environments on the performance of sorghum cultivars, and to achieve more focused testing
- serve as an information dissemination center on sorghum cultivar performance over a range of environments.

During 1989-92, trials were conducted in 59 locations spanning 26 countries in Asia, Africa and Latin America. The test locations and their physical environments are described in Table 11.1.

---

4 Spillin and spillover refer to the same phenomenon of externality. The terms are used interchangeably depending on whether a research program is receiving or producing the externality.

Figure 11.2 shows the locations of the trials. The trials comprised of about 25 cultivars common to all the locations (17 varieties and 8 hybrids, including a hybrid and a variety check). The AICSIP contributed 1 hybrid and 2 varieties. ICRISAT-Patancheru's Cereals Program contributed 6 hybrids and 6 varieties while its regional programs contributed 10 varieties (2 from WASIP, 4 from EARCAL, 2 from the SADC/ICRISAT Program and 2 from LASIP. Table 11.2 summarizes the number of locations to which ISVHAT data were made available between 1989 and 1992. The pedigrees of all the cultivars used in the trials are given in Table 11.3. Besides common cultivars, cooperators were asked to include some of their choice and a local check (a variety or hybrid). The trials were conducted using randomized complete block design with three replications.

AICSIP Trial Data

The AICSIP has been conducting adaptive research trials in different states and locations in the country. The data for 1975/76 to 1995/96 were utilized to quantify spillover impacts among different sorghum domains in India. Figures 11.3 and 11.4 show the locations of the trials conducted in India. Details of the locations and year of the trials are given in Table 11.4.

NARS Survey Data

A questionnaire (Appendix III) was sent to different sorghum-producing countries in Asia, Africa and Latin America to gather information on the cultivars released, their characteristics (origin, type of cultivar, ie, variety or hybrid), pedigree, year of release, morphological traits (grain color, insect and disease resistance), ecological niches, crop domains for which they were released, commercial success (area cultivated) and reasons for release (grain, forage, dual purpose). It also provided information on the status of sorghum cultivation in the country, ie, area, production and yield in different countries by environment and cultivar. The country's research capability and infrastructure measured by the number of scientists that support crop improvement in public and private research organizations as well as information on subsequent efforts to produce and promote improved seed (number of seed companies operating in the country) was sought.

11.2.2. Research Methodology

Sorghum research in different locations was conducted under eight research domains. A research domain was delineated as a homogeneous ecoregion defined in terms of its soil and climatic conditions and spreading beyond the geographical boundary of a country. For example, the major problem in Sorghum Research Domain (SRD) 2 is grain mold and in SRD3 stem borer and *Striga.* The eight sorghum research domains were: wide adaptability (SRD1), dual purpose with specific adaptability (SRD2), dual purpose with fodder emphasis (SRD3), forage sorghum (SRD4), early sowing postrainy-season sorghum (SRD5), late sowing postrainy-season sorghum (SRD6), irrigated sorghum (SRD7) and extreme altitude sorghum (SRD8). These have already been discussed in detail in Chapter 1. Here we have estimated the potential technology spillover impact for these eight research domains.

Two types of measurement techniques—subjective and objective—have been used to assess the spillover effects in agriculture (Deb and Bantilan 2001). Subjective estimates are based on value judgments rather than experimental or farm yield/cost data. They are often arrived at through elicitation from experts. Objective estimates, on the other hand, are based on hard data

Table 11.1. The physical environment of the ISVHAT test locations, 1989-92.

Country	Location	Country code	Location code	Latitude	Longitude	1989	1990	1991	1992
Brazil	Caruaru Pe	1	1	8°.3' S	36°.0'W			–	
Burkina Faso	Farako-Ba	2	2	10°.3'N	6°.5'W		*	*	*
Burkina Faso	Saria	2	3	12°.2' N	1°.9'W		*		
Cameroon	Maroua	3	4	10°.3'N	14°.7' E		*	*	*
China	Shenyang	4	5	42° .5' N	123°.0'E		*		*
Ecuador	E.E.Boliche	5	6	2°.2' S	79°.6'W			*	
Egypt	Assiot	6	7	30°.0' N	30°.0' E				
Egypt	Sandaweel	6	8	26°.0' N	31°.0'E		*	*	*
Guatemala	Cuyata	7	9	14°.7' N	90°.5' W			*	
India	Anantapur	8	10	14°.5' N	77°.0' E				
India	Bhavanisagar	8	11	11°.0'N	77°.0' E		*	*	*
India	Jalna	8	12	19°.5'N	75°.5' E		*		*
India	Medchal	8	13	17°.3'N	78°.2' E		*	*	*
India	Patancheru	8	14	17°.3'N	78° 2 E		*	*	*
India	Surat	8	15	21°.1'N	72°.5' E		*	*	*
India	Thimmapur	8	16	17°.3'N	78°.2' E				*
Indonesia	Balittan Munene	9	17	7°.6'S	113° .2'E				
Indonesia	Bontobili-Sulawesi	9	18	5°.2' S	119°.3'E				*
Indonesia	Citayam	9	19	7°.0'S	107°.0'E		*		
Indonesia	Maumere	9	21			*			
Indonesia	Muara Bogor	9	22	7°.0' S	107°.0'E				*
Indonesia	Muneng	9	23	7°.6'S	113°.2'E		*	*	*
Indonesia	Pati	9	24	7°.0' S	111°.0'E				
Indonesia	Sulawesi (Maros)	9	25	5°.0' S	119°.3'E				
Iran	Isfahan	10	26	32°.5' N	51°.5'E			*	*
Iran	Karaj	10	27	35°.5' N	51°.0'E				*
Kenya	Alupe	11	28	0°.3' N	34°.1'E		*	*	
Kenya	Katumani	11	29	1°.4'S	37°.1'E *		*	*	
Kenya	Kiboko	11	30			*	*	*	
Kenya	Kiboko (long rains)	11	31	1°.3'S	37°.1'E				
Mali	Bema	12	32	14°.7' N	9°.5' W		*		
Mali	Cinzana	12	33	13° 2 N	5° .6' E *				
Mali	Niangoloko	12	34						
Mali	Samanko	12	35	12°.3' N	8°.7'E *		*	*	
Mali	Sikasso	12	36	11°.2'N	5°.4' W			*	*
Mexico	Poza Rica	13	37	18° .4' N	99°.1'W *		*	*	
Myanmar	CARI Yezin	14	38	19°.5'N	96°.7'E *		*	*	*
Myanmar	Mahlaing	14	39	21°.5'N	95° .4' E			*	*
Myanmar	Myingyan	14	40	21°.3'N	95° 2 E			*	*
Nepal	Khumaltar	15	41	27°.4' N	85°.2' E				*
Nicaragua	Managua	16	42	21°.1'N	86°.1'W *				
Niger	Bengou	17	43	11°.5'N	3°.3'E *				
Nigeria	Bagauda	18	44	11°.4'N	8°.3' E *				
Pakistan	Islamabad	19	45	33°.4' N	73°.7' E *		•	*	*
Pakistan	Yusafwala	19	46	31°.0'N	74°.0' E *		*	*	*
Sudan	Sim-Sim (Khartoum)	20	47	24°.4' N	46°.5' E *				
Sudan	Wad Medani	20	48	14°.4' N	33°.3'E				•
Tanzania	Hombolo	21	49	5°.5'S	35°.6' E *				

...continued

Table 11.1 *Continued*

Country	Location	Country code	Location code	Latitude	Longitude	1989	1990	1991	1992
Thailand	Khon Kaen	22	50	16°.0' N	103°.0'E	*		*	*
Thailand	Pakchong	22	51	14°.5' N	101°.5'E		*	*	*
Thailand	Suphanburi	22	52	14° .2' N	99° .5'E	*	*	*	*
Venezuela	Magdaleno	23	53	10°.6'N	67°.3' E		*		
Vietnam	Tu Loc	24	54	20°.6' N	105°.0' E			*	*
Vietnam	Tu Loc Hai Huing	24	55	21°.0'N	105.1'E		*		
Zimbabwe	Lucydale	25	56	20°.5'S	28°.3' E		*	*	*
Zimbabwe	Makoholi	25	57	19°.5'S	30°.5' E	*			
Zimbabwe	Matapos	25	58	20°.2' S	28°.3' E	*	*		*
Zimbabwe	Mzarabani	25	59	16°.2'S	32°.0' E	*			
Saudi Arabia	Riyadh	26	60	24°.4' N	46°.5' E		*	*	

* = Data available.
Source: ISVHAT reports.

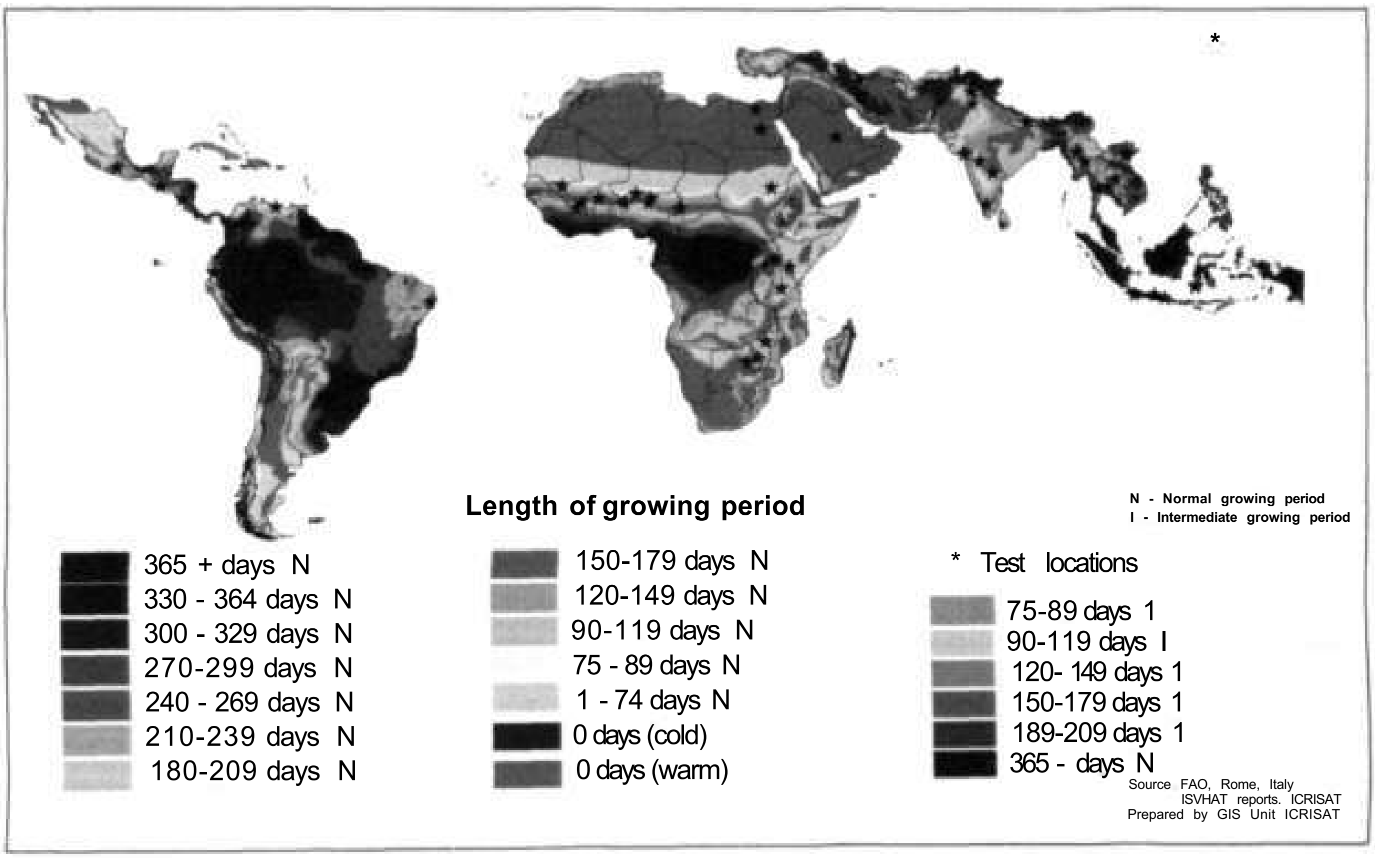


Figure 11.2. ISVHAT trial locations, 1989-1992.

and evidence reflecting the extent of applicability of a new technology across environments or commodities beyond the research target. Data requirement and methods of analysis for objective estimates vary, depending on the type of spillover to be assessed.

To quantify spillover impacts (ie, estimation of the coefficients of sorghum spillover matrix), an econometric approach based on yield trial data, similar to that of Maredia et al.(l 996) was used. The first step was to identify the origin domain and trial (test) domain of sorghum cultivars tested in AICSIP and ISVHAT trials. The final step was to quantify spillover matrices.

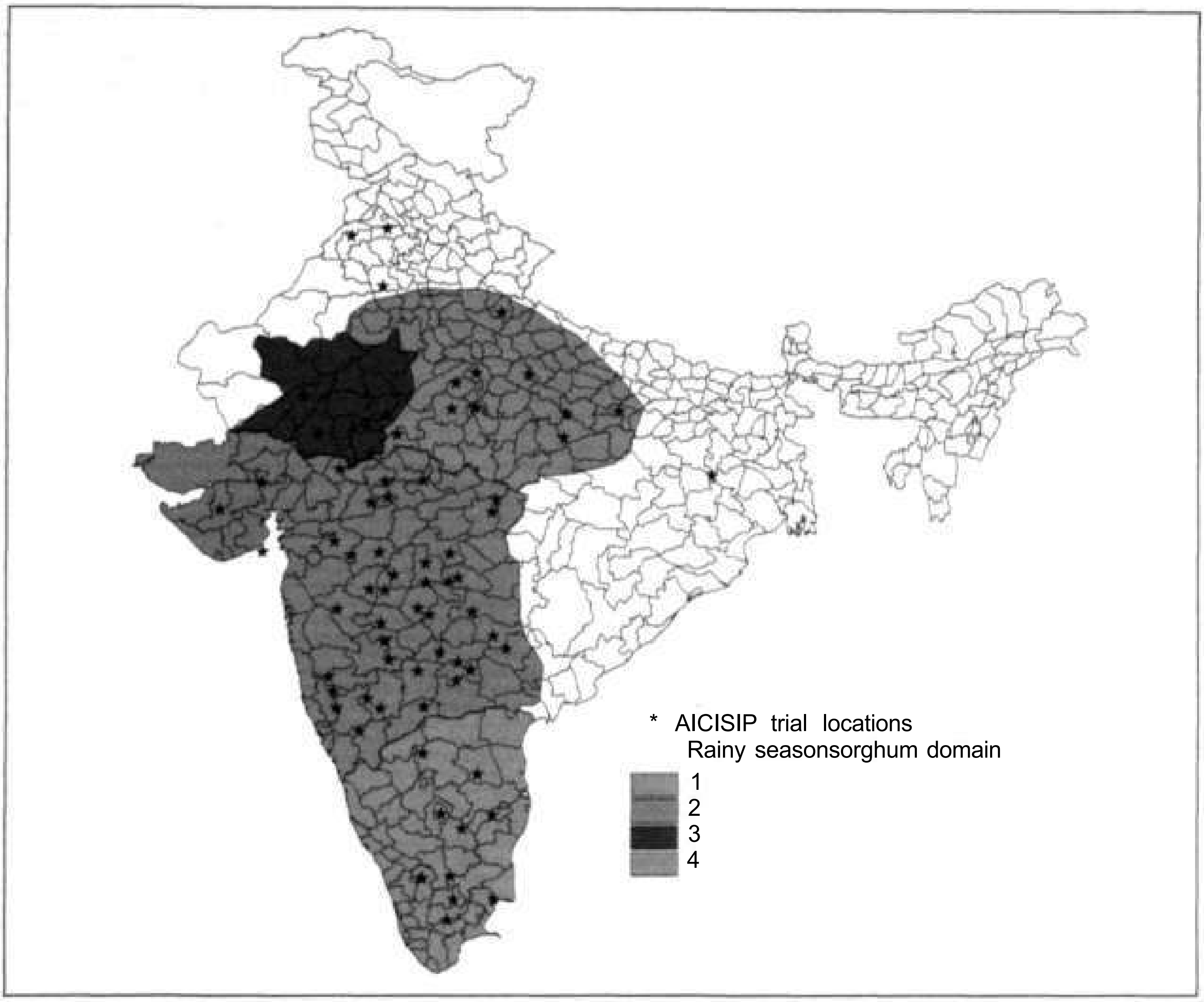


Figure 11.3. AICSIP trial locations.

Table 11.2. Number of locations to which ISVHAT data was made available, 1989-92.

	Data received for the year				Complete data received for the year			
Region	1989	1990	1991	1992	1989	1990	1991	1992
Asia	12	14	17	23	9	9	13	19
EARCAL[1]	2	3	4	-	2	3	4	-
WASIP[2]	7	7	7	3	5	4	4	3
Egypt	1	1	1	1	1	1	1	1
Southern Africa (SADC)[3]	4	2	1	2	4	2	-	2
Latin America (LASIP)[4]	3	2	5	-	3	--	5	-
RAB[5]	-	-	-	1	-	-	1	1
Other locations	1	3	2	-	-	2	-	-
Total	30	32	37	30	24	21	28	26

1 EARCAL = East African Regional Cereals and Legumes Program.
2 WASIP = West African Sorghum Improvement Program.
3 SADC = Southern African Development Committee.
4 LASIP = Latin American Sorghum Improvement Program.
5 RAB = Regional Arab Bureau.
Source: ISVHAT reports.

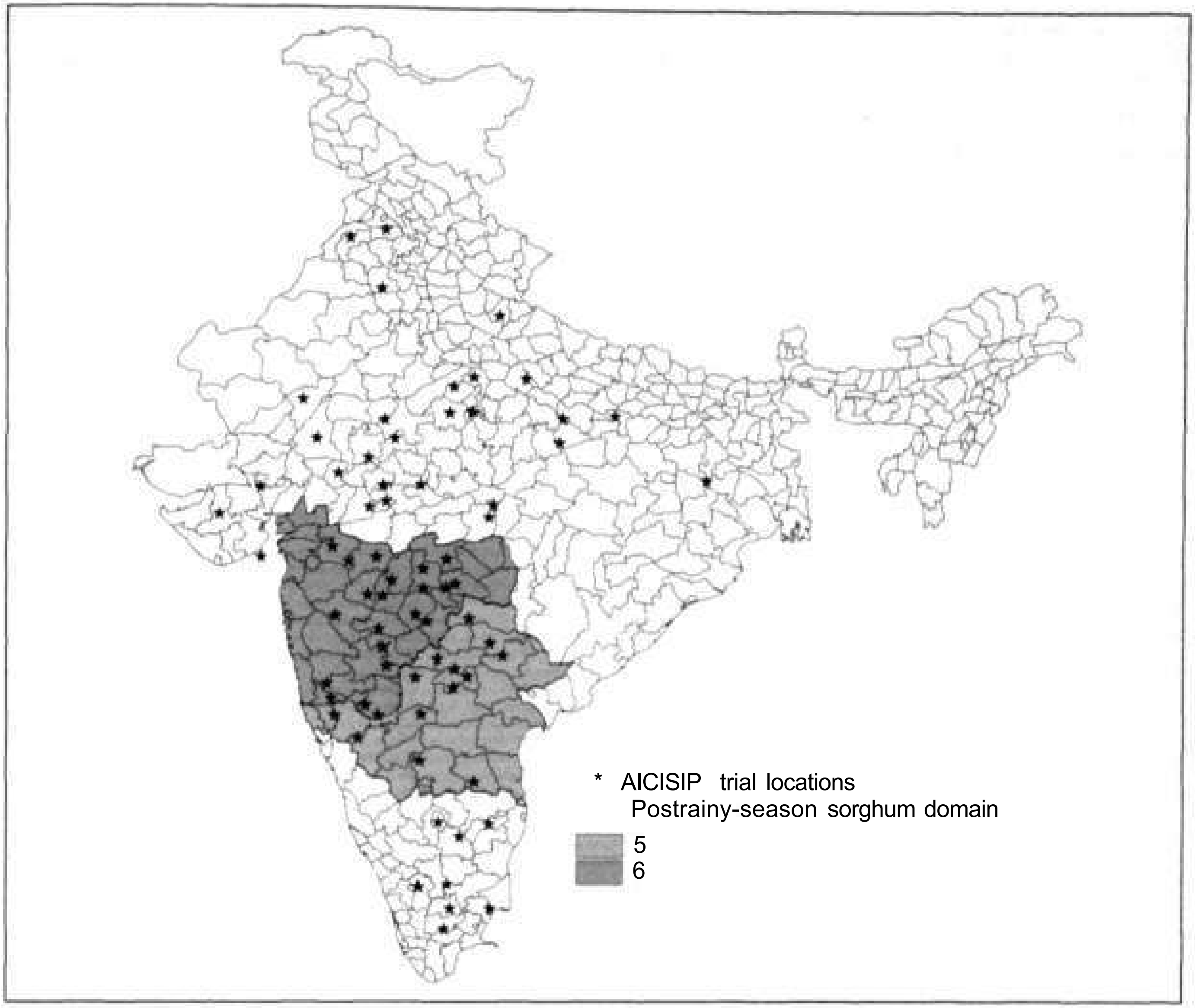


Figure 11.4. AICSIP trial locations.

Estimation of Spillover Matrix

Following Maredia et al. (1996), it was assumed that the performance of a variety is a function of environmental variables (location dummy, year dummy) and technology variables (vintage and origin of the variety). Technology variables were included to represent characteristics of varietal technology. The following regression model was used to estimate the spillover matrix.

$$Y^{i}_{hgt} = a + b_h DLOC_h + c\, DYEAR + v\, VINT + w_i\, DORIG_i + r\, MR + €_{hgt}$$

for j =1,2,..,n (11.1)

where,

j is the test domain in which the yield data point is observed

Y^{j}_{hgt} is the observed yield (kg ha^{-1}) of the g^{th} entry at the h^{th} trial location in environment j in the t^{th} trial year

$DLOC_h$ is a vector of dummy variables equal to 1 if the data point belongs to location h, and 0 otherwise

DYEAR is a vector of dummy variables equal to 1 if the data point belongs to year t, and 0 otherwise

VINT is a variable to reflect the vintage of a variety approximated by the trial year in which the g^{th} variety first appeared

Table 11.3. Name, pedigree and origin of cultivars included in ISVHAT, 1989-92.

Cultivar	Pedigree	Origin	Trial years
5D 160		EARCAL (Burundi)	1990,1991,1992
CSH 9	296A x CS 3541	AICSIP	1989,1990
CSV 10	SB 1066 x CS 3541	AICSIP	1989, 1990
ICSH 110	296A x MR 836	IC	1989,1990,1991,1992
ICSH 205	SPL117A x SPL 16 R	IC	1989, 1990
ICSH 310	ICSA 32 x MR 841	IC	1989
ICSH 401	ICSA 11 x MR 913	IC	1989
ICSH 566	ICSA 42 x SPL 13 R	IC	1989,1990
ICSH 798	ICSA17xMR926	IC	1989, 1990
ICSH 807	ICSA 17 x SPL 6 R	IC	1989, 1990
ICSH 871001	ICSA 84 x ICSR 172	IC	1991
ICSH 88051	ICSA 22 x MR 841	IC	1989,1990
ICSH 88056	ICSA 32 x MR 924	IC	1989
ICSH 88058	ICSA 52 x MR 846	IC	1989, 1990
ICSH 88065	ICSA 67 x ICSR 154	IC	1991,1992
ICSH 88071	ICSA 37 x MR 908	IC	1989
ICSH 88074	ICSA 39 x MR 844	IC	1989
ICSH 89020	ICSA 31 x ICSR 89022	IC	1991,1992
ICSH 89034	ICSA 88005 x ICSR 89032	IC	1991,1992
ICSH 89034	ICSA 88005 x ICSR 89032	IC	
ICSH 89051	ICSA 11 x ICSR 89018	IC	1991,1992
ICSH 89123	ICSA 56 x ICSR 89028	IC	1991,1992
ICSH 90002	ICSA88005 x ICSR 112	IC	1991,1992
ICSV-LM 86513		LASIP	1990,1991,1992
ICSV 202	(SPV 350 x SPV 475)-2-2-7	IC	1989
ICSV 1	(SC 108-3 x CS 3541)-19-1	IC	1989, 1990
ICSV 111		WASIP	1990,1991,1992
ICSV 112	[((IC 12622C x 555) x ((IS 3612C x 2219B)-5-1)) x E 35-1]-5-2	IC	1991,1992
ICSV 210	(SPV 350 x SPV 475)-2-2-5	IC	1989, 1990
ICSV 233	[IS 9562 (IS 12611 x SC-108-3)]-3-2-2-5-1	IC	1989, 1990
ICSV 298	[(M-35-1 x M-1009)-3-2-1 x 6 F5 s]-5-1-4-2	IC	1989
ICSV 401		WASIP	1990,1991,1992
ICSV 421	(148 x 555)-Bulk-1-1-1	IC	1989
ICSV 689	(PS 21314 x A6180)-8-9-1-1-2	IC	1989
ICSV 725	(M 60048 B x PS 19230) -17-2-2-1-1	IC	1989
ICSV 745	(PM 11344 x A 6250)4-1-1-1	IC	1989
ICSV 747	(PM 11344 x A 6250)-8-2-1-4-3	IC	1989
ICSV 88002	[(ICSB 3 x SPV 615) x (BT x 678)B.bulk))]-1-9-2-1	IC	1991,1992
ICSV 88013	(PM 11344 x SPV 351)-27-1-1-2	IC	1990,1991,1992
ICSV 88032	(PM 11344 x SPV 351)-27-1-1-2	IC	1990,1991,1992
ICSV 89102	[(IS 23528 x SPV 475) x PS 29159]-4-2-1	IC	1991,1992
ICSV 89106	[(IC 149 x SPV 475) x ICSB 1]-6-1-1	IC	1991,1992
IS 23496		SADC	1990
IS 23509		SADC	1990,1991,1992
IS 8193		EARCAL (Kenya)	1990,1991,1992
IS 9302		EARCAL (Ethiopia)	1990,1991,1992
ISIAP DORADO		LASIP	1990,1991,1992
KAT/83369		EARCAL (Kenya)	1990,1991,1992
Local check			1989
Local check			1990
Local check			1991
Local check			1992
SPH 468	AKMS14AxR150	AICSIP	1991,1992
SPV 462	MS 8271 x IS 3691	AICSIP	1989,1990
SPV 669	[353 (604 x 512) x (Vidisha 60-1 x CS 1151)]	AICSIP	1991,1992

Source: ISVHAT reports.

Table 11.4. Multilocational trials conducted by AICSIP, 1975-95.

Location	Trails conducted (year)																				
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Maharashtra																					
Parbhani	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•
Akola	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•
Nagpur		•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•
Gadhinglaj			•								•	•	•	•		•		•	•		•
Jalgaon	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•		•
Karad	•		•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•
Jalna									•												
Digraj	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•		•
Somanathpur		•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•
Amaravati	•	•	•	•	•	•	•	•	•	•	•	•	•	•					•	•	•
Nanded		•	•	•	•	•	•	•	•	•	•	•	•						•		•
Dhulia	•	•	•	•	•	•		•	•	•	•	•	•	•		•		•			•
Ekarjuna									•											•	
Mohol									•											•	
Badnapur									•											•	
Solapur									•											•	
Rahuri		•		•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	
Buldana	•	•	•	•	•	•	•	•	•	•	•		•	•		•		•	•	•	•
Yeotmal	•	•	•	•	•	•	•	•	•	•		•	•	•		•		•	•	•	•
Kolhapur			•											•							
Ambejogai		•											•								
Akola (Dryland Project)	•		•																•		
Aurangabad														•		•				•	•
Karnataka																					
Dharwar	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•
Gulbarga								•											•		
Arbhavi	•	•	•	•	•	•	•														

...continued

Table 11.4 *Continued*

Location	Trails conducted (year)																				
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Bijapur		*														*			*		
Raichur	*		*																		
Bagalkot	*	*	*	*	*	*	*		*				*								
Bidar									*									*	*	*	*
Gangavati	*	*		*																	
Baihongal	*							*	*	*	*	*	*	*		*		*	*	*	
Dharwar ADC			*			*															
Konnur			*			*															
Jhamkhandi			*																		
Tyavangi		*				*															
Andhra Pradesh																					
Palem	*	*	*	*	*	*	*	*	*	*		*				*		*	*	*	*
Hayatnagar																					
Rajendranagar		*		*	*	*	*														
Anantapur		*	*	*		*	*		*	*	*		*								
Dindi									*												
Madhole	*		*	*	*					*	*										
Adilabad	*	*	*	*		*	*	*	*		*	*	*			*		*	*	*	*
ICRISAT							*	*	*	*	*	*	*			*					
Karimnagar		*	*		*				*	*		*	*								
Dryland Project, Hyderabad				*																	
Warangal	*		*	*																	
Sadhasivpet													*								
Madhira																		*			
Madhya Pradesh																					
Indore	*	*	*	*	*	*	*	*	*	*	*	*	*			*		*	*	*	*
Sehore												*									
Gwalior	*		*							*	*					*			*		
Mandsaur	*	*	*	*	*	*	*		*	*						*					
Khargaon			*	*		*			*									*			

...continued

Table 11.4. *Continued*

Location	Trails conducted (year)																				
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Chindwara	•	•	•					•	•	•	•										
Poewerkheda		•	•		•																
Tikamgarh									•												
Rewa		•																			•
Burhanpur	•			•																	
Ujjain																•		•			
Tamil Nadu																					
Coimbatore	•	•	•	•	•	•	•	•	•	•	•	•	•			•		•	•	•	•
Bhavanisagar	•	•	•		•	•	•	•	•	•	•	•									
Kudumlai		•	•	•																	
Paiyur			•	•	•	•	•	•	•	•	•							•	•	•	•
Krishnagiri	•	•																			
Vellore											•	•									
Kaveripattinam		•																			
Kovilpati																•					
Rajasthan																					
Vallabhnagar	•																				
Udaipur		•	•	•	•	•	•	•	•	•	•	•		•		•		•	•	•	•
Sumerpur			•		•	•	•														
Aklera		•	•								•		•					•			•
Pali			•	•	•			•	•	•											
Kota	•					•	•	•	•	•	•										
Diggi						•										•		•			
Banswara	•	•	•							•		•		•							
Jhalwar	•																				
Gujarat																					
Navsari	•	•	•	•	•	•		•	•	•		•	•	•		•		•	•	•	•
Surat	•	•	•	•	•	•	•	•				•	•	•		•		•	•	•	•
Targhadia									•	•				•				•			
Dharia									•		•										
Talaja		•	•	•																	

...continued

Table 11.4. *Continued*

Location	Trails conducted (year)																				
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Deesa			*		*	*	*	*	*	*	*	*	*	*		*		*	*	*	*
Manavadar		*	*																		
Veerangam						*	*	*	*	*	*										
Rajkot			*	*			*	*								*					
Chharodi												*	*	*		*		*			*
Uttar Pradesh																					
Jhansi (RAS)		*																			
RATDC Jhansi					*																
Jhansi		*	*					*		*		*	*			*		*			
Jhansi (IGFRI)	*																				
Varanasi			*																		
Pantnagar		*	*	*	*	*	*	*	*	*			*	*				*	*		
Kanpur	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*
Mauranipur									*	*	*	*	*	*					*	*	*
Bareilly											*										
Bulandshahar			*																		
Bihar																					
Ranchi	*	*	*																		
Mungir											*								*		
Kanki				*																	
Dholi								*													
Sabour								*	*	*											
Orissa																					
Bhavani Patna											*										
Punjab																					
Ludhiana								*	*	*	*	*	*								
Faridkot									*												
Haryana																					
Hissar		*	*	*	*	*		*		*											
Jammu & Kashmir																					
RK Pura (Jammu)	*	*																			

* = Data available.
Source: AICSIP reports (various years).

$DORIG_i$ is a vector of dummy variables equal to 1 if the g^{th} variety belongs to the origin group i, and 0 otherwise

MR is the inverse Mill's ratio

€ is the error term

ISVHAT panel data was used to estimate the model. Location and year dummies (DLOC and DYEAR) were included to factor out the site and time effects (such as different levels of management) on the observed trial. To correct probable selection bias related to the correlation between varietal attrition and experimental response (ie, yield) of nonrandomly missing varieties in the trials conducted over a number of years, the variable MR (inverse Mill's ratio) was included. The model was estimated separately for each sorghum domain; therefore the coefficients for DORIG represent the performance of varieties of different environmental origins in a given sorghum domain relative to the 'home varieties'[5]. The varietal group originating from the test domain was considered the benchmark variable (ie, the dummy variable DORIG was dropped from the equation for each domain). Therefore, the coefficients of $DORIG_i$ are the differential yields defined as ($w^j_i = Y_{ij} - Y_{jj}$). These coefficients were used to estimate Y_{ij}/Y_{jj} to give the elements of the spillover matrix, C_{ij}, based on the constant Y_{jj} (approximated by the arithmetic mean) for each domain.

11.3. Technology Spillover Potential

11.3.1. Across Sorghum Research Domain Spillover Matrix for the World

Model parameters in Equation (11.1) were estimated using the ordinary least square method from ISVHAT data. Results from the regression analyses (Table 11.5.) indicate that the inclusion of the location dummy variables had a significant positive effect on the R^2 of all the seven regression models. Similarly, the year dummy variables for the trial years significantly increased the R^2 of the estimated models. The coefficient of the MR variable indicates the relationship between observed yields and the probability of retention in the trials.

The coefficient of origin variables (w.) estimate the yield advantage or disadvantage (kg ha^{-1}) of varieties originating in different sorghum domains relative to the test sorghum domain. The zeros on the diagonal indicate that the coefficient of variety group of the same domain origin as the test domain is defined as the 'benchmark' and all the other coefficients in that column represent deviations from that value.

The negative values of NARS technology in most of the sorghum research domains (Table 11.5) confirm the hypothesis that varieties developed in a test domain perform better than those developed in other domains. For example, NARS varieties of SRD2 origin on an average yielded 96 kg less in SRDI (after adjusting for other variables). However, it needs to be mentioned that the values (related to DORIG) in most of the cases were not statistically significant. Negative values in a given column result from either both genetic differences among cultivars and a difference in the selective domain at the test versus origin domain, or only from a difference in the genetic properties of the cultivars tested. The latter circumstances could reflect different levels of breeding success and would result in a symmetrical relationship such that $w_i^j = - w_j^j$. The abundance of negative values both above and below the diagonal shows that ICRISAT's sorghum domains reflect true differences in selective environmental properties.

5 Home varieties are the best performing varieties presently cultivated in the area. In other words, the 'checks' used in the yield trails.

Table 11.5. Regression results of potential spillover at the sorghum research domain level using ISVHAT data, 1989-92.

Independent variables	SRD1	SRD2	SRD3	SRD4	SRD7	SRD8.1	SRD8.2
Constant[1]	4779***	4506***	4199***	4341***	8331***	15968***	5936***
Dummies for year							
R^2 change[2]	0.07	0.02	0.04	0.09	0.06		0.06
F change[3]	-15	-32	-6	-2	-6		-17
Dummies for location							
R^2 change[2]	0.07	0.39	0.22		0.22		0.18
F change[3]	-27	0	3		7		-12
Mill's ratio (MR)[1]	-4101902***	-2071749***	-1496520***	-3054522***	-6644808***	-9772124***	-7674958***
Origin, DORIG[1,4]							
DORIG1		-139	24	-126	-797	-5221**	440
DORIG2	-96		-134	53	-316	-5989**	734*
DORIG3	148	-97		-2323	-76	-4443*	732*
DORIG4	-642						
DORIG7		74	-764	810	-26		93
DIDC	277*	175	354	-56			
Number of observations	457	1549	601	249	307	194	371
R^2	0.53	0.26	0.32	0.61	0.32	0.65	0.54
F value	102***	109***	57***	65***	30***	31***	87***

1. Estimated coefficient (kg ha^{-1}).
2. Change in R^2 when a given set of dummy variables is included in the equation that includes all the other variables.
3, Change in the F-ratio when a given set of dummy variables is included in the equation that includes all the other variables.
4. Origin groups DORIG1 to DORIG7 represent cultivars developed by national programs for the respective domains. DIDC indicates cultivars developed at ICRISAT-Patancheru.

* = $P<0.05$, ** = $P<0.01$, *** = $P<0.001$.

The last row shows that ICRISAT cultivars performed well in most sorghum research domains, especially SRD1, SRD2, SRD3 and SRD8.2. For example, ICRISAT cultivars bred at Patancheru enjoyed a yield advantage of 277 kg ha^{-1} in SRD1, 354 kg ha'1 in SRD3 and 175 kg ha^{-1} in SRD2. This positive yield advantage indicates their potential to spill over to these test domains. It also indicates the success of ICRISAT's breeding for wide adaptability. This interpretation is strengthened by data in Table 11.6.

Table 11.6 presents the average yield (kg ha^{-1}) of sorghum cultivated in ISVHAT trials. The grain yield of ICRISAT-bred cultivars was higher in all the sorghum domains compared to those bred exclusively for those domains, except in the case of SRD7 and SRD8.1. In SRD1, it was 472 kg ha^{-1} while in SRD2 it was 446 kg ha^{-1}. In SRD3, ICRISAT-bred cultivars had a yield advantage of 256 kg ha^{-1} while in SRD4 and SRD 8.2 the corresponding figures were 1645 kg ha^{-1} and 995 kg ha^{-1}. SRD4 is the sorghum domain for forage-type sorghum. Therefore, comparing grain yield is not appropriate. One of the major limitations in ISVHAT is the lack of data on fodder yield. ICRISAT's programs were not breeding and testing for forage. However, the lower grain yield of NARS-bred cultivars for forage in SRD4 compared to those developed in other sorghum domains suggests that research on forage sorghum was probably successful in developing more stalk-producing cultivars (but with low grain yield). Sorghum cultivars developed for SRD7 (irrigated environment) and SRD3 (dual purpose, late maturing) also performed better in SRD2 (dual purpose, early maturing) than the local NARS-bred cultivars. This indicates the potential of sorghum cultivars developed for irrigated domain to spill over into rainy season, late maturing and dual-purpose sorghum areas. However, it may be noted here that irrigated-type sorghums may not have an advantage in terms of fodder yield since this was not available in ISVHAT data. The higher grain yield of SRD3 cultivars compared to SRD2 cultivars indicates the high spillover potential between two different maturity groups of dual-purpose sorghum. Again, firm conclusions cannot be drawn without analyzing fodder yield data which is one of the two major objectives—high grain yield and high fodder yield—of sorghum breeding for dual purposes.

The spillover coefficients are presented in Table 11.7 in terms of percentage coefficients based on average yields of the benchmark variables (i.e., $c_{ij} = Y_{ij}/Y_{jj}$). Off-diagonal values of less than one indicate that sorghum cultivars directly introduced from other sorghum domains yielded less than those developed by local breeding programs in the test domain. Similarly, values greater

Table 11.6. Average yield (kg ha^{-1}) of sorghum obtained in ISVHAT trials, 1989-92.

Origin of cultivar	Sorghum Research Domains where cultivars were tested						
	SRD1	SRD2	SRD3	SRD4	SRD7	SRD8.1	SRD8.2
SRD1	3123	3288	2946	2103	5418	5390	4266
SRD2	2991	3463	3042	2633	5733	3498	4705
SRD3	2758	3622	3500	2362	6267	6275	4457
SRD4	No cultivar	No cultivar	No cultivar	1404 16	No cultivar	No cultivar	No cultivar
SRD7	2490	3913	2788	1793	7381	No cultivar	No cultivar
SRD8.1	No cultivar	No cultivar	No cultivar	No cultivar	No cultivar	15089 (11)	No cultivar
SRD8.2	No cultivar	No cultivar	No cultivar	No cultivar	No cultivar	No cultivar	3677 (23)
ICRISAT-Patancheru	3595	3909	3756	3049	6142	4973	4672

Source: Authors' estimate.

Table 11.7. Estimated spillover matrix for sorghum improvement research at the global Sorghum Research Domain level (computed from ISVHAT trial data, 1989-92).

Origin of cultivar	Sorghum Research Domains where cultivars were tested						
	SRD1	SRD2	SRD3	SRD4	SRD7	SRD8.1	SRD8.2
SRD1	1.00	0.95	0.84	1.50	0.73	0.36	1.16
SRD2	0.96	1.00	0.87	1.88	0.78	0.23	1.28
SRD3	0.88	1.05	1.00	1.68	0.85	0.42	1.21
SRD4				1.00			
SRD7	0.80	1.13	0.80	1.28	1.00		
SRD8.1						1.00	
SRD8.2							1.00
ICRISAT-Patancheru	1.15	1.13	1.07	2.17	0.83	0.33	1.27

Source: Authors' estimate.

than one (as in the case of ICRISAT-Patancheru-bred cultivars) indicate that sorghum cultivars directly introduced from these sources tended to yield more than those developed by local breeding programs in the test domain.

The significant yield advantages shown by varieties developed and evaluated in SRD7 and SRD 8.1 (implying less direct spillins of cultivars developed for other sorghum domains) can be explained by the fact that sorghum cultivars bred for rainfed environments cannot perform better in irrigated environments. 'Environmental distance' plays a role in explaining the significant yield advantage enjoyed by locally-bred cultivars in SRD7 (irrigated) and SRD8.1 (high altitude). The poor performance of all the cultivars developed for other sorghum research domains or bred for wide adaptability by ICRISAT-Patancheru in SRD8.1 (high altitude, ie, China) can be explained by the fact that the climate adaptation patterns are entirely different compared to other domains. Therefore, the best way ICRISAT can assist China's national program is by providing intermediate products (enhanced germplasm materials) rather than finished ones (varieties/hybrids). This argument is strengthened by the fact that of the 10 hybrids developed in China after 1987, 7 are derived from ICRISAT materials, but after incorporating genes for local adaptation. The implications for ICRISAT are that the focus should be on upstream (strategic) research to develop basic materials and provide NARS with strong research programs. ICRISAT moved in this direction in 1995.

Sorghum cultivars developed for irrigated environments (SRD7) showed 13% grain yield advantage in SRD2 (late maturing, dual purpose) but not vice versa. The asymmetry of these two domains explains the asymmetry in the spillover matrix (i.e. $c_{ij} \neq c_{ji}$). However, without comparing fodder yield it cannot be said that sorghums bred for irrigated environments (SRD7) were really performing better in SRD2. The major objective of dual-purpose sorghum (SRD2) is to provide high grain and fodder yield, while breeding of irrigated sorghum concentrates on increasing grain yield. Therefore, SRD7 cultivars may provide higher grain yield but not higher fodder (stalk) yield.

An analysis of the performance of ICRISAT-Patancheru-bred cultivars across sorghum domains using the regression analyses reveals wide adaptability and transferability to different sorghum growing domains. This points to the success of research in reducing G X E interactions and developing widely adaptive cultivars, especially in all types of rainfed cultivation and in low altitude areas, which account for a significant share of the sorghum growing area in developing countries.

These results are based on a spillover analysis at the global sorghum domain level using data from ISVHAT coordinated by ICRISAT and with considerable representation of ICRISAT-bred-cultivars. In order to check if the evidence of high transferability of ICRISAT-bred cultivars is sustained, the model in Equation (11.1) was estimated for India in the country-level environments using AICSIP trial data.

11.3.2. Across Sorghum Research Domain Spillover Matrix for India

The AICSIP trial data for 1975-96 was used to estimate the spillover coefficient matrix for sorghum in India. It was computed for each of the eight sorghum domains for ICRISAT-derived-cultivars (IDCs) and NARS-derived cultivars. IDCs are those varieties/hybrids developed through research partnership between ICRISAT and NARS using ICRISAT-derived germplasm or breeding material, while NARS-developed cultivars are cultivars developed solely by NARS.

The results of the regression analyses (Table 11.8) indicate that the inclusion of dummy variables for the year had a significant positive effect on the R^2 of all the seven regression models.

As mentioned earlier, the coefficient of the MR variable indicates the relationship between observed yields and the probability of retention in the trials.

It may be recalled that the coefficient of origin variables (w_i) estimate the yield advantage or disadvantage (kg ha^{-1}) of varieties originating in different environments relative to the test environment. The zeros on the diagonal indicate that the coefficient of variety group with the same origin and test domains is defined as the 'benchmark'; and all the other coefficients in that column represent deviations from that value.

The dominance of the positive values of Indian NARS-developed varieties for wide adaptability (SRD1) and dual purpose with specific adaptability (SRD2) to other test domains except irrigated sorghum domain (SRD7) confirms the hypothesis that varieties developed by the Indian NARS in SRD1 and SRD2 perform better than varieties developed in other domains. For example, Table 11.8 shows that NARS varieties of SRD1 origin yielded 320 kg more on an average in SRD2 (after adjusting for other variables). Similarly, NARS varieties of SRD1 have a yield advantage of 305 kg ha^{-1} in SRD3 and 423 kg ha"[1] in SRD6. The implication of this finding is that the Indian NARS was successful in its efforts to generate widely adaptable cultivars.

A few negative values can also be found in the coefficients. For example, the field of cultivars originating from SRD2 and SRD5 is less than the cultivars that originated in SRD1 (the wide adaptability domain). Negative values in a given column result from either both genetic differences among cultivars and/or a difference in the adaptation pattern at the test versus origin domain. The genetic difference could reflect different levels of breeding successes and would result in a symmetrical relationship such that $w_i' = - w_j^i$. The presence of negative values both above and below the diagonal show that the sorghum domains used for the analysis reflect the true differences in selective environmental properties in India.

The last row in Table 11.8 shows that ICRISAT-derived cultivars perform well in most sorghum domains, especially in SRD1, SRD2, SRD3 and SRD4. For example, the dummy for IDCs indicate that they enjoy a yield advantage of 354 kg ha"[1] in SRD1, 418 kg ha^{-1} in SRD2 and 576 kg ha"[1] in SRD3. The positive yield advantage of IDCs is an indication of their potential to spill over to these test domains. It also indicates the success of ICRISAT-Patancheru's breeding program in developing enhanced materials for wide adaptability. This interpretation is strengthened by Table 11.9.

Table 11.9 presents the average yield $(kg\ ha)^{-1}$ of sorghum obtained in AICS1P trials during 1975-96. The per hectare grain yield of IDCs was higher in all the sorghum domains compared to the cultivars bred for those domains, except in SRD7. In SRD1, yield increase was 166 kg ha^{-1} while in SRD2 it was 328 kg ha^{-1}. The corresponding figures for SRD5 and SRD6 were 492 kg ha^{-1} and 252 kg ha^{-1}.

The spillover coefficients are presented in Table 11.10 in terms of percentage coefficients based on average yields of the benchmark variables (ie, $c_{ij} = Y_{ij}/Y_{jj}$). Off-diagonal values of less than one indicate that sorghum cultivars directly introduced from other sorghum domains yield less than those developed in the test domain. Similarly, values greater than one (as in the case of IDCs) indicate that sorghum cultivars directly introduced from these sources yield more than those developed in the test domain.

A regression analyses of the performance of IDCs across sorghum domains shows their wide adaptability and transferability to different domains. The environmental specificity and associated selective environmental heterogeneity evident in the comparison of NARS-developed cultivars are minimized when IDCs are compared across different sorghum domains. This indicates the success of the collaboration between ICRISAT and Indian NARS in reducing G x E interactions and developing widely adaptive cultivars in India.

Table 11.8. Regression results of potential spillover at the Sorghum Research Domain level using AICSIP trial data, 1975-96.

Independent variables	SRD1	SRD2	SRD3	SRD4	SRD5	SRD6	SRD7
Constant[1]	2302***	2965***	1472***	2423***	2400***	2388***	2880***
Dummies for year							
R^2 change[2]	0.04	0.04	0.27	0.08	0.10	0.04	0.03
F change[3]	-79.03	-161.13	-5.91	-49.94	-70.56	-127.04	-3.78
Mill's ratio (MR)[1]	-109475***	-197034***	-79704***	-239804***	-240648***	-345329***	-209760***
Origin, DORIG[14]							
DORIG1		320***	305*	27	117	423*	38
DORIG2	-257**				54	1303***	-431*
DORIG5	-492	-311				5	-90
DORIG6		4			-143*		
DIDC	354***	418***	576***	103	466***	-4	-389
Number of observations	2048	10851	635	1575	2644	3278	466
R^2	0.16	0.10	0.11	0.11	0.18	0.21	0.22
F value	102.71***	230.15***	27.89***	66.75**	116.49***	174.53***	27.34***

1. Estimated coefficient (kg ha^{-1}).
2. Change in R^2 when a given set of dummy variables is included in the equation that includes all the other variables.
3. Change in the F-ratio when a given set of dummy variables is included in the equation that includes all the other variables.
4. Origin groups DORIG1 to DORIG6 represent cultivars developed by national programs for the respective domains. DIDC indicates cultivars developed at ICRISAT-Patancheru.

* = P<0.05, ** = P<0.01, *** = P<0.001.

Source: Authors' estimate.

Table 11.9. Average yield (kg ha^{-1}) of sorghum obtained in AICSIP trials, 1975-96.

Origin of	Sorghum Research Domains where cultivars were tested							
cultivar	SRD1	SRD2	SRD3	SRD4	SRD5	SRD6	SRD7	Outside
SRD1	2054	3175	1686	2297	2339	2406	2652	1910
SRD2	1928	2943	1434	2276	2368	3551	2179	1523
SRD5	1717	2545			2172	2098	2710	
SRD6		2954			1999	2153	2759	
ICRISAT-Patancheru	2220	3271	1960	2392	2664	2405	2402	2028

Table 11.10. Estimated spillover matrix for sorghum improvement research at the Sorghum Research Domain level (computed from AICSIP trial data, 1975-96).

	Sorghum Research Domains where cultivars were tested							
cultivar	SRD1	SRD2	SRD3	SRD4	SRD5	SRD6	SRD7	Outside
SRD1	1.00	1.08			**1.08**	**1.12**		
SRD2	0.94	1.00			**1.09**	**1.65**		
SRD5	0.84	0.86			**1.00**	**0.97**		
SRD6		1.00			**0.92**	**1.00**		
ICRISAT-derived cultivar	1.08	1.11			1.23	1.12		

11.4. Spillover Impacts

Brennan and Bantilan (1999) quantified the spillover impact of ICRISAT research on breeding programs and agricultural production in Australia. They identified ICRISAT germplasm lines released in Australia and grown by farmers there. In the case of sorghum, ICRISAT's most significant contribution to Australian agriculture has been the introduction of improved midge-resistant lines combined with desirable white grain and tan-colored plant (ICSV 745 and PM 13654). There are several advanced breeding lines that have incorporated midge resistance and a combination of other useful characteristics from ICRISAT-derived material. As a result, experts from the sorghum industry expect hybrids with midge resistance to be available in the near future, and that the resistance of such material will have a significant economic impact on the industry. Assuming that such resistance is likely to increase yield by 5% in 50% of the crop affected by midge each year, the expected yield gains to Australia are estimated at 2.5%. This translates into a cost reduction of $4.02 ton^{-1} or an annual cost saving of $4.69 million at current average production levels.

Brennan and Bantilan (1999) also assessed the impact of ICRISAT's global research on Australia, via an impact on prices. ICRISAT's global research has increased production and decreased sorghum price. Given finite supply and demand elasticities, ICRISAT's research is likely to have a downward impact on prices for the predominantly export-oriented sorghum industries in Australia. Thus, Australian industries face lower prices and increase in yield. An economic analysis of those spillover impacts in an economic welfare framework revealed that the overall net effect for Australia was a reduction in benefits gained by producers. Australian sorghum producers will lose more through lower prices than through the benefits they gain from higher yields, resulting in an overall loss of A$ 0.55 million per year. These losses occur because Australian producers are unable to make use of the productivity gains from ICRISAT's research as much as producers in the rest of the world. Hence, other producers experience greater cost reductions than do Australian producers. On the other hand, Australian consumers of sorghum (ie, primarily the livestock sector) will gain an average of A$1.69 million per year. Overall, the net gain to Australia as a result of ICRISAT's sorghum research effort averages A$ 1.14 million per year, or an aggregate of A$27.3 million (in 1996 dollars) over the period to 2022.

Actual spillover benefits have accrued in sorghum-growing countries. Macia, a variety released in Mozambique, was also later released in Botswana, Tanzania and Namibia (Table 11.11). Similarly, S 35 was developed in India and adopted by farmers of Cameroon and Chad. ICSV 111 was developed in India and released in Burkina Faso, Chad and Nigeria. ICSV 1079 BF was developed in Burkina Faso but is now cultivated by farmers in Mali. SPV 475 developed for India is now cultivated in Malawi, Swaziland and Zimbabwe. Seredo was developed for Uganda but 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; and do not substantiate the 'location specificity' argument (at least in terms of yields). Sorghum cultivars originating from the collaborative ICRISAT-NARS international research system have proven to be highly transferable within sorghum domains and across different countries around the world.

Table 11.11. Sorghum germplasm spillovers.

Cultivar	Production system[1] and country where originally selected	Spillover into
5D x160	21 Uganda	21 Rwanda; 20,21 Burundi
Dinkmash	8 India	19,20 Ethiopia
Gambella1107	20 Ethiopia	20,21 Burundi
Ingazi	8 India	19,20 Kenya
Macia	20 Mozambique	19 Botswana Tanzania, Namibia
Melkamash	8 India	20 Ethiopia
Seredo	21 Uganda	19 Ethiopia; 20,21 Kenya; 20 Tanzania
SPV 475	8 India	20 Malawi; Swaziland, Zimbabwe
SRN 39	8 India; 19 Sudan	20 Kenya; 20 Ethiopia
Tegemeo	21 Uganda	19,20 Tanzania; 20 Burundi
S 35	India	Cameroon, Chad
CE 151	Senegal	Mauritania
CE 145-66	Senegal	Mauritania
Malisor 84-1	Mali	Ivory Coast
BF 83-3/ 48-2-2	Burkina Faso	Senegal
IRAT	Niger	Burkina Faso, Chad
ICSV111 IN	India	Benin, Ghana, Nigeria
ICSV 1079 BF	Burkina Faso	Mali
ICSV 1083 BF	Burkina Faso	Togo
ICSV 1089 BF	Burkina Faso	Senegal
ICSV 400	India	Nigeria

1. Production system 8 (PS 8): tropical, low rainfall, primarily rainfed, postrainy season crops are sorghum/oilseed and includes the Western Deccan Plateau of India; Production system 19 (PS 19): lowland, rainfed, short season (less than 100 days) and suitable for sorghum/millet/rangeland and located in Sahelian Eastern Africa and the margins of the Kalahari Desert; Production system 20 (PS 20): covers semi-arid area, intermediate season (100-125 days), suitable for sorghum/maize/rangeland and located in Eastern Africa and parts of Southern Africa; and Production system 21 (PS 21): intermediate season (125-150 days), suitable for sorghum/maize/finger millet/legumes and located in Eastern and Southern Africa. The agroecological details of each PS are given in the ICRISAT Annual Report, 1993.

Source: ICRISAT Southern and Eastern Africa Highlights (1996); International Sorghum and Millet Newsletter (1997).

11.5. Determinants of Technology Spillover

To identify the factors responsible for technology spillover, the strengths of different NARS in terms of scientific capability measured through the number of scientists and their formal education level was dwelt on. India and China are the two countries with strong research capabilities in Asia (see Chapter 1). They have a large scientific mass (China - 200 scientists and India - 150). Other countries have a limited number of scientists ranging between 3 (Rwanda) and 50 (Ethiopia). The extent of the formal education of sorghum breeders in a country indicates the country's capability to generate new technology while its number of agronomists, seed technologists, entomologists, pathologists and social scientists reveals its strength in adaptive research. Therefore, it is likely that the larger share of released cultivars from international sources after adaptive trials comes from countries with fewer breeders. On the other hand, countries with a large pool of breeders are expected to release more cultivars from their own crosses. Countries with good research strength are also expected to use large amounts of breeding material from international research centers. This is reflected in the pedigree of their released cultivars. An analysis in Chapter 1 shows that more cultivars are released from ICRISAT-supplied materials in countries with limited research capability than in countries with good research capability.

11.6. Lessons from Spillover Estimates

Many important results pertaining to technology transfer emerge from the estimation of the spillover matrix at the global and country levels. Research evaluation models have often used the spillover matrix to account for the benefits from research conducted by other research programs in similar and different environments. These estimates have been based solely on subjective guesses and on the assumption of location specificity which implies that the values of the off-diagonal elements in the spillover matrix are less than those of the diagonal elements.

The results of our analysis do not substantiate the 'location specificity' argument (at least in terms of yield) when the international research system is considered a source of research spillovers. Sorghum cultivars originating from collaborative ICRISAT-NARS research have proven to be highly transferable among sorghum domains and across different countries around the world. The yield advantage of the international research system (located in SD1) was as high as 27% in SD 8.2, 15% in SD1, 13% in SD2 and 7% in SD3. It was found that IDCs generally performed better than NARS-derived cultivars. This scenario holds good for sorghum varieties developed for India. In India, the potential for technologies developed by the Indian NARS for SD1 to spill over to other sorghum domains is high. An analysis also revealed that the extent of technology spillover from finished products is negatively related to the research capability of NARS. The higher the NARS capability, the lower is the possibility of technology spillover from finished products (varieties/hybrids). This calls for separate breeding strategies at ICRISAT, one for a strong NARS and the other for a weak one. While ICRISAT should continue strategic research and develop intermediate products for a strong NARS, it should also engage in productive partnerships with a weak NARS in order to help them develop finished products (varieties, hybrids).

11.7. References

Alagarswamy G. Van Oosterom ET and Sethi SC. 1996. International multi-environment trails at the International Crops Research Institute for the Semi-Srid Trops (ICRISAT). Pages 165-174 *in* Plant adaptation and crop improvement (Cooper M and Hammter GL, eds.). Wallingford, UK: CAB International.

Bantilan MCS and Davis JS. 1991. Across-commodity spillover effects of research and opportunity costs in a multi-product production environment. ACIAR/ISNAR Project Paper Series no. 30. Canberra, Australia: Australian Center for International Agricultural Research, and The Hague: International Service for National Agricultural Research. 21 pp.

Brennan JP and Bantilan MCS. 1999. Impact of ICRISAT research on Australian agriculture. Report prepared for the Australian Center for International Agricultural Research, Economic Research Report No. 1, NSW Agriculture, Wagga Wagga. 52 pp.

Byerlee D. 1997. Advantages of international agricultural research - Exploiting economies of size to generate global spillover. Pages 167-184 *in* Integrating research evaluation efforts: Proceedings of an International Workshop, 14-16 Dec 1994, ICRISAT, Patancheru, India. Patancheru, Andhra Pradesh 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Deb UK and Bantilan MCS. 2001. Spillover impacts of agricultural research: A review of studies. Working Paper Series no. 8. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 32 pp.

Evenson RE. 1989. Spillover benefits of agricultural research: Evidence from U.S. experience. American Journal of Agricultural Economics 71:441-452.

Evenson RE. 1994. Analyzing the transfer of agricultural technology. Pages 166-179 *in* Agricultural technology: Policy issues for international community (Anderson JR, ed.). Wallingford, Oxfordshire, UK: CAB International.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

Maredia MK, Ward R and Byerlee D. 1996. Econometric estimation of global spillover matrix for wheat varietal technology. Agricultural Economics 14:159-173.

Future Directions for Food Security and Diversity: Partnership and Research Strategy for Sorghum

12

MCS Bantilan, UK Deb, CLL Gowda, BVS Reddy,
AB Obilana and RE Evenson

Future Directions for Food Security and Diversity: Partnership and Research Strategy for Sorghum

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

12.1. Introduction

Future demand for sorghum is going to be different from the demand pattern observed at present and in the past. The demand for sorghum grain as food is expected to decline in the future while its demand as poultry feed, flour, ethanol (biofuel) and alcoholic beverages is going to increase. The demand for sorghum - both green and dry plants - as livestock feed will also go up. It is also expected that the demand for sorghum grain and stalk for industrial end use in nutrition and health products would increase. Thus, sorghum will essentially enhance the performance of integrated crop-livestock systems and improve options for commercialization in semi-arid agriculture. Therefore, any strategy to promote sorghum must be designed from this perspective.

In addition to the shifts in demand for sorghum grain and stalk, the vast developments in science and scientific tools can be used for germplasm evaluation, selection, screening and development of new cultivars and their utilization. The progress in Information and Communication Technology (ICT) can lead to the dissemination of knowledge and technology and the management and coordination of networks and partnerships. Visible changes have occurred in seed policies and seed delivery systems in countries where ICRISAT is operating. The new millennium has led to a new vision and strategies of the donor community. At present, agricultural research is viewed as a mechanism to alleviate poverty and hunger, ensure food security and sustain the livelihoods of poor communities around the world rather than just a means of increasing productivity. Considering these factors and the findings reported in previous chapters, there is a need to devise future strategies for sorghum breeding and partnership, formulate technology exchange policies and pave pathways for promoting diversity in sorghum cultivation.

12.2. Future Breeding Strategy

The strengths of NARS in Asia and Africa vary. There are a greater number of scientists working in Asia, particularly in India and China, than in Africa (see Chapter 1 for details). It has also been observed that national systems in Asia (India and China) mostly benefited from improved parental lines and breeding materials developed by ICRISAT. On the other hand, African countries were the beneficiaries of semi-finished and finished products like breeding lines, varieties and hybrids. Varieties developed by ICRISAT based in India, Zimbabwe and Mali generated spillover benefits across different African countries (see Chapters 4 and 11). Overall, priorities in sorghum breeding research must be identified considering both direct and spillover benefits.

[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.

Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE. 2004. Future directions for food security and diversity: Partnership and research strategy for sorghum. Pages 263-268 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Strategies for Asia, Africa and Latin America must vary. In order to benefit farmers of Asia, the development of parental and enhanced breeding materials is important. So are broader partnerships with research institutes in the public and private sectors. On the other hand, ICRISAT should concentrate on developing breeding lines, varieties and hybrids using indigenous cultivars for African farmers, in partnership with national research programs in Africa. In breeding and improvement, the focus should be on end-use qualities, increased productivity and input efficiency for impact. Regional breeding involving strategic partnerships in varietal testing that has begun in Southern Africa, should be continued and modified across regions. It would be rewarding to have an integrated strategy for sorghum development among the key players in Africa (ICRISAT, ECARSAM, SMINET, West Africa Sorghum and Millet Network and ARIs including INTSORMIL), so that all stakeholders work together to achieve the critical effort and investments required to tackle important problems. Thinly spread out resources would not bring out the desired effect.

Setting up centers for regional variety testing, release and seed production systems particularly in Africa, would provide high payoffs. Such procedures will to a great extent augment the shortage of human and financial resources, reduce the time spent on variety development and release and speed up and enhance the dissemination of knowledge and technologies. Thus, regional efforts are expected to be highly efficient and effective in sorghum research and development in Africa. Efforts in this direction have already begun in Southern Africa through SMINET and SMIR Further progress is required with the participation of the nascent private seed sector in Africa. A similar strategy for Western and Central Africa as well as for Eastern Africa would pay high dividends. In the case of Latin America, an integrated strategy among key players including ICRISAT, INTSORMIL, CIAT, national systems and private seed companies would be essential.

Biotechnology, including plant genomics, has ushered in new scope for germplasm mapping, identification of novel and marker genes and the development of improved cultivars with desirable traits. Using tools of biotechnology has enhanced the efficiency, effectiveness, speed and precision of plant breeding across the globe. Now the development of cultivars with near-complete grain mold resistance, shoot fly resistance, *Striga* resistance or drought resistance in sorghum cultivars is achievable. There has been some progress in this area in recent years. Biotechnology-assisted germplasm enhancement activities need to be deployed along with conventional breeding methods at ICRISAT to solve such complex problems. The focus of biotechnology research in sorghum at ICRISAT must be such that appropriate policies and strategic partnerships enhance expected efficiency.

12.3. Private-public Partnership

Adoption studies conducted in Asia show that the private sector flourished in Asia in the 1990s in the areas of development and marketing of sorghum seed. The same cannot be said of African countries, where the private sector is yet to make large investments in these areas. Studies on seed systems in Africa reveal that optimal seed multiplication and distribution strategies involving community-level cooperation are viable options in addressing binding seed constraints. Partnerships among advanced laboratories, international research organizations, national institutes, private companies, NGOs and civil society organizations are alternative strategies. Without effective partnerships, no single institute would be able to achieve lasting results in technology generation and dissemination. ICRISAT has already proven its ability to build and sustain partnerships in using conventional and advanced breeding technologies for the improvement of sorghum. The Institute must continue and strengthen broadbased partnerships. It may be noted that a number of private seed companies have come together with ICRISAT to form a hybrid parents' research consortium for sorghum. So far, 16 private seed companies operating in India partially support sorghum improvement research at ICRISAT through this consortium. This is an indication of the growing support to partnerships for the development and dissemination of appropriate sorghum cultivars to farmers.

Partnerships with the private sector should be strengthened in Africa and Asia for greater impacts in the farmers' field and agroprocessing industries. Technologies transferred to farmers during the 1990s mostly came from the private sector which used improved parental materials from ICRISAT and other public research institutes. Africa has witnessed two-way, public-private research for development (R4D) partnerships for processing and developing food and beverage products. According to a recent study by Reddy (2000), the private sector in Asia depends substantially on breeding materials from ICRISAT. The study also states that companies having partnerships with ICRISAT lasting one or two years feel the need to strengthen such ties. Researchers at ICRISAT should take note of this and ensure broadened partnerships. Obilana (2003) has highlighted some instances of knowledge transfer that have worked for rural farmers in Africa. Such cases need to be collated in order to broaden options.

In the African SAT, sorghum (together with millets) constitutes a major source of dietary energy and protein for nearly 1 billion people. In addition to being nutritionally vital, the proteins and micronutrients are potential sources for value-added products for vitamin deficiency (as in yellow endosperm sorghums containing beta-carotene) and diabetes (due to low/slow digestibility of sorghum protein), and biodegradable films in fruit and vegetable preservation. Knowledge of these and other unique traits of sorghum need to be developed and shared widely in Africa, Europe and the Americas, so that a useful and broad database can be developed for use in collaborative R4D ventures.

ICRISAT can provide complementary support to the private sector by developing parental lines, standard protocols, gene discovery and transformation. This will create greater impacts in farmers' fields and the industry. A biotechnology-assisted plant-breeding consortium to cater to such needs would substantially benefit smaller companies that can't afford the large investment that goes into setting up a biotech research facility. The high costs would render them uncompetitive in the market since they won't be able to face the transition from conventional to biotechnology-assisted breeding. As a result, there is the danger of cultivar development being concentrated in the hands of a few companies in the private sector. ICRISAT must take the initiative in establishing such a consortium with the goal of achieving greater impacts, encouraging competition and ensuring the availability of affordable and improved quality of seeds. Private sector companies in India would also require support from international and public institutes to train their personnel in the tools of applied biotechnology and to use enhanced germplasm materials developed through marker-assisted techniques.

12.4. Technology Exchange Policy

- The adoption of cultivars is related to the presence of farmers' preferred traits in new cultivars
- Adoption level is related to the access to cultivars or options available of cultivars that can be grown
- The speed of adoption depends on the availability of seeds and the profits from the cultivation of new cultivars.

These findings have important implications for policies on technology exchange and seed delivery systems. Seed availability should be ensured through the participation of public and private sector companies, community-level seed producers or farmer groups. It has been observed that-private companies to a great extent participate in the marketing of hybrid seeds. Therefore, promoting sorghum hybrids in Asian and later in African countries may be possible through broader and enhanced partnerships with the private sector. On the other hand, promoting OPVs may require greater involvement of public companies, NGOs, progressive seed farmers/farmer groups and community-level seed producers. Availability of source seed (breeder's seed) is a necessary precondition for the development of foundation and certified seeds. It is essential that ICRISAT and its partners concentrate on a sustained supply of breeder's seed to public and private seed companies and community-level seed producers.

Broadbased partnerships among international and national research institutions, advanced laboratories, the private sector, civil society and farmer's organizations are essential to develop and transfer cutting-edge technology. ICRISAT can promote existing partnerships among these players through its recently established Technology Innovation Centre and two other initiatives in progress, namely the Agri-Business Incubator and the Agri-Biotech Park, part of the Andhra Pradesh Government's Genome Valley Project. The Virtual Academy for the Semi-Arid Tropics (VASAT) can serve as a platform for linking partners in sorghum development and technology exchange.

Transmitting knowledge on the appropriate technology of improved sorghum varieties and hybrids to rural farmers (and even industry) is easier said than done. What works and what does not depends on several interwoven issues in a mesh of theories, methodologies and actual practice. In practice, technology exchange is participatory, slow, time consuming and depends on the appropriateness of the improved varieties/hybrids and the commitment of partners and stakeholders. Technology exchange cannot succeed without enabling factors such as the availability of and access to improved seeds; wide dissemination of information about them; effective partnerships among stakeholders; appropriate, supportive and effective policies; an enabling environment including service providers, expertise and skill; and those who play the roles of bridge, catalyst, broker and promoter. These factors are more or less in place for ICRISAT and some partners in Asia, but need to be further developed in Africa.

12.5. Pathways for Promoting Biodiversity

There is a growing concern that the adoption of improved cultivars of different crops is decreasing the diversity of varieties grown by farmers. The analyses reported in Chapter 10 reveals that the number of improved sorghum cultivars and their rate of adoption in India, China, Pakistan, Iran, Myanmar, Thailand, Indonesia and Nigeria have increased over time. The genetic diversity of improved sorghum cultivars in India has increased, indicating that sorghum breeders in India have used diverse parental materials to develop new cultivars rather than relying on a few. Improved sorghum cultivars with preferred traits and high profit potential are expected to expand further in farmers' fields. Therefore, promoting diversity in farmers' fields will essentially depend on the availability of a large number of cultivars improved for various specific adaptations and end uses having different genetic backgrounds.

A close look at the research focus of private seed companies in India reveals their interest in making greater investments in the development of hybrids, mostly from parental materials available in the public domain, developed either by ICRISAT or public research institutes. This is obvious considering the investment needed, risks and returns. The implications of such a focus are as follows:

- Public and international institutes must develop a large number of parental materials improved for various specific adaptation and end uses with diverse genetic backgrounds
- Closer links with private companies and community-level seed producers is essential to build awareness about the materials currently available and those likely to be available in the future
- Timely and cost-effective dissemination of materials to companies
- Intellectual Property Rights (IPR)/participatory plant breeding (PPB) regimes "friendly" to plant varietal selection and development.

12.6. Implications for Research Investment

Investments by the public and private sectors are correlated. It was observed that countries with higher levels of public investment experienced comparatively higher levels of investment by the private sector. Public investment in agricultural research promotes private sector investment in the following ways:

- By ensuring the availability of scientific manpower for research
- Technologies generated and disseminated through the public sector create markets for new technologies and reduce risks
- By increasing the probability of access to appropriate germplasm resources with traits preferred by farmers.

Though some major multinational companies had invested heavily in upstream research in biotechnology in the 1990s, they have backtracked in recent years. In their assessment, biotechnology research for Asian and African countries is no longer economically profitable because of the predominance of small and marginal farmers, high cost of the technology in relation to profits and time scale and the high transaction costs of enforcing Intellectual Property Rights under weak judicial systems. It is for this reason that public investment in sorghum research should be sustained and increased. Without public investment, the possibility of investment by the private sector becomes bleak.

12.7. Conclusions

The future strategy for sorghum at ICRISAT must be in harmony with the changing needs of end users (eg, ethanol, poultry feed); recent developments in new sciences (biotechnology, bioinformatics, geographic information systems and ICT); the trading environment (regionalization and globalization of agricultural ventures and WTO); IPR; indigenous farmer knowledge and private sector investment in crop improvement. There are visible shifts in the demand for sorghum and suppliers of sorghum technologies. Today's problems and concerns differ from those in the past, indicating that old prescriptions can't solve present day and future problems. ICRISAT and its partners must take the initiative to implement these suggestions in order to attain and sustain food and health security in the SAT. Capitalizing on synergies will ultimately benefit both farmers and consumers.

12.8. References

Obilana AB. 2003. From science to production - Transferring knowledge to the rural African farmers: what works and what doesn't. Presented at the Conference and Workshop on Science & technology and food security in Africa, 10-15 Nov 2003, Maseru, Lesotho. Lesotho: African Technology Policy Studies (ATPS) Network and Ministry of Communications, Science & Technology (MCST).

Reddy BVS. 2000. Report on sorghum Scientists' Field Day 2000.

Appendixes

Appendix I. List of improved sorghum cultivars (varieties and hybrids) in different countries of the world.

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
1	W. Africa	Benin	ICSV 111	ICSV 111	[(SPV 35 X E 35-1) X (CSV4)-8-1	1999			ICRISAT bred						
2	S. Africa	Botswana	SDS 3220	Phofu	(Syn: Macia, SDS 3220, M91057, F3A-115-2)	1994			ICRISAT bred						Originated in Zimbabwe
3	S. Africa	Botswana	(SDS 2583) IS 3923	Mahube (SDS 2583)	IS 3923	1994			ICRISAT network						Originated in Zimbabwe
4	S. Africa	Botswana	SDSH 48	BSH 1 (SDSH 48)	SDSH 48 F1 Hybrid	1994			ICRISAT bred					Hybrid	Originated in Zimbabwe
5	S. Africa	Botswana		Nmabaitse (Bot 79)		1994			ICRISAT bred						
6	S. Africa	Botswana		Radar		1960s			Others						
7	S. Africa	Botswana		8 D		1960s			Others						
8	S. Africa	Botswana		Kanye Standadrd		1960s			Others						
9	S. Africa	Botswana		Marupaantse		1960s			Others						
10	S. Africa	Botswana		Segaolane		1970s			Others						
11	S. Africa	Botswana		Town		1970s			Others						
12	S. Africa	Botswana		65 D		1970s			Others						
13	W. Africa	Burkina Faso		E-35-A		1975			ICRISAT network						
14	W. Africa	Burkina Faso		IRAT 204		1980			ICRISAT network						
15	W. Africa	Burkina Faso	IS 18758	E 35-1		1983			ICRISAT network						
16	W. Africa	Burkina Faso	ICSV 1001 BF	Framida		1986			ICRISAT bred						Originated in Burkina Faso
17	W. Africa	Burkina Faso	ICSV 1049	ICSV 1049		1989			ICRISAT bred						Originated in Burkina Faso
18	W. Africa	Burkina Faso	SARIAGO-B	Sariago B (BF 83-48-2-1)	BF 83-48-2-1	1992			ICRISAT network						Originated in Burkina Faso
19	E. Africa	Burkina Faso		Sariabo 13		2000			ICRISAT network						
20	E. Africa	Burkina Faso		Sariabo 14		2000			ICRISAT network						
21	E. Africa	Burundi		5Dx160 sorghum		1989			ICRISAT network						

...continued

Appendix I. ***Continued***

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
22	E. Africa	Burundi	E 35-1	Gambella 1107	IS 18758	1990			ICRISAT network						Originated in Ethiopia Sorghum
23	C. Africa	Cameroon	ICSV 111	S 35	S 35	1987			ICRISAT bred						Originated in India/Nigeria
24	C. Africa	Chad	ICSV 111	S 35	S 35	1989			ICRISAT bred						Originated in India/Nigeria
25	Asia	China		Jin Za No. 1	TX 3197	1973			Others						
26	Asia	China		Xin Za No. 52	TX 3197	1973			Others						
27	Asia	China		Jin Za No. 4	TX 3197	1973			Others						
28	Asia	China		Jin Za No. 5	TX 3197	1973			Others						
29	Asia	China		Ji Za No. 11	TX 3197	1978			Others						
30	Asia	China		Ji Za No. 26	TX 3197	1978			Others						
31	Asia	China		Tie Za No. 6	TX 3197	1980			Others						
32	Asia	China	A 3681	Yuan 1-98		1982			ICRISAT parent						
33	Asia	China	A 3872	Yuan 1-28		1982			ICRISAT parent						
34	Asia	China	A 3895	Yuan 1-505		1982			ICRISAT parent						
35	Asia	China	A 6072	Yuan 1-54		1982			ICRISAT parent						
36	Asia	China		Liao Za No. 1	TX 622	1983			Others						
37	Asia	China		Liao Za No. 2	TX 622	1983			Others						
38	Asia	China		Jin Za No. 83	TX 622	1983			Others						
39	Asia	China		Shen Za No. 4	TX 622	1983			Others						
40	Asia	China		Tie Za No. 7	TX 622	1983			Others						
41	Asia	China		Shen Za No. 5	TX 622	1986			Others						
42	Asia	China		Qiao Za No. 2	TX 622	1987			Others						
43	Asia	China	SPL 132 A parent	Liao Za No. 4	SPL 132	1988			ICRISAT parent						
44	Asia	China		Jin Za No. 94	SPL 132	1996			ICRISAT parent						
45	Asia	China		Long Si Za No. 1	MR 741	1997			ICRISAT parent						
46	Asia	China		Jin Za No. 12	V4	1997			ICRISAT parent						
47	Asia	China		Tie Za No. 10	TX 622	1994									
48	Asia	China		Liao Za No. 5	TX 622	1996			ICRISAT parent						
49	Asia	China		Long Za No. 3	TX 623										1995

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
50	Asia	China		Liao Za No. 6	SPL 132	1996			ICRISAT parent						
51	Asia	China		Liao Za No. 7	SPL 132	1996			ICRISAT parent						
52	Asia	China		Liao Za No. 10	SPL 132	1997			ICRISAT parent						
53	Asia	China		Gileza 80	A_2 hybrid IC A line converted to A_2 and was used as female parent	1997			ICRISAT parent						
54	Asia	China	D-71278-4	Jin XA 4	Converted to 3197 A_2	1992			ICRISAT parent						
55	S. America	Colombia	A 3895	ICA Yanuba		1992			ICRISAT parent						
56	S. America	Colombia		Sorghica PH 302		1992			ICRISAT network						
57	S. America	Colombia		HE 241					ICRISAT network (early 1990s)						
58	C. America	Costa Rica		Escameka		1991			ICRISAT network						
59	W. Africa	Cote'd Ivoire	ICSV 1001 BF	Framida		1986			ICRISAT bred						Orginated in Burkina Faso
60	W. Africa	Cote'd Ivoire	ICSV 1063 BF	ICSV 1063		2000			ICRISAT bred						Orginated in Burkina Faso
61	L. America	Dominican Republic	ICSV-LM 90501	Surena-1		1993			ICRISAT bred						
		Ecuador	-	INIAP 201 [(GPR148 x E 35-1)-4-1-x CSV 4 desi]-1-1		1987									
62		Egypt		Giza 114	Selection from Local	1962									
63		Egypt		Giza 15	Two local lines	1978									
64		Egypt		Dorado	Dorado	1993									
65		Egypt		Giza 113	Local x Exotic	1994									
66		Egypt		Hybrid 1	Dorado x ICSA 1	1996								Hybrid	
67		Egypt		Hybrid 2	Dorado x ICSA 37	1996								Hybrid	

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
68		Egypt		Hybrid 3	Dorado x ATX 631	1996								Hybrid	
69	C. America	El Salvador		Centa S-2		1976			ICRISAT network						
70	C. America	El Salvador		Centa SS-41		1978			ICRISAT network						
71	C. America	El Salvador	M 91057 * M 90950 (Breeding line)	ISIAP Dorado		1981			ICRISAT bred						
72	C. America	El Salvador	M 90361	Centa Orintal		1987									
73	C. America	El Salvador	M 90362 (Male Parent)	AGROCONSA 1		1987			ICRISAT network						
74	C. America	El Salvador	ICSV LM 90502 (M 3628)	SOBERANO		1996									
75	C. America	El Salvador	ICSV LM 90503 (M 3558)	RCV		1996									
76	C. America	El Salvador	ICSV LM 90508 (PP 290)	Jocoro		1997									
77	E. Africa	Eritrea	ICSV 210	Bushuka		2000									
78	E. Africa	Eritrea	PP 290 (Intsormil)	Shambuko		2000									
79	E. Africa	Eritrea	89 MW 5003	Shieb		2000									
80	E. Africa	Eritrea	89 MW 5056	Laba		2000									
81	E. Africa	Eritrea	IS 29415	Shiketi		2000									
82	E. Africa	Ethiopia	Melkamesh	Melkamesh	Diallel Pop. 7-682	1988			ICRISAT network						Originated in Ethiopia
83	E. Africa	Ethiopia	IS 9302	ESIP 11		1984			ICRISAT network						
84	E. Africa	Ethiopia	IS 9323	ESIP 12		1984			ICRISAT network						
85	E. Africa	Ethiopia	ICSV 1	Dinkmash	SC 108 - 3 x CSV 4	1988			ICRISAT network						
86	E. Africa	Ethiopia		Seredo		1990			ICRISAT network						
87	E. Africa	Ethiopia	ICSV 1	SPV 351		1996			ICRISAT bred (1996)						
88	E. Africa	Ethiopia	E 35-1	Gambella 1107		1980									
89	E. Africa	Ethiopia	76 TI #23	76 TI #23		1980									
90	E. Africa	Ethiopia	M 36121	M 36121		1980									
91	E. Africa	Ethiopia	IS 9302	IS 9302		1980									
92	W. Africa	Ghana	ICSV 1001 BF	Framida		1986			ICRISAT bred						Originated in S.Africa

...*continued*

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
93	W. Africa	Ghana	ICSV 111	Kaapala	[(SPV 35 x E 35-1) x (CSV 4)-8-1	1997									
94	C. America	Guate-mala	M 90975	ICTA Mitlan	GPR 168 x 85 (ICTA C-21)	1985 SC 170			ICRISAT					bred	
95	C. America	Honduras	CS 3541	Tortillero 1	IS 18484	1984			ICRISAT network						
96	C. America	Honduras	AT x 623 x Tortiller	Catracho		1984			ICRISAT bred						
97	C. America	Honduras	M 62650	Sureno	(SC 423 x	1985 CS 3541) x E35-1			ICRISAT bred						
98	Asia	India		CSH-1	MSCK 60A x IS 84	1964	4045/24.9.69, 786/2.2.76		ICRISAT parent	Rainy	3.0-3.5			Hybrid	
99	Asia	India		CSH-2	MSCK 60A x IS 3691	1965	4045/24.9.69		ICRISAT parent	Rainy	3.0-3.5			Hybrid	
100	Asia	India		Swarna (CSV-1)	Selection from IS 3924	1968	4045/24.9.69		ICRISAT network		3.0-3.5				
101	Asia	India		Muguthijola (5-4-1)	Colo-2 x M 35-1	1969	786/2.2.76			Postrainy	2.0-2.5				
102	Asia	India		Gujarat Jowar-108 (GJ-108)	Surat-1 x Nursery-108	1969	19(E)/14.1.82			Rainy	2.0-2.5				
103	Asia	India		M 35-1	Selection from local Mandandi Jowar released in 1930.	1969	596(E)/13.8.84								
104	Asia	India		Annigeri-1 (A-1)	M 35-1 x CS 560-1-1	1969	—				2.0-2.5				
105	Asia	India		CSH-3	2219A x IS 3691	1970	566(E)/21.9.74		ICRISAT parent		3.5-3.8			Hybrid	
106	Asia	India		Kovilpatti Tall	2219A x IS 3541	1970	786/2.2.76			Rainy	2.5-3.0				
107	Asia	India		JS-20		1973	361(E)/30.6.73,786/2.2.76				(Rain) 5.0-6.0 (Irrig.)				
108	Asia	India		JS-263		1973	361(E)/30.6.73								
109	Asia	India		JS-29/1		1973	361(E)/30.6.73								

...*continued*

Appendix I. *Continued*

Sl. No.	Region	Country	IC-name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
110	Asia	India		CSH-4 (PSH-2)	MSCK 1036A x IS 3924 (Swarna)	1973	440(E)/21.8.75		ICRISAT parent	Rainy and postrainy	3.5-3.8			Hybrid	
111	Asia	India		Jaya	Selection from Aispuri Jowar	1974	566(E)/21.9.74								
112	Asia	India		302 (CSV-2)	IS 3922 x Karad Local	1974	440(E)/ 21.8.75,786/ 2.2.76, 13/ 19.12.78		ICRISAT parent	Early rainy	3.0-3.5				
113	Asia	India		CSH-5	2077A x CS 3541	1974	786(E)/ 2.2.76,13/ 19.12.78				3.8-4.0			Hybrid	
114	Asia	India		CSV-3 (370)	IS 2954 x B.P. 53	1974	786(E)/ 2.2.76,13/ 19.12.78		ICRISAT parent	Rainy	3.5-4.0				
115	Asia	India		CSV-4 (CS-3541)	IS 3675 x IS 3541	1974	786/ 2.2.76,13/ 19.12.78		ICRISAT parent	Rainy	3.0-3.5				
116	Asia	India		148/168 (CSV-5)	IS 3687 x Aispuri	1974	13/19.12.78		ICRISAT parent	Rainy	3.0-3.5				
117	Asia	India		604 (CSV-6)	IS 3922 x Aispuri	1974	—		ICRISAT parent		3.2-3.5				
118	Asia	India		CSV-7R (R-16)	IS 2950 x M 35-1	1974	—		ICRISAT parent	Rainy	2.0-2.5				
119	Asia	India		SL-44		1975	440(E)/21.8.75, 786/2.2.76								
120	Asia	India		MSH 33	SMS-35 x SL 292	1975	—				2.0-2.5				
121	Asia	India		RSH-1	M 35-1 x ISR-1	1976	786/2.2.76			Postrainy					
122	Asia	India		Vidisha 60-1	Selection from local material of Shankarpur Village, Ujjain district, Madhya Pradesh	1976	786/2.2.76, *563(E)/30.8.91			Rainy	2.0-2.3				
123	Asia	India		Haryana Chari		1976	786/2.2.76						Forage		
124	Asia	India		MSH 37	SMS-307 x SL 292	1976	—				2.5-3.0				
125	Asia	India		CSH-6	MSCK 2219A x CS 3541	1977	1004/23.3.78			Rainy	3.5-3.8			Hybrid	

...*continued*

Appendix I. ***Continued***

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
126	Asia	India		CSH-7R (SPH-6)	MS 36A x 168	1977	1004/23.3.78			Postrainy	2.5-3.0			Hybrid	
127	Asia	India		Mau Type-1	Selection from local material in Uttar Pradesh	1977	13/19.12.78			Rainy					
128	Asia	India		CO-21 (SPV 80) (USV 1)	Induced mutant from 148 (699)	1977	540(E)/24.7.85				2.0 (rain) 4.2 (irrig)				
129	Asia	India		CSH-8R (SPH 16)	MS 36A x PD 3-1-11	1978	1004/23.3.78, 19 (E)/14.1.82			Postrainy	2.5-3.0			Hybrid	
130	Asia	India		Mau Type-2	Selection from local material in Uttar Pradesh	1978	13/19.12.78			Rainy					
131	Asia	India		Moti (SPV 141)	Induced mutant line from IS 6928	1978	13/19.12.78		ICRISAT network	Rainy (Maghi)	2.0-2.5				
132	Asia	India		MP Chari		1978	13/19 12.78						Forage		
133	Asia	India		MSH-8	SMS 35 x SL-254	1978	13/19.12.78				4.5-6.0				
134	Asia	India		MSH-21	SMS 149 x SL-249	1978	13/19.12.78				5.0-6.0				
135	Asia	India		SDM-9	An outdated variety	1978	13/19.12.78								
136	Asia	India		Vasant-1 (V-1)	NMS 8A x (IS 84 x Sel. 1-22)	1978	13/19.12.78	Nimkar Seeds	ICRISAT parent	Rainy and postrainy				Hybrid	
137	Asia	India		Kovilpatti-6 (K-6)	Pure line selection from Usilampatti local Sen Cholam	1978	19(E)/14.1.82, *563(E)/30.8.91				2.8-2.9				
138	Asia	India		CSV-8R	R 24 x R 16	1979	470/19.2.80								
139	Asia	India		SB-1079	Shallu x CS 3541	1979	19(E)/14.1.82			Rainy and postrainy	2.5-3.0				
140	Asia	India		SB-1066 (SPV-35)	Selection from an introduction from Purdue base No. 954	1979	295(E)/9.4.85			Rainy	2.0-2.5				
141	Asia	India		CO-23 (USV 3) (SPV 136)	Multiple cross involving four elite lines 2077A, 2947A, CS 3678, CS 3687	1979	19(E)/14.1.82				2.7 (rain) 5.0 (irrig)				
142	Asia	India		Pusa Chari-6		1980	470/19.2.80						Forage		
143	Asia	India		CO-24 (USV 5) (SPV 138)	CK 60A x SPR 1341	1980	19(E)/14.1.82				2.8				

...*continued*

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
144	Asia	India	IS 30468	NTJ 2 (IS 30468) (E 1966)	IS 30468 Zera Zera Landrace	1980		Nuzuveedu Seeds	ICRISAT network	Rainy				Hybrid	Originated in Ethiopia
145	Asia	India		CSH-9 (SPH-61)	296A x CS 3541	1981	19(E)/14.1.82			Rainy	4.0-4.2			Hybrid	
146	Asia	India		COH 3 (USH 1)	2077A x 699 Tall	1981	832(E)/18.11.85				3.0			Hybrid	
147	Asia	India		Jowahar Jowar-E144235 (SPV 235) (I-781)	(IS 2954 x CS 3541) 11 x 1	1981	—				2.5-3.0				
148	Asia	India		Jowahar Jowar-236 (SPV 236)	(Vidisha 60-1 x CS 3687) 5 x (Swarna x CS 3687) 596-2-3-3	1981	—				2.9-3.0				
149	Asia	India		Jawahar Chari-6		1982	19(E)/14.1.82						Forage		
150	Asia	India		Jawahar Chari-69		1982	19(E)/14.1.82						Forage		
151	Asia	India		K-7		1982	19(E)/14.1.82								
152	Asia	India		HC-136		1982	19(E)/14.1.82								
153	Asia	India		SPV-245 (SV 14)	SB 1066 x CS 3541	1982	540(E)/24.7.85				3.8-4.0				
154	Asia	India		MSH 51		1983		Mahyco			7.5-8.0			Hybrid	
155	Asia	India		UP Chari-1 (IS-4776)	IS 4776	1983	499(E)/8.7.83		ICRISAT network						
156	Asia	India		SPV-126 (CSV-9)	Natural mutant isolated from CS 3542 (CSV-4)	1983	499(E)/3.7.83			Rainy	3.0-3.2				
157	Asia	India		CSV-10 (SPV-346)	SB 1066 x CS 3541	1983	295(E)/3.7.83			Rainy	3.0-3.5				
158	Asia	India		Gujarat Sorghum-35 (GJ 35) (SPV 565)	(2077A x M25) x Malvan	1983	295(E)/9.4.85			Rainy	3.5-4.0				
159	Asia	India		Gujarat Sorghum HY-1 (GSH 1)	2077A x NSV-13	1983	295(E)/9.4.85			Rainy	3.2-3.5				
160	Asia	India		Varsha	T22 x 5742-1A	1983	540(E)/24.7.85			Rainy	2.5-3.0				
161	Asia	India		SPV-297	CS 3541 x IS 3924	1984	540(E)/24.7.85		ICRISAT	Rainy	3.7-4.0				
162	Asia	India		Swati (SPV-504) (RSV-9R)	SPV 86 x M 35-1	1984	540(E)/24.7.85		parent	Postrainy	2.5-3.0				

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
163	Asia	India		Gujarat Jowar-36 (GJ36) (M-74) (SPV 596)	(2219A x BP 53) x BP 53	1984	258(E)/14.5.86			Rainy	3.2-4.0				
164	Asia	India		DSH 1 (SPH-196)	296A x SB 1085	1984	—				4.0				
165	Asia	India		Rajasthan Chari-1 (SU-52)		1985	295(E)/9.4.85						Forage		
166	Asia	India		Pusa Chari-9 (PC-9)		1985	295(E)/9.4.85						Forage		
167	Asia	India		UP Chari-2		1985	295(E)/9.4.85						Forage		
168	Asia	India		Pusa Chari-23 (PC-23)		1985	295(E)/9.4.85						Forage		
169	Asia	India	ICSV 1	CSV-11 (SPV-351)	SC 108-3 x CS 3541	1982	295(E)/9.4.85		ICRISAT bred	Rainy	3.0-3.5				
170	Asia	India		SB 905 (SPV 247)	Selection from an outcross in Kalagonda	1985	540(E)/24.7.85				2.5-3.0				
171	Asia	India		SPV-96	148 x 512	1985	540(E)/24.7.85			Rainy	2.0				
172	Asia	India		CO-22 (SPV 81) (USV 2)	Multiple cross involving 2077A, 3660A, 2219A	1985	540(E)/24.7.85			Rainy	2.3 (rain) 4.5 (irrig)				
173	Asia	India		Rajasthan Chari-2 (SU-45)		1985	832(E)/18.11.85						Forage		
174	Asia	India		Gujarat Jowar-9	Selection from local Rabi type	1985	832(E)/18.11.85			Postrainy	1.5-1.8				
175	Asia	India		CO-25 (SPV 542) (TNS 27)	IS 4283 x 699 tall	1985	832(E)/18.11.85		ICRISAT parent		2.8-3.0 (rain) 5.0-6.0 (irrig)				
176	Asia	India		COH-3		1985	832(E)/18.11.85							Hybrid	
177	Asia	India		K-4 (Kovil Patti-4)		1986	258(E)/14.5.86								
178	Asia	India		SPH-201	296A x PVR 10	1986	867(E)/26.11.86								
179	Asia	India		SPV-462	MS 8271 x IS 3691	1986	867(E)/26.11.86		ICRISAT parent						
180	Asia	India		CSH-10 (DSH-1)	296A x SB 1085	1986	867(E)/26.11.86							Hybrid	
181	Asia	India	ICSH 153	CSH-11 (SPH-221)	296A x MR 750	1986	867(E)/26.11.86		ICRISAT bred		4.0-4.2 (rain)			Hybrid	
182	Asia	India		CSH-12R (KD RSH-1)	296A x M 148-138	1986	867(E)/26.11.86							Hybrid	

...*continued*

Appendix I. ***Continued***

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
183	Asia	India		Gujarat Jowar-37	2077A x M 28 (Gundri)	1987	165(E)/6.3.87				3.5	88	Dual purpose		
184	Asia	India		Haryana Chari-171 (HC-171)		1987	834(E)/18.9.87						Forage		
185	Asia	India		Haryana Chari-260 (HC-260)		1987	834(E)/18.9.87						Forage		
186	Asia	India		Pro-Agro 8320		1988		Pro-Agro						Hybrid	
187	Asia	India	ICSV 112	CSV-13	(IS 12622 x 555) x IS 3612 x 2219B x E 35-1	1988	471(E)/5.5.88				3.5-4.0 (rabi)				
188	Asia	India	ICSV 145	SAR-1	555 x GPR 148	1988	471(E)/5.5.88		ICRISAT bred					Variety	
189	Asia	India		K-8		1989	915(E)/6.11.89		-do-						
190	Asia	India		MFSH-3 (Forage Sorghum)		1990	386(E)/15.5.90	MAHYCO				500-600	Forage	Hybrid	
191	Asia	India		SPH-468 (AKSH-14-150)	AKMS 14A x R 150	1990	386(E)/15.5.90								
192	Asia	India		SPH-388 (AKSH-73)	296A x R 73	1990	386(E)/15.5.90								
193	Asia	India		SPV-669 (AKSV-37)	SPV 97 x SPV 29	1990	386(E)/15.5.90								
194	Asia	India		DSV-1		1990	639(E)/17.8.90								
195	Asia	India		GFS-4	GJ 37 x Sudan	1990	639(E)/17.8.90					350-400	Forage		
196	Asia	India		Nandyala Tella Jonna-2		1990	639(E)/17.8.90								
197	Asia	India		N-14 (Yellow Sorghum)		1990	639(E)/17.8.90								
198	Asia	India		Ajeet 999		1991		Ajeet Seeds		Rainy	5.5-6.0			Hybrid	
199	Asia	India		CSH-13R (SPH-504)	296A x RS 29	1991	527(E)/16.8.91							Hybrid	
200	Asia	India		Pro-Agro Chari (SSG-988)		1991	527(E)/16.8.91						Forage		
201	Asia	India		Pant Chari-3		1991	527(E)/16.8.91						Forage		
202	Asia	India		Jawahar Jowar-741		1991	527(E)/16.8.91								
203	Asia	India		Pro-Agro 8340		1992		Pro-Agro						Hybrid	

...continued

Appendix 1. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
204	Asia	India		SSV-84		1992	814(E)/4.11.92								
205	Asia	India		CSV-14 (R) (SPV 839)	M 35-1 x (CS 2947 x CS 2644) x M 35-1	1992	814(E)/4.11.92								
206	Asia	India	Parent Source	JKSH 22		1999		JK Seeds	ICRISAT parent					Hybrid	
207	Asia	India	Parent Source	PJH 55		1993		Hindustan Lever	ICRISAT parent	Rainy	3.0-3.5			Hybrid	
208	Asia	India	Parent Source	PJH 58		1993		Hindustan Lever	ICRISAT parent	Rainy	3.3-3.8			Hybrid	
209	Asia	India	Parent Source	PSH 8340		1993		Pro-Agro	ICRISAT parent					Hybrid	
210	Asia	India		Gujarat Forage Sorghum-1		1993	615(E)/17.8.93						Forage		
211	Asia	India		K-9 (Kovil Patti-9)		1993	615(E)/17.8.93								
212	Asia	India		COH-4		1993	615(E)/17.8.93							Hybrid	
213	Asia	India	PVK 400	PVK-400		1999									
214	Asia	India	SPH 468	CSH 14	AKMS 14A x AKR 150	1993			ICRISAT parent					Hybrid	
215	Asia	India	ICSV 745	DSV 3	ICSV 197 x A 6250	1993			ICRISAT bred					Hybrid	
216	Asia	India		PKH 400		1993			ICRISAT parent						
217	Asia	India	ICSV 197	ICSV 197	ICSV 197	1993			ICRISAT bred						
218	Asia	India	Parent Source	MLSH 36		1994		Mahendra Hybrid Seeds Co.	ICRISAT parent					Hybrid	
219	Asia	India		JKSH 45		1994		JK Seeds	ICRISAT parent					Hybrid	
220	Asia	India		HES-4		1994	836(E)/2.9.94								
221	Asia	India		Speed Feed		1994	837(E)/2.9.94						Forage		
222	Asia	India		Jambo		1994	837(E)/2.9.94								
223	Asia	India		CSH-13	296A x RS 29	1994								Hybrid	
224	Asia	India		Harasona (855F)		1995	408(E)/4.5.95								
225	Asia	India		Punjab sudex (Chari-1)		1995	408(E)/4.5.95						Forage		

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
226	Asia	India		GJ-38		1995	408(E)/4.5.95								
227	Asia	India		GJ-39		1995	408(E)/4.5.95								
228	Asia	India		MBSH 7		1996		Maharashtra State Seed Corporation (MSSC)					Substitute for CSH 14	Hybrid	
229	Asia	India		Jawahar Jowar-938		1996	1(E)/1.1.96								
230	Asia	India		CSH-15R (SPH-677)	104 A x RS 585	1996	1(E)/1.1.96							Hybrid	
231	Asia	India		Selection-3		1996	1(E)/1.1.96								
232	Asia	India		ICSV-745 (SPV-949)	(PM 11344 x A 6250)-4-1-1-1	1996	1(E)/1.1.96								
233	Asia	India	Parent source	CSV-15 (SPV 946)	SPV 475 x SPV 462	1994	349(E)/10.2.96		ICRISAT parent						
234	Asia	India		Pro-Agro 8560		1997		Pro-Agro						Hybrid	
235	Asia	India		SUNZO 261		1997		Navartis India Ltd.		Rainy				Hybrid	
236	Asia	India		Pusa Chari Hybrid-106 (PCH-106)	2219 x PC-23	1997	360(E)/1.5.97						Forage		
237	Asia	India	ICSV 239	BSR-1		1989	360(E)/1.5.97		ICRISAT bred						
238	Asia	India		GJ-40		1997	360(E)/1.5.97								
239	Asia	India		Pant Chari 4		1997	360(E)/1.5.97						Forage		
240	Asia	India		MLSH-296 (MLSH-14)		1997	647(E)/9.9.97	Mahendra Hybrid Seeds Co.						Hybrid	
241	Asia	India		CSH-16 (SPH 723)	27 A x C 43	1997	647(E)/9.9.97							Hybrid	
242	Asia	India		DSV-5 (GRS-1)		1997	647(E)/9.9.97								
243	Asia	India		APK-1		1997	662(E)/17.9.97								
244	Asia	India		CSH-17		1997	647(E)/9.9.97							Hybrid	
245	Asia	India		JKSH 273		1998		JK Seeds						Hybrid	
246	Asia	India		C 71		1998		Cargill						Hybrid	
247	Asia	India		Pro-Agro 8562		1998		Pro-Agro						Hybrid	
248	Asia	India		ASH 1	ICSA 91001 x ICSR 90017	1997			Adilabad	Rainy	4.8-5.0		purpose	Dual Hybrid	
249	Asia	India	ICSH 88688	PSH 1		1999									

...*continued*

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
250	Asia	India	Parent Source	SPH 840		2000									
251	Asia	India	GD 34553	PVK 801		2000									
252	Asia	India	GD 31-4-2-3	Parbhani Moti (SPV 1411)		2002									
253	Asia	India		MSH 50				MAHYCO			5.5-6.2			Hybrid	
254	Asia	India		MSH 55				MAHYCO			5.0-6.2			Hybrid	
255	Asia	India		MSH 61				MAHYCO			6.0-6.4			Hybrid	
256	Asia	India		MSH 65				MAHYCO			6.0-6.5			Hybrid	
257	Asia	India		MSH 66				MAHYCO			6.0-6.5			Hybrid	
258	Asia	India		MSH 70				MAHYCO			6.4-6.6			Hybrid	
259	Asia	India		MSH 83				MAHYCO						Hybrid	
260	Asia	India		MSH 92				MAHYCO						Hybrid	
261	Asia	India		MSH 109R				MAHYCO		Postrainy	4.5-5.0			Hybrid	
262	Asia	India		MFSH 4				MAHYCO				580-640	Forage	Hybrid	
263	Asia	India		MFSH 5				MAHYCO				610-640	Forage	Hybrid	
264	Asia	India		MLSH 13				Mahendra Hybrid Seeds Co.						Hybrid	
265	Asia	India		MLSH 32				Mahendra Hybrid Seeds Co.						Hybrid	
266	Asia	India		Research 351				Maharaja Hybrid Seeds						Hybrid	
267	Asia	India		JKSH 188				JK Seeds						Hybrid	
268	Asia	India		JKSH 267				JK Seeds						Hybrid	
269	Asia	India		PJH 53				Hindustan Lever		Rainy	2.8-3.3			Hybrid	
270	Asia	India		PJH 62				Hindustan Lever		Rainy	3.0-3.5			Hybrid	
271	Asia	India		PAC 501				ITC Zeneca	ICRISAT parent	Rainy	3.5-4.5			Hybrid	
272	Asia	India		PAC 505				ITC Zeneca	ICRISAT parent	Rainy	3.5-4.5			Hybrid	
273	Asia	India		PAC 537				ITC Zeneca	ICRISAT parent	Rainy	4.0-5.0			Hybrid	
274	Asia	India		PSH 63				Prabhat Agro-biotec (Pvt.) Ltd		Rainy	3.2-3.5			Hybrid	
275	Asia	India		PSH 65				Prabhat Agro-biotec (Pvt.) Ltd		Rainy	3.0-3.2			Hybrid	
276	Asia	India		PSH 68				Prabhat Agro-biotec (Pvt.) Ltd		Rainy	3.5-3.8			Hybrid	

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
277	Asia	India		Amarnath 251				Nath Seeds		Rainy	2.5-2.8			Hybrid	
278	Asia	India		PO 8201				Pioneer Seeds		Rainy				Hybrid	
279	Asia	India		KSH 24				Kalyani Seeds, Pune						Hybrid	
280	Asia	India						Nath Seeds						Hybrid	
281	Asia	India						Birla Seeds						Hybrid	
282	Asia	India						Ankur Seeds						Hybrid	
283	Asia	India						Pioneer						Hybrid	
284	Asia	India						Nimkar Seeds						Hybrid	
285	Asia	India		Haryana Chari -308									Forage		
286	Asia	India		SAR 2					ICRISAT parent						
287	Asia	India		GFS 3 (Gujarat Forage Sorghum 3) (IS 5026)	Raj 69 x R 23158 (Gundri)				GAU	Rainy		431	Fodder		
288	Asia	Indonesia		No. 46	Introduction	1967					4.0				
289	Asia	Indonesia		No. 6C	Selection from Local	1969					4.5				
290	Asia	Indonesia		UPCA-S2	Introduction	1972					4.5				
291	Asia	Indonesia		UPCA-S1	Introduction	1972					4.0				
292	Asia	Indonesia		KD4	Introduction	1973					4.0				
293	Asia	Indonesia		Keris	Introduction	1973					3.0				
294	Asia	Indonesia		Badik	Introduction	1983					3.0				
295	Asia	Indonesia		Hegari genjah	Selection from Local	1985					3.7				
296	Asia	Indonesia		Mandau	Introduction	1991					4.5				
297	Asia	Indonesia		Sangkur	Introduction	1991					3.8				
298	Asia	Indonesia		Cempaka	Introduction	Before 1960					3.5				
299	Asia	Indonesia		Birdroof	Introduction	Before 1960					3.5				
300	Asia	Indonesia		Katengu	Introduction	Before 1960					3.5				
301	Asia	Iran		Speed Feed	Introduced from Australia	1990									
302	Asia	Iran		Lumbo	Introduced from Australia	1992									

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
303	Asia	Iran		Sugar graze	Introduced from Australia	1992									
304	Asia	Iran		Payam	Cross selected	1997									
305	Asia	Iran		Kimiya	Cross selected	1997									
306	Asia	Iran		Sepeeden	Cross selected	1997									
307	E. Africa	Kenya		Serena		1972			Others						
308	E. Africa	Kenya		E 6518		1978			Others						
309	E. Africa	Kenya		E 1291		1978			Others						
310	E. Africa	Kenya		Seredo		1982			ICRISAT network						
311	E. Africa	Kenya		2KX17		1983			ICRISAT network						
312	E. Africa	Kenya		E 525HR		1984			ICRISAT network						
313	E. Africa	Kenya	IS 76T1#23	IS 76		2001			ICRISAT network						
314	E. Africa	Kenya	ICSV 112	CSV 13		1988			ICRISAT bred						
315	E. Africa	Kenya		IS 8193		1993			ICRISAT network						
316	E. Africa	Kenya	KAT 83/369	KARI/MTAMA 1 (KAT 369)		1994			ICRISAT bred						
317	E. Africa	Kenya	PGRC/E16740	KARI/MTAMA 3		2001									
318	E. Africa	Kenya	IS 8193	KARI/MTAMA 2		2001			ICRISAT network						
319	E. Africa	Kenya		Dobb Bora					Others (1960s)						
320	S. Africa	Malawi		PN 3		1983			USA						
321	S. Africa	Malawi	ICSV 1	Pirira 1 (Syn: SPV 351, ICSV 1)	(SC 108-3 x CS 3541) 19-1	1993			ICRISAT bred						
322	S. Africa	Malawi	ICSV 112	Pirira 2 (Syn: SPV 475, ICSV 112, SV1)	[(IS 12622C x 555) x (IS 3612C x 2219B)-1 x E 35-1] 5-2	1993			ICRISAT bred						Originated in India
323	W. Africa	Mali	Malisor - 1	Malisor - 1		1987									
324	W. Africa	Mali	Malisor - 4	Malisor - 4		1987									
325	W. Africa	Mali	Malisor - 5	Malisor - 5		1987									
326	W. Africa	Mali	Malisor - 7	Malisor - 7		1987									
327	W. Africa	Mali	ICSV 1079	ICSV 1079 BF		1993									
328	W. Africa	Mali		ICSV 1063		1991									
329	W. Africa	Mali		ICSV 1095		1991									

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
330	W. Africa	Mali	ICSV 1063 BF	ICSV 1063 BF		1993									Originated in Burkina Faso
331	W. Africa	Mali	ICSV 401	ICSV 401		1994									
332	W. Africa	Mali	CSM 335	Tieble		2001									
333	W. Africa	Mali	CSM 485	Kossa		2001									
334	W. Africa	Mali	CSM 660	Ngolofing		2001									
335	W. Africa	Mali	Nazongola Anthocyane	Nazomble		2001									
336	W. Africa	Mali	Nazongola Tan	Nazondje		2001									
337	W. Africa	Mali	IS 15401	Soumalemba		2001									
338	W. Africa	Mali	(Pedigree : 87-38 * 57-)	Marakanio		2001									
339	W. Africa	Mali	CIRAD 406	Soumba		2001									
340	W. Africa	Mali	ICSV 1079 BF	Yagare		2001									Originated in Burkina Faso
341	N.America	Mexico	ICSV 112	UANL-1-187		1987			ICRISAT bred						
342	N.America	Mexico	M 90362	UANL-1-287		1987			ICRISAT bred						
343	N.America	Mexico	M 62641	COSTENO 201	(SC 108-3 x CS 3541) x E15 - 5	1989			ICRISAT network						
344	N.America	Mexico	ICSV 112	PACIFICO 301		1990			ICRISAT network						
345	N.America	Mexico	M 91057	ISTMENO (ICTA C-25)	(GPR 148 x E 35 - 1)	1991		-	ICRISAT bred						
346	N. America	Mexico	Valles Altos			1978									
347	N.America	Mexico	PP 290	Perlita		1991			ICRISAT network						
348	N.America	Mexico		VARIADAD 110		1998			ICRISAT bred						
349	N.America	Mexico	ICSV LM 89510	BLANCO 86		1986			ICRISAT network						
350	N.America	Mexico	M 90812	Tropical 401	IS 12611 x (BULK 'Y' x GPR 165)	1991			ICRISAT bred						
351	N.America	Mexico		Valles Altos 110		1978									

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
352	N.America	Mexico	IS 9468	Maravilla, No. SOF-043-201092		2000			ICRISAT bred						
353	E.Africa	Mozambique	SDS 3220	Macia	F3A-115-2 (Syn: M91057, SDS 3220)	1989			ICRISAT bred						Originated in Zimbabwe
354	E.Africa	Mozambique	IS 8571	Mamonhe		1989			ICRISAT network						Originated in Zimbabwe
355	E.Africa	Mozambique	ICSV 112	Chokwe	Selection from SV1 (Syn: SPV 475, ICSV 112)	1993			ICRISAT bred						Originated in India
356	Asia	Myanmar	IS 8965	Shwe Ni 1		1980			ICRISAT network						Originated in Kenya
357	Asia	Myanmar	IS 2940	Shwe Ni 2		1981			ICRISAT network						Originated in USA
358	Asia	Myanmar		Shwe Ni 3	CS 99	1979									
359	Asia	Myanmar		Shwe Ni 4	UPLB Scr 5	1979									
360	Asia	Myanmar		Shwe Ni 5	D-67-4	1979									
361	Asia	Myanmar		Shwe Ni 6	CS 102	1980									
362	Asia	Myanmar		Shwe Ni 7	CS 103	1980									
363	Asia	Myanmar		Shwe Ni 8	IS 5424	1980			ICRISAT network						
364	Asia	Myanmar		Shwe Ni 9	—	1980									
365	Asia	Myanmar		Shwe Ni 10	IS 302	1980			ICRISAT network						
366	Asia	Myanmar		Shwe Ni 11	CS 105	1982									
367	Asia	Myanmar		Shwe Ni 12	—	1982									
368	Asia	Myanmar		Shwe Ni 13	COSOK 3	1982									
369	Asia	Myanmar		Shwe Ni 14	498003	1982									
370	Asia	Myanmar	M 90906	Yezin White Grain 1	M 90906	1984			ICRISAT bred						
371	Asia	Myanmar	M 36248	Yezin White Grain 2	M 36248	1984			ICRISAT bred						
372	Asia	Myanmar	M 36335	Yezin White Grain 3	M 36335	1984			ICRISAT bred						
373	Asia	Myanmar	M 36172	Yezin White Grain 4	M 36172	1984			ICRISAT bred						

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
374	Asia	Myanmar	ICSV 804	Yezin White Grain 5	(ICSV 197 x SPV 351) -3-1-1-1-1	1996			ICRISAT bred						
375	Asia	Myanmar	ICSV 735	Yezin White Grain 6	(ICSV 197 x SPV 351) -9-1-1-2-6	1996			ICRISAT bred						
376	Asia	Myanmar	ICSV 758	Yezin White Grain 7	(ICSV 197 x A 13108) -1-2-1-1-1	1996			ICRISAT bred						
377	S.Africa	Namibia	SDS 3220	Macia	F3A-115-2 (Syn: M91057, SDS 3220)	1998			ICRISAT bred						
378	C.America	Nicaragua	Sepon 77	Nica-sor (T43)		1985			ICRISAT network						
379	C.America	Nicaragua	ICSV 112	Pinolero 1		1990			ICRISAT bred						
380	W. Africa	Niger	M 90038	Sepon 82		1993			ICRISAT bred						
381	W. Africa	Niger	ICSV 1007 BF	SRN 39		1993			ICRISAT bred						
382	W. Africa	Nigeria	ICSH 89002NG	ICSH 89002NG (ICSA38 x ICSV 247)		1995			ICRISAT bred						Originated in Nigeria
383	W. Africa	Nigeria	ICSH 89009NG	ICSH 89009NG (ICSA 39 x MR908)		1995			ICRISAT bred						Originated in Nigeria
384	W. Africa	Nigeria	ICSV 111	ICSV 111		1995			ICRISAT bred						
385	W. Africa	Nigeria	ICSV 400	ICSV 400		1997			ICRISAT bred (1995)						
386	W. Africa	Nigeria	NR 71176	NR 71176		1997			ICRISAT bred						
387	W. Africa	Nigeria	NR 71182	NR 71182		1997			ICRISAT bred						
388	W.Africa	Nigeria	NSSH 91001	NSSH 91001		1997			ICRISAT bred						
389	W.Africa	Nigeria	NSSH 91002	NSSH 91002		1997			ICRISAT bred (1995)						
390	Asia	Pakistan		D.G. Pearl	Local line	1967									
391	Asia	Pakistan		Red Janpur	Local pure line	1967									
392	Asia	Pakistan		DS 75	No. 954125, Purdue Univ., USA	1975									

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
393	Asia	Pakistan		Pak SS II	Entry No. 78447, Purdue Univ., USA	1976									
394	Asia	Pakistan		Sarokarthuho	Local pure line	1978									
395	Asia	Pakistan		Jowar 86	JS-1 x 7078 (BR 307)	1986									
396	Asia	Pakistan	ICSV 107	PARC-SS 1	(SC 108-3 x CSV 4)-19-1	1991									
397	Asia	Pakistan	IRAT 408	PARC-SS 2		1991									
398	Asia	Pakistan		Bagdar	Local pure line	—									
399	Asia	Pakistan		PARC SH 1	CSH 6	Candidate			ICRISAT network						
400	Asia	Pakistan		PARC SS 1	ICSV 107	Candidate			ICRISAT bred						
401	Asia	Pakistan		PARC SS 2	IRAT 204	Candidate			IDC						
402	Asia	Pakistan		PARC SV 1	ICSV 107 x Red Janpur	Candidate			ICRISAT parent						
403	C. America	Panama		Alanje Blanquito		1991			IDC						
404	S. America	Paraguay	ISIAP DORADO	DORADO					IDC						
405	Asia	Phillipines	ICSV 120	IES Sor 1	PSB SG 93-20	1993			ICRISAT bred						
406	Asia	Phillipines	PSB Sg 94-02	IES Sor 4		1994			ICRISAT network						
407	C. Africa	Rwanda		5Dx160		1980			ICRISAT network						
408	C. Africa	Rwanda		1Kinyamka		1980			ICRISAT network						
409	C. Africa	Rwanda	IS 25395			2001			ICRISAT network						
410	C. Africa	Rwanda	IS 21219			2001			ICRISAT network						
411	C. Africa	Rwanda	IS 8193			2001									
412	W. Africa	Senegal		IRAT 204		1980									
413	E. Africa	Somalia	IESV 92043 DL			2001									
414	E. Africa	Somalia	CR 35:5			2001									
415	E. Africa	Somalia	Gedam el Hammam			2001									
416	E. Africa	Sudan	HD1 (T * 623 A * K 1597 (Karper-1597))	Hageen Durra (HD-1)	AT x 623 x Karper - 1597	1983			ICRISAT bred						Originated in Sudan
417	E. Africa	Sudan	ICSV 1007 HV	Mugawim Buda 1 (SRN 39)		1991			ICRISAT bred						
418	E. Africa	Sudan	IS 9830	Mugawim Buda 2 (IS 9830)		1991			ICRISAT bred						

...*continued*

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
419	E. Africa	Sudan	ICSV 1001 BF	Framida (SRN 39)		1991			ICRISAT bred						
420	E. Africa	Sudan	M 90393	INGAZI (M90393)	(GPR 148 x E35 - 1) x CS 3541	1992			ICRISAT bred						
421	E. Africa	Sudan	IS 13444	Arous el rimal		2000									
422	E. Africa	Sudan		F.W. Ahmed											
423	E. Africa	Sudan		Sheikan											
424	E. Africa	Sudan		Tabat											
425	E. Africa	Sudan		Rabbih											
426	S. Africa	Swaziland	SDSV 1513	MRS 13	IS 2391 (Syn: SDS 1513)	1989			ICRISAT bred						
427	S. Africa	Swaziland	SDSV 1594-1	MRS 94	IS 3693 (Syn: SDS 1594)	1989			ICRISAT bred						
428	S. Africa	Swaziland	ICSV 112	MRS 12	Selection from SV1 (Syn: SPV 475, ICSV 112)	1992			ICRISAT bred						
429	E. Africa	Tanzania		Lulu Tall		1971			Tanzania						
430	E. Africa	Tanzania		Lulu Dwarf		1971			Tanzania						
431	E. Africa	Tanzania		Serena		1976			Tanzania						
432	E. Africa	Tanzania	2KX 17/B/1	Tegemeo	2K x 17/B/1	1988			ICRISAT bred						
433	E. Africa	Tanzania	IS 23496 (syn: SDS 2293-6)	Pato	IS 23496 (Syn: SDS 2293-6	1995			ICRISAT network						
434	E. Africa	Tanzania	F3A-115-2 (Syn: M91057, SDS 3220)	Macia	SDS 3220	1999			ICRISAT bred						
435	E. Africa	Tanzania		Dobs Bora		1960s			Tanzania						
436	Asia	Thailand		Early Hegari	Introduced variety	1963					2.0-2.5		Grain		
437	Asia	Thailand		Late Hegari	Introduced variety	1963					1.2-3.7		Grain		
438	Asia	Thailand		U-Thong 1	Ce 151.262.A1P1A1	1982					3.0-4.0		Grain		
439	Asia	Thailand		Suphan Buri 60	U-Thong 1 x SW 240	1987					2.5-3.0		Grain		
440	Asia	Thailand		Suphan Buri 1	M 91019 x WAE	1996			ICRISAT parent		3.0	39	Dual		
441	Asia	Thailand		KU 9501	KU 9410A x KU 804	1994					4.6		Grain		
442	Asia	Thailand		KU 9502	KU 9402 x KU 630	1994					4.6		Grain		
443	W.Africa	Togo	ICSV 1001 BF	Framida		1986			ICRISAT bred						

...continued

Appendix I. *Continued*

Sl. No.	Region	Country	IC name	Release name of the cultivar	Pedigree	Year of release	Notification No. and date	Company name	Classification	Season	Yield (t/ha)	Fodder yield (q ha-1)	Purpose of release	Type	Remarks
444	W. Africa	Togo	SEPON 82 x S 34	SORVATO 1		1998									
445	W. Africa	Togo	Framida x S 34	SORVATO 28		1998									
446	E. Africa	Uganda		Hibred		1966			Others						
447	E. Africa	Uganda		Hijack		1967			Others						
448	E. Africa	Uganda		Lulu D		1972			Others						
449	E. Africa	Uganda		Lulu T		1972			Others						
450	E. Africa	Uganda		Himidi		1972			Others						
451	E. Africa	Uganda		SEREDO		1980			ICRISAT Network			450			
452	E. Africa	Uganda		Sekedo		1995			Others						
453	E. Africa	Uganda	Tegemeo	Epuripur		1995			Others						
454	E. Africa	Uganda		Dobbs		1960s			Others						
455	E. Africa	Uganda		Serena		1966/67			Others						
456	S. Africa	Zambia	ICSV 2	ZSV 1 (SPV 386)	SC 108-4-8 x CSV 4	1983			ICRISAT bred						
457	S. Africa	Zambia	ICRISAT line	WSH 287	F1 Hybrid	1987			ICRISAT network						Hybrid
458	S. Africa	Zambia	WSV 387	KUYUMA (MR4/4606T11),	MR4/4606T11 (Syn: WSV387, SDS 3136-2)	1989			ICRISAT network						
460	S. Africa	Zambia	WSV 187	SIMA (IS 23520)		1989			ICRISAT network						
461	S. Africa	Zambia	ICRISAT line [ICSA 104 (SPL 177A)]	MMSH 413	F1 Hybrid	1990			ICRISAT network						
462	S. Africa	Zambia		MMSH 375	F1 Hybrid	1990			ICRISAT network						
463	S. Africa	Zambia	IPA-47-38-2-C8203 (Syn:SDS 3136-2)	ZSV 12	IPA-47-38-2-C8203	1995			ICRISAT bred						
464	S. Africa	Zambia		FSH 22		1995			Zambia						
465	S. Africa	Zambia		Framida		1960s			Others						
466	S.Africa	Zimbabwe	ICSV 112	SV 1	[(IS 12622 (x 555) x (IS 3612C x 2219B) 5-1 x E-35-1]5-2	1985			ICRISAT bred						
467	S.Africa	Zimbabwe	ICSV 88060	SV 2	(IS 24704 x IS 10558) -1-3-BWK-2-BK-BK (Syn: A6460, ICSV 88060)	1987			ICRISAT bred						
468	S.Africa	Zimbabwe		ZWSH 1	F1 Hybrid	1992			Zimbabwe						
469	S.Africa	Zimbabwe	SDS 3220	Macia (M91057/ SDS 3220)	F3A-115-2	1998			ICRISAT bred						
470	S.Africa	Zimbabwe		SV 3 (NL 499)	43-1-1-2 (Upper Volta) x 10 CR-2-2 (Syn: NL 499)	1998			ICRISAT bred						
471	S.Africa	Zimbabwe		SV 4 (NL 330)	9/97 x MR844-1-1 (Syn: NL 330)	1998			ICRISAT bred						

Appendix II. List of improved sorghum cultivars (varieties and hybrids) available in the USA in 2002.

Name of the cultivar	Company name	Remarks
2140	AgriPro Seeds	
2233	AgriPro Seeds	
2440	AgriPro Seeds	
2468	AgriPro Seeds	
2660	AgriPro Seeds	
2731	AgriPro Seeds	
2800	AgriPro Seeds	
2838	AgriPro Seeds	
2949	AgriPro Seeds	
9135	AgriPro Seeds	
9210	AgriPro Seeds	
9850	AgriPro Seeds	
Cherokee	AgriPro Seeds	
Honcho	AgriPro Seeds	
Wings	AgriPro Seeds	
A201	Asgrow	
A298	Asgrow	
A459	Asgrow	
A504	Asgrow	
A570	Asgrow	
A571	Asgrow	
A581	Asgrow	
A603	Asgrow	
A603(1)	Asgrow	
LASER	Asgrow	
MISSILE	Asgrow	
SANECA	Asgrow	
576	Cargill	
606	Cargill	
627	Cargill	
697	Cargill	
737	Cargill	
770Y	Cargill	
775Y	Cargill	
TR 440	CropLan Genetics	
380	Crosbyton Seed Co.	
1489	Crosbyton Seed Co.	
5050	Crosbyton Seed Co.	
5914	Crosbyton Seed Co.	
6035	Crosbyton Seed Co.	
6080	Crosbyton Seed Co.	
6092	Crosbyton Seed Co.	
7031	Crosbyton Seed Co.	
7050	Crosbyton Seed Co.	
8060	Crosbyton Seed Co.	
8080	Crosbyton Seed Co.	
9080	Crosbyton Seed Co.	
4 Row Y	Crosbyton Seed Co.	
6 Row GBT	Crosbyton Seed Co.	
6 Row R	Crosbyton Seed Co.	

...continued

Appendix II. *Continued*

Name of the cultivar	Company name	Remarks
6 Row Y	Crosbyton Seed Co.	
DK28E	DEKALB	
DK36	DEKALB	
DK38Y	DEKALB	
DK39Y	DEKALB	
DK40Y	DEKALB	
DK41Y	DEKALB	
DK43A	DEKALB	
DK44	DEKALB	
DK45	DEKALB	
DK47	DEKALB	
DK53	DEKALB	
DK54	DEKALB	
DK55	DEKALB	
DK56	DEKALB	
DK65	DEKALB	
DK66	DEKALB	
734	Douglass King	
765	Douglass King	
751B	Dyna-Grow	
762B	Dyna-Grow	
780B	Dyna-Grow	
F-200E	Frontier Hybrids	
F-227E	Frontier Hybrids	
F-270E	Frontier Hybrids	
F-303C	Frontier Hybrids	
F457E	Frontier Hybrids	
F-501E	Frontier Hybrids	
F647E	Frontier Hybrids	
F-700	Frontier Hybrids	
SG-677	Garrison & Townsend	
SG-753	Garrison & Townsend	
SG-822	Garrison & Townsend	
SG-925	Garrison & Townsend	
SG-94249	Garrison & Townsend	
SG-95207	Garrison & Townsend	
SG-95392	Garrison & Townsend	
SG-95512	Garrison & Townsend	
SG-96258	Garrison & Townsend	
SG-96275	Garrison & Townsend	
SG-97157	Garrison & Townsend	
5319	Garst Seed	
5429	Garst Seed	
5440	Garst Seed	
5503	Garst Seed	
5515	Garst Seed	
5616	Garst Seed	
5664	Garst Seed	
5715	Garst Seed	

...continued

Appendix II. *Continued*

Name of the cultivar	Company name	Remarks
5727	Garst Seed	
5522Y	Garst Seed	
5631Y	Garst Seed	
411	Golden Acres Genetics	Mycogen list included this
1482	Golden Acres Genetics	Mycogen list included this
1506	Golden Acres Genetics	Mycogen list included this
1552	Golden Acres Genetics	Mycogen list included this
3300	Golden Acres Genetics	
3595	Golden Acres Genetics	Mycogen list included this
3636	Golden Acres Genetics	Mycogen list included this
3694	Golden Acres Genetics	Mycogen list included this
3696	Golden Acres Genetics	Mycogen list included this
3700	Golden Acres Genetics	Mycogen list included this
1498E	Golden Acres Genetics	Mycogen list included this
444E	Golden Acres Genetics	Mycogen list included this
522 DR	Golden Acres Genetics	Mycogen list included this
M3838	Golden Acres Genetics	Mycogen list included this
ORO ALPHA	Golden Acres Genetics	Mycogen list included this
ORO G XTRA	Golden Acres Genetics	Mycogen list included this
ORO XTRA	Golden Acres Genetics	Mycogen list included this
T-E PROSPER	Golden Acres Genetics	Mycogen list included this
T-E-EDEN	Golden Acres Genetics	Mycogen list included this
T-E-Y-101G	Golden Acres Genetics	Mycogen list included this
T-E-Y-75	Golden Acres Genetics	Mycogen list included this
H-296W	Golden Harvest	
H-388W	Golden Harvest	
H-390W	Golden Harvest	
H-393	Golden Harvest	
H-403	Golden Harvest	
H-403Y	Golden Harvest	
H-430Y	Golden Harvest	
H-471	Golden Harvest	
H-483	Golden Harvest	
H-495W	Golden Harvest	
H-499Y	Golden Harvest	
H-502	Golden Harvest	
H-505BW	Golden Harvest	
H-512	Golden Harvest	
411	Mycogen	
1482	Mycogen	
1506	Mycogen	
1552	Mycogen	
3595	Mycogen	
3636	Mycogen	
3694	Mycogen	
3696	Mycogen	
3700	Mycogen	
1498E	Mycogen	
444E	Mycogen	
522 DR	Mycogen	

...continued

Appendix II. *Continued*

Name of the cultivar	Company name	Remarks
M3838	Mycogen	
0R0 ALPHA	Mycogen	
ORO G XTRA	Mycogen	
ORO XTRA	Mycogen	
T-E PROSPER	Mycogen	
T-E-EDEN	Mycogen	
T-E-Y-101G	Mycogen	
T-E-Y-75	Mycogen	
NC+262	NC+ Hybrids	
NC+271	NC+ Hybrids	
NC+371	NC+ Hybrids	
NC+4R48	NC+ Hybrids	
NC+5B74E •	NC+ Hybrids	
NC+5B89	NC+ Hybrids	
NC+5C35	NC+ Hybrids	
NC+6B50	NC+ Hybrids	
NC+6B67	NC+ Hybrids	
NC+6B70	NC+ Hybrids	
NC+6C21	NC+ Hybrids	
NC+6C69	NC+ Hybrids	
NC+6R21	NC+ Hybrids	
NC+6R30	NC+ Hybrids	
NC+7B29	NC+ Hybrids	
NC+7B47	NC+ Hybrids	
NC+7C49	NC+ Hybrids	
NC+7R37E	NC+ Hybrids	
NC+7R83	NC+ Hybrids	
NC+7W97	NC+ Hybrids	
NC+7Y57-K	NC+ Hybrids	
NC+8R18	NC+ Hybrids	
NC+Y363	NO Hybrids	
Northrup King K73-J6	Northrup King	
251	Novartis	
2030	Novartis	
8310	Novartis	
8414	Novartis	
8500	Novartis	
8505	Novartis	
8699	Novartis	
8875	Novartis	
8925	Novartis	
8950	Novartis	
8212Y	Novartis	
83G66	Novartis	
84G62	Novartis	
84G82	Novartis	
8522Y	Novartis	
85G85	Novartis	
85Y34	Novartis	

...continued

Appendix II. *Continued*

Name of the cultivar	Company name	Remarks
86G71	Novartis	
87G57	Novartis	
K35-Y5	Novartis	
KS310	Novartis	
8310	Pioneer	
8414	Pioneer	
8500	Pioneer	
8505	Pioneer	
8699	Pioneer	
8875	Pioneer	
8925	Pioneer	
8950	Pioneer	
8212Y	Pioneer	
83G66	Pioneer	
84G62	Pioneer	
84G82	Pioneer	
8522Y	Pioneer	
85G85	Pioneer	
85Y34	Pioneer	
86G71	Pioneer	
87G57	Pioneer	
82G63	Pioneer	
PS 233	Pogue	
PP333	Production Plus	
PP 599W	Production Plus	
PP644	Production Plus	
PP777	Production Plus	
PP 799E	Production Plus	
9300	Richardson Seeds	
9322	Richardson Seeds	
202CR	Richardson Seeds	
9200Y	Richardson Seeds	
9200Y	Richardson Seeds	
9212Y	Richardson Seeds	
DASHE	Richardson Seeds	
JOWAR-1	Richardson Seeds	
RS200E	Richardson Seeds	
RS225	Richardson Seeds	
RS250E	Richardson Seeds	
SPRINT E	Richardson Seeds	
SPRINT II	Richardson Seeds	
251	Sorghum Partners	
2030	Sorghum Partners	
K35-Y5	Sorghum Partners	
K59-Y2	Sorghum Partners	
KS310	Sorghum Partners	
KS524	Sorghum Partners	
KS560Y	Sorghum Partners	
KS585	Sorghum Partners	
KS710	Sorghum Partners	

...continued

Appendix II. *Continued*

Name of the cultivar	Company name	Remarks
800	Southern States	
TV1050	Terral	
TV9421	Terral	
TS489	Texas Seed	
TR430	Triumph	
TR432	Triumph	
TR438	Triumph	
TR445	Triumph	
TR447	Triumph	
TR459	Triumph	
TR461	Triumph	
TR462	Triumph	
TR464	Triumph	
TR474	Triumph	
TR481	Triumph	
TR60G	Triumph	
TR65G	Triumph	
TR82G	Triumph	
Two 80-D	Triumph	
DG 730B	UAP Seed	
DG 740C	UAP Seed	
DG 752B	UAP Seed	
DG 760C	UAP Seed	
DG 762B	UAP Seed	
DG 780B	UAP Seed	
DALE(1970)	USDA-ARS & MAFES	
M81-E(1981)	USDA-ARS, MAFES, and the Experiment Stations of Alabama, Florida and Georgia, Kentucky, and South Carolina	
THEIS(1974)	USDA-ARS, MAFES, and the Experiment Stations of Alabama, Florida and Georgia	
Topper 76-6(1994)	USDA-ARS, MAFES, and the University of Georgia	
W-494	Warner Seeds	
W-528W	Warner Seeds	
W-560T	Warner Seeds	
W-588Y	Warner Seeds	
W-614-W	Warner Seeds	
W-622E	Warner Seeds	
W-624-Y	Warner Seeds	
W-625Y	Warner Seeds	
W-632W	Warner Seeds	
W-644E	Warner Seeds	
W-664T	Warner Seeds	
W-816-E	Warner Seeds	
W-818E	Warner Seeds	
W-839-DR	Warner Seeds	
W-844E	Warner Seeds	
W-851DR	Warner Seeds	
W-858E	Warner Seeds	
W-876-DR	Warner Seeds	
W-902W	Warner Seeds	
W-965E	Warner Seeds	

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

Research Evaluation and Impact Assessment (REIA) Project

Sorghum Research Impacts Questionnaire

for Public National Agricultural Research Systems
Global Sorghum Cultivar Releases, 1972-1997.

Country:

Respondent:

Name:

Organization

Position:

Address:

The following information is being collected as part of a Joint NARS-ICRISAT study which will quantify the global impact of sorghum research activities by National Agricultural Research Systems and ICRISAT. It also aims to create, and periodically update, a comprehensive database of public sorghum varieties and hybrids released by public NARSs since 1972.

This questionnaire focuses on the following areas:

1) Sorghum varieties and hybrids released by NARS from 1972 to 1997
2) Area planted to different sorghum varieties and hybrids
3) Sorghum research effort

Please return this questionnaire to:

Dr. MCS Bantilan, Research Evaluation and Impact Assessment (REIA) Project, ICRISAT, Patancheru -502 324, AP, India.

Part I. Public sorghum cultivars (varieties and hybrids) released during the period 1972-1997.

(If the full list of releases is unavailable, please give information for as many years as available. Information on public releases before 1972 and on private sector releases is optional.)

Name of the cultivar released	Year of release	Name of source germplasm	Origin (Code A)	Type of cultivar (Code B)	Ecological niche (Code C)	Commercial success (Code D)	Grain color (Code E)	Insect resistance (Code F)	Disease resistance (Code G)	Reasons for release/ cultivation(Code H)
e.g. CSV 13	1988	ICSV 112	4	1	1	1	1	2	2	1

Code A. ***(Origin code)***: 1 = Public material, contains no ICRISAT germplasm; 2 = Public material, contains some ICRISAT germplasm; 3 = Public material, contains substantial ICRISAT germplasm; 4 = Public material, contains 100% ICRISAT germplasm; 5 = Private (proprietary) hybrid, contains no ICRISAT germplasm; 6 = Private (proprietary) hybrid, contains some ICRISAT germplasm. **Code B.** ***(Type of cultivar)***: 1 = Open pollinated variety (OPV); 2 = Conventional hybrid; 3 = Non-conventional hybrid; 4 = Others (please specify). **Code C.** ***(Ecological niche)***: 1 = Moist semi-arid tropics; 2 = Dry semi-arid tropics; 3 = Humid tropics; 4 = Sub-humid tropics; 5 = Others. **Code D.** ***(Commercial success)***: 1 = Yes (covered at least 5% of total national sorghum area, or 25,000 ha in 1995 or before); 2 = No (did not meet criterion in 1). **Code E.** ***(Grain color)***: 1 = White; 2 = Yellow; 3 = Red; 4 = Brown; 5 = Buff; 6= Other color (specify). **Code F.** ***(Insect resistance)***: 1 = Resistant; 2 = Moderately resistant; 3 = Susceptible; 5 = Severely susceptible. **Code G.** ***(Disease resistance)***: 1 = Resistant; 2 = Moderately resistant; 3 = Susceptible; 4 = Severely susceptible. **Code H.** ***(Reasons for release/cultivation)***: 1 = Grain purpose; 2 = Forage purpose; 3 = Dual purpose; 4 = Other purposes (please specify)

Part I. Public sorghum cultivars (varieties and hybrids) released during the period 1972-1997. (Contd.)

(If full list of releases is unavailable, please give information for as many years as available. Information on public releases before 1972, and also on private sector releases is optional.)

Name of the cultivar released	Year of release	Name of source germplasm	Origin (Code A)	Type of cultivar (Code B)	Ecological niche (Code C)	Commercial success (Code D)	Grain color (Code E)	Insect resistance (Code F)	Disease resistance (Code G)	Reasons for release/ cultivation(Code H)
e.g. CSV 13	1988	ICSV 112	4	1	1	1	1	2	2	1

Code A. *(Origin code)*: 1 = Public material, contains no ICRISAT germplasm; 2 = Public material, contains some ICRISAT germplasm; 3 = Public material, contains substantial ICRISAT germplasm; 4 = Public material, contains 100% ICRISAT germplasm; 5 = Private (proprietary) hybrid, contains no ICRISAT germplasm; 6 = Private (proprietary) hybrid, contains some ICRISAT germplasm. **Code B. *(Type of cultivar)***: 1 = Open pollinated variety (OPV); 2 = Conventional hybrid; 3 = Non-conventional hybrid; 4 = Others (please specify). **Code C *(Ecological niche)***: 1 = Moist semi-arid tropics; 2 = Dry semi-arid tropics; 3 = Humid tropics; 4 = Sub-humid tropics; 5 = Others. **Code D. *(Commercial success)***: 1 = Yes (covered at least 5% of total national sorghum area, or 25,000 ha in 1995 or before); 2 = No (did not meet criterion in 1). **Code E. *(Grain color)***: 1 = White; 2 = Yellow; 3 = Red; 4 = Brown; 5 = Buff; 6= Other color (specify). **Code F. *(Insect resistance)***: 1 = Resistant, 2 = Moderately resistant; 3 = Susceptible; 5 = Severely susceptible. **Code G. *(Disease resistance)***: 1 = Resistant; 2 = Moderately resistant; 3 = Susceptible; 4 = Severely susceptible. **Code H. *(Reasons for release/cultivation)***: 1 = Grain purpose; 2 = Forage purpose; 3 = Dual purpose; 4 = Other purposes (please specify).

Part II. Status of Sorghum Cultivation in the country.

Summary of national sorghum area under different types of materials in different years.

Year of reference	Type of material	Total area planted (hectares)	Percent of national sorghum area
1975-76	Hybrids		%
	Improved open pollinated varieties		%
	Local varieties		%
	TOTAL		100 %
1980-81	Hybrids		%
	Improved open pollinated varieties		%
	Local varieties		%
	TOTAL		100 %
1985-86	Hybrids		%
	Improved open pollinated varieties		%
	Local varieties		%
	TOTAL		100 %
1990-91	Hybrids		%
	Improved open pollinated varieties		%
	Local varieties		%
	TOTAL		100 %
1995-96 ***or***	Hybrids		%
most recent year	Improved open pollinated varieties		%
	Local varieties		%
	TOTAL		100 %

Source of above estimates (check one or more):

Official statistics ________ Seed sales ________

Breeders' estimates ________ Farm surveys ________

Other (specify) ________

Part III. *Percent area planted to major sorghum varieties and hybrids in different crop years.*
(Please make sure that all listed varieties in this section are also included in section I. Also, if necessary, please fill in the bottom part of this table so that the total sorghum area reported adds up to the national sorghum area in the country.)

Crop year = 1975-76

Name of material	Total area planted to this variety or hybrid (Thousand ha)	Percent of national sorghum area planted to this variety or hybrid	Yield level (kg/ha) at the experimental field	Yield level (kg/ha) at the farmers' field	Remarks (varieties replaced)
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
Other public varieties (OPVs)		%			
Other public hybrids		%			
Other proprietary hybrids		%			
Local varieties		%			
TOTAL		100%			

Part III. Percent area planted to major sorghum varieties and hybrids in different crop years.

(Please make sure that all listed varieties in this section are also included in section I. Also, if necessary, please fill in the bottom part of this table so that the total sorghum area reported adds up to the national sorghum area in the country.)

Crop year = 1980-81

Name of material	Total area planted to this variety or hybrid (Thousand ha)	Percent of national sorghum area planted to this variety or hybrid	Yield level (kg/ha) at the experimental field	Yield level (kg/ha) at the farmers' field	Remarks (varieties replaced)
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
Other public varieties (OPVs)		%			
Other public hybrids		%			
Other proprietary hybrids		%			
Local varieties		%			
TOTAL		100%			

Part III. Percent area planted to major sorghum varieties and hybrids in different crop years.

(Please make sure that all listed varieties in this section are also included in section I. Also, if necessary, please fill in the bottom part of this table so that the total sorghum area reported adds up to the national sorghum area in the country.)

Crop year = 1985-86

Name of material	Total area planted to this variety or hybrid (Thousand ha)	Percent of national sorghum area planted to this variety or hybrid	Yield level (kg/ha) at the experimental field	Yield level (kg/ha) at the farmers' field	Remarks (Varieties Replaced)
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
Other public varieties (OPVs)		%			
Other public hybrids		%			
Other proprietary hybrids		%			
Local varieties		%			
TOTAL		100%			

Part III. Percent area planted to major sorghum varieties and hybrids in different crop years.

(Please make sure that all listed varieties in this section are also included in section I. Also, if necessary, please fill in the bottom part of this table so that the total sorghum area reported adds up to the national sorghum area in the country.)

Crop year = 1990-91

Name of material	Total area planted to this variety or hybrid (Thousand ha)	Percent of national sorghum area planted to this variety or hybrid	Yield level (kg/ha) at the experimental field	Yield level (kg/ha) at the farmers' field	Remarks (varieties replaced)
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
Other public varieties (OPVs)		%			
Other public hybrids		%			
Other proprietary hybrids		%			
Local varieties		%			
TOTAL		100%			

Part III. Percent area planted to major sorghum varieties and hybrids in different crop years.
(Please make sure that all listed varieties in this section are also included in section I. Also, if necessary, please fill in the bottom part of this table so that the total sorghum area reported adds up to the national sorghum area in the country.)

Crop year = 1995-96 *or most recent year for which data is available*

Name of material	Total area planted to this variety or hybrid (Thousand ha)	Percent of national sorghum area planted to this variety or hybrid	Yield level (kg/ha) at the experimental field	Yield level (kg/ha) at the farmers' field	Remarks (varieties replaced)
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
		%			
Other public varieties (OPVs)		%			
Other public hybrids		%			
Other proprietary hybrids		%			
Local varieties		%			
TOTAL		100%			

Q. What factors are responsible for the differences between on-station and on-farm yield level? Please mention the percent contribution of different components to the total yield gap.

Part IV. Sorghum research effort (Give data for most recent year available.)

Reference Year = 199_

1. Number of full-time equivalent scientists working on developing improved sorghum varieties in the public sector.

	Breeders	Agronomists	Seed technologist	Other*	Total
B.Sc.					
M.Sc.					
Ph.D.					
Other					
TOTAL					

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

2. Number of sorghum seed companies operating in the country:

Government or parastatal seed company ____________

Private sector - international company ____________

Private sector - national (domestic) company ____________

3. Approximate number of sorghum scientists in the private sector working on:

Crop improvement research ____________

Varietal testing ____________

Seed production only ____________

Sorghum Research Impact Questionnaire

for Private Sorghum Seed Companies

Global Sorghum Hybrid Releases, 1972-1997.

Country:

Respondent:

Name:

Organization:

Position:

Address:

The following information is being collected as part of a Joint NARS-ICRISAT study which will quantify the global impacts of sorghum research activities by public National Agricultural Research Systems and by ICRISAT as well as research in the Private Sector. It also aims to create, and periodically update, a comprehensive database on sorghum varieties and hybrids released by public NARSs and Private Seed Companies since 1972.

This questionnaire focuses on the following areas:

1) Sorghum varieties and hybrids released since 1992.
2) Area planted to different sorghum varieties and hybrids
3) Sorghum research effort

Please return this questionnaire to:

Dr. MCS Bantilan
Research Evaluation and Impact Assessment (REIA) Project
Socio-Economics and Policy Division (SEPD)
ICRISAT, Patancheru -502 324
Andhra Pradesh, India.

Private Sorghum Varieties and Hybrids Released during the Period Since 1972

(Please give information about your company releases and use the following codes to fill up different sections of the questionnaire).

Code A. 1 = Public material, contains no ICRISAT germplasm
2 = Public material, contains some ICRISAT germplasm
3 = Public material, contains substantial ICRISAT germplasm
4 = Public material, contains 100% ICRISAT germplasm
5 = Private (proprietary) hybrid, contains no ICRISAT germplasm
6 = Private (proprietary) hybrid, contains some ICRISAT germplasm

Code B. 1 = Open pollinated variety (OPV)
2 = Conventional hybrid
3 = Non-conventional hybrid
4 = Other

Code C. 1 = Moist semi-arid tropics
2 = Dry semi-arid tropics
3 = Humid
4 = Sub-humid
5 = Others

Code D. 1 = Yes (covered at least 5% of total national sorghum area, or 25,000 ha in 1995 or before)
2 = No (did not meet criterion in 1)

Code E. 1 = White grain
2 = Yellow
3 = Red
4 = Brown
5 = Buff
6= Other grain color (specify)

Code F. 1 = Resistant
2 = Moderately resistant
3 = Susceptible
5 = Severely susceptible

Code G. 1 = Resistant
2 = Moderately resistant
3 = Susceptible
5 = Severely susceptible

Questionnaire for Private Sorghum Seed Companies

Name of the company:
Company address:

Name of person who filled up the questionnaire:
Designation:
Telephone No:

Date of filling up the questionnaire:

1. When your company was established (month and year) ______________
2. Under which category does your company fall?
   a. Sole proprietorship ______________
   b. Partnership ______________
   c. Private Limited ______________
   d. Public Limited ______________
   e. Co-operative ______________
3. In which countries does your company operate (cite country names) ______________

   (If your company operates in more than one country, then **please complete a separate questionnaire for each country in which your company operates**)
4. Do you have any collaboration with ICRISAT Yes/No

   If yes, since when (year) and what type of collaboration

5. First Sorghum hybrid released by your company was in (year) ______________
6. Total number of hybrids released by your company (to date) ______________
7. Number of these hybrids with some ICRISAT germplasm ______________
8. No of ICRISAT populations, gene pools, or lines requested/used
   a) Requested ______________
   b) Used ______________
9. Does your company have its own research and development program on sorghum? Yes/No.
10. Please indicate the number of experiment stations your company uses for sorghum research and the total area used by your company.

    Number : ______________ Area used: ______________ ha.

11. Please indicate the **number of research personnel** (B.Sc., graduates and above) that your company currently employs in breeding and support activities (eg, pathology, entomology, seed technology).

	Total	Percent of time spend for sorghum research
a. Diploma	______	______
b. B.Sc./B.S	______	______
c. M.Sc./M.S.	______	______
d. Ph.D.	______	______

12. a) Do you receive any sorghum germplasm from ICRISAT? Yes/ No.

b) If yes, then state the condition of germplasm you usually receive from ICRISAT:

Very satisfactory condition / Satisfactory condition/ Unsatisfactory condition

13. In your opinion, how can ICRISAT improve its sorghum germplasm enhancement and distribution process to fulfill your future need?

Please complete for each country in which your company operates.

Name of hybrid	Year of release	Ecological niche (Code C)	Potential yield(t/ha)	Quantities of seed sold in the latest year___	Price of seed(____/kg)

Country	Year your first sorghum hybrid was released	Total number of hybrids released by you to date	Number of these hybrids with ICRISAT germplasm	Main ICRISAT populations, pools, or lines used	Total sorghum research staff in your company*

* Please include only staff with a minimum level of training of B.S. or equivalent in sorghum breeding and support activities (e.g., pathology, entomology, seed technology).

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 +254 20 524001
icrisat-nairobi@cgiar.org

ICRISAT-Niamey
(Regional hub WCA)
BP 12404
Niamey, Niger (Via Paris)
Tel +227 722529, 722725
Fax +227 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 +265-1-707298
icrisat-malawi@cgiar.org

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

Visit us at **www.icrisat.org**

ISBN 92-9066-470-3 Order code BOE 033 639-2003