workshops and scientist exchanges to formal master and doctor degree graduate programs. Some graduate students are following a program of completing their course work in the U.S. and their thesis or dissertation research in their home countries.

In summary, INTSORMIL's sorghum research role is one of joining with others who have an interest in sorghum and millet with leadership and research collaboration. The collaboration of national research programs, the international centers (in this case CIAT and ICRISAT), and INTSORMIL gives the kind of research expertise and momentum that can and will lead to improvement of sorghum production and utilization where there are problems with acid soils, production stress related to drought and other weather conditions, insects, diseases, and problems of storage and utilization.

We believe the workshops and the training of Latin American students will spread the state-of-the-art knowledge and will lead to a continuation of the work done by Dr. Lynn Gourley and others of you with acid soils research. The results so far have been impressive, but I believe that you will agree there is still a lot of research to be done.

The INTSORMIL input into sorghum-acid soils research has strong support from the INTSORMIL Technical Committee, Board of Directors, and the External Evaluation Panel. Mississippi State University has the leadership with the project for INTSORMIL and is in the process of recruiting a sorghum research scientist who will continue the research when Dr. Gourley returns to the U.S. in November of this year.

I challenge you all to participate and to do what you can to contribute to this important research effort.

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ICRISAT's Sorghum Research in the Semi-Arid Tropics

*J. M. Peacock**

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is one of 13 international centers in a worldwide research network devoted to improving food production in less-developed countries (CGIAR, 1980). ICRISAT's mandate is to improve the yield, stability, and food quality of five crops basic to life in the semi-arid tropics (SAT), and to develop farming systems that will make maximum use of the human and animal resources and the limited rainfall of the region. The crops are sorghum, pearl millet, pigeon pea, chickpea, and groundnut. Groundnut, rich in oil, is an important cash crop for the SAT farmer, while the others are all primarily subsistence food crops.

The seasonally dry semi-arid tropics are spread over nearly 20 million square kilometres and cover all or parts of 50 nations on five continents. They include much of South Asia, parts of Southeast Asia, West Asia, and Australia, two wide belts of Africa, areas of South America and Central America, and much of Mexico (Figure 1).

The SAT is a harsh region of limited, erratic rainfall and nutrient-poor soils (Sivakumar and Virmani, 1982). It is populated by more than 700 million people, most of them living at subsistence levels and dependent on limited food production on their small farms. ICRISAT's headquarters is at Patancheru, India, 26 km northwest of Hyderabad, but it also has scientific staff posted in nine countries of Africa, in Mexico, in Syria, and at a number of research stations in India. Principal operations in Africa are in Niger, Burkina Faso, Mali, Senegal, Nigeria, Sudan, Kenya, Malawi, and Zimbabwe.

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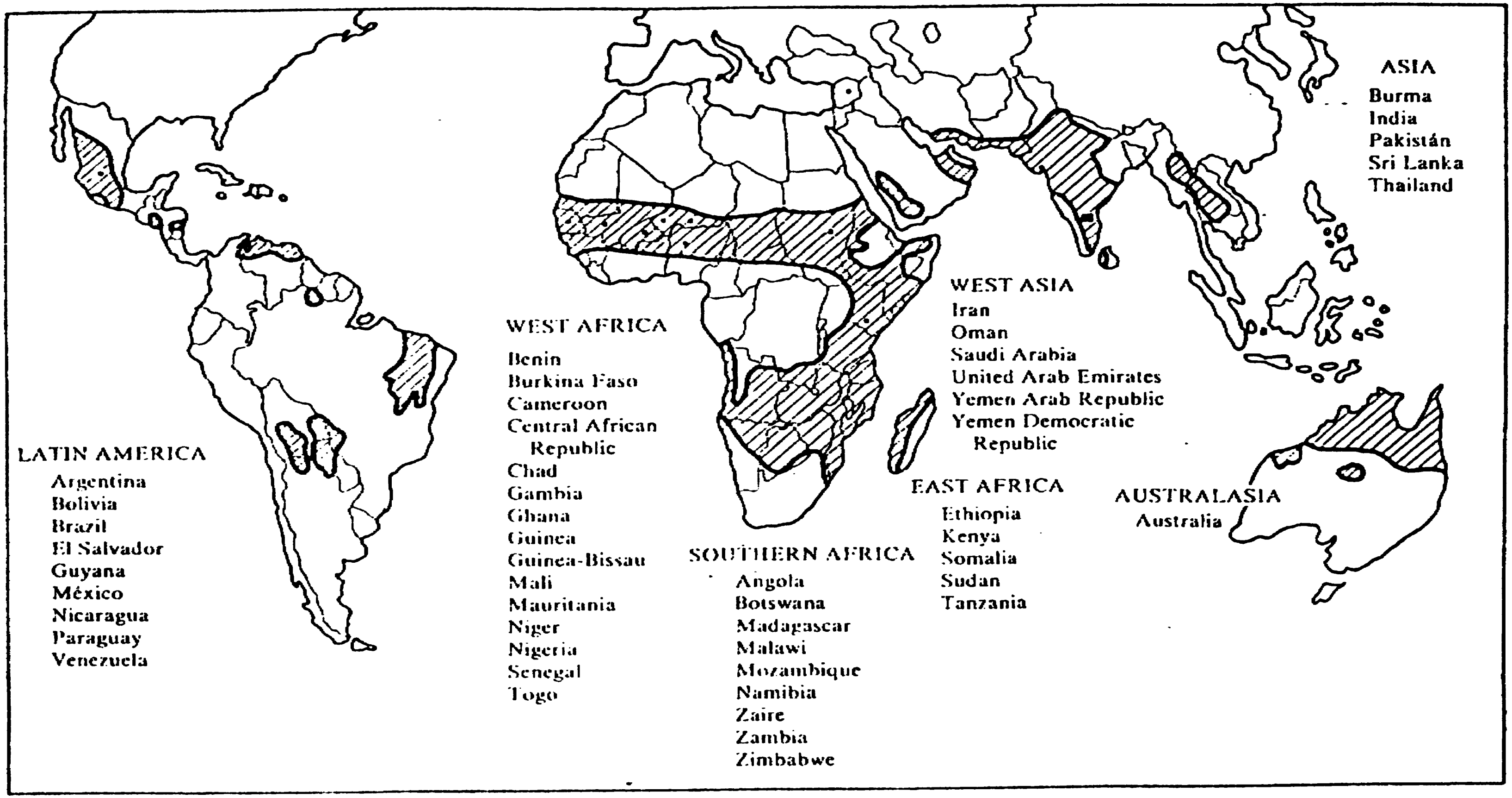

Figure 1. *Semi-arid areas (shaded) covered by ICRISAT's mandate. Dots indicate location of ICRISAT Center in India, Sahelian Center in Niger, and collaborative research stations with resident ICRISAT staff.*

Training

As this is an international teaching and training workshop, I will, at the outset, comment on ICRISAT's training activities which are one of the most important aspects of our work and provide one of the main channels through which we transfer our technology to the developing world. Each year, agricultural scientists and technical assistants come from many countries to learn about our research and improve their own skills. In 1983, a total of 144 persons from 37 countries came for training. These included 66 inservice trainees, 22 research scholars, 12 inservice fellows, and three research fellows. Four additional scientists completed their postdoctoral studies. Ninety ICRISAT scientists helped with this training program.

Our training in other countries included 15 scientists who worked with our sorghum breeders and agronomist posted in Mexico, and Malian students who worked on their theses with our agronomist and cereals breeder in Mali. We are particularly encouraged with the progress our scientists have made in Central America and in Mexico. Since 1975, 27 people have been trained from the following countries: El Salvador, Colombia, Costa Rica, Dominican Republic, Honduras, Ecuador, Nicaragua, Guatemala, Haiti, Panama, and Venezuela, plus more than 60 people from Mexico who have participated in short-term courses. In the course of this workshop, we shall hope to identify further candidates for training from Latin America.

Another channel is the Sorghum and Millets Information Centre (SMIC) which produces a newsletter and a sorghum and millet Annual Bibliography (SMIC, 1984). SMIC will provide, on request, any reprint, specific bibliography, or status report. ICRISAT also produces a wide range of publications on sorghum through its Information Services. These are listed in our catalogue (ICRISAT, 1984a) and can be obtained from Information Services.

Sorghum: its world distribution, domestication, and uses

It is not known when sorghum (*Sorghum bicolor* (L.) Moench) was first brought into cultivation, but Murdock (1959) suggests that with several other West African crops, it was first domesticated in eastern Africa some 7000 years ago. It is thought to have reached India no earlier than 1500 B.C. and China by A.D. 900.

Cultivated sorghum were first introduced to the Americas and Australia about 100 years ago, and domestication and cultivation of sorghum has now spread throughout the world. Today, it is grown on 47.8 million hectares (FAO, 1982), ranking fifth among cereals behind wheat, rice, maize, and barley in area sown. The major production areas today include the Great Plains of North America, sub-Saharan Africa, northeastern China, the Deccan plateau of central India, and Argentina.

Potential grain yields of sorghum are similar to those of the other important cereals. Yields in excess of 14,000 kg/ha have been reported by Pickett and Fredericks (1959) and Fischer and Wilson (1975). However, sorghum has achieved its importance not as a high-yielding cereal, but as a well-adapted crop of the arid and semi-arid tropics. Average yields in the developing world are near 1000 kg/ha, ranging from as low as 660 kg/ha in parts of Africa to as high as 3127 kg/ha in Latin America. Present-day uses are numerous, but the grain is most important as a human food in tropical zones, and for animal feed in the more temperate climates. Sorghum stems and foliage are often used for animal fodder and, in some areas, the stems are used for building and fuel purposes.

Overall objective of the sorghum improvement program

We all recognize that low yields in the developing world are the result of actions and interactions of many factors, and that there are no simple, easily implementable solutions. ICRISAT's primary concern is with the interactions of biological, climatic, edaphic, and management factors, and the development of production technologies that in the appropriate socio-political-economic climate will result in increased sorghum production on a sustained basis. To achieve this objective, the program has identified a number of priority traits for sorghum improvement (Table 1), and these form the basis of our research program.

In brief, our overall objective is to develop high and stable yielding varieties and hybrids with acceptable food quality. Our

Table 1. Priority traits in ICRISAT's sorghum improvement program.

Trait	Description
Grain yield	Higher and more stable
Grain quality	Acceptable food and nutritional quality
Stress resistance	
Abiotic stresses:	
Drought	Water, temperature, and nutrient stress
Crop establishment	Seedling emergence through crust and high surface temperature
Biotic Stresses:	
Pests	Shoot fly, stemborer, midge, and head bugs
Diseases	Grain mold, stalk rot, downy mildew, leaf diseases
Witchweed	*Striga hermonthica* and *S. asiatica*

ultimate aim is to improve the sorghum production of the poor farmers in the developing countries of the world.

Organization and research strategy

The area of the SAT for which ICRISAT has the mandate has been divided into nine geographical regions (Table 2) (ICRISAT, 1980), each consisting of between 8 and 12 contiguous countries. Table 3 shows the five regions designated as priority zones, together with data on average yields and areas under cultivation. ICRISAT now has research programs in these five regions. As these programs are established and work most closely with national programs, their main responsibility is for regional research activities. However, there is strong interaction with center scientists which includes visits by scientists, exchange of germplasm and breeder lines, collaborative workshops, and annual in-house reviews.

The Center program is multidisciplinary and is supported by: five scientists in breeding; three scientists each in physiology, pathology, and entomology; and one scientist each in microbiology, biochemistry, and genetic resources. The microbiology,

Table 2. Geographic regions for sorghum production.

Indian subcontinent and Southeast Asia
(India, Bangladesh, Pakistan, Sri Lanka, Thailand)

West Africa and Sudan
(Benin, Cameroun, The Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Sierra Leone, Senegal, Burkina Faso)

East Africa and Yemen Arab Republic
(Burundi, Ethiopia, Kenya, Rwanda, Somalia, Tanzania, Uganda, Yemen Arab Republic)

Southern Africa
(Angola, Botswana, Madagascar, Malawi, Mozambique, Zambia, Zaire, Zimbabwe)

Central America and Mexico
(Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Netherlands Antilles, Nicaragua)

South America
(Argentina, Bolivia, Brazil, Colombia, Paraguay, Venezuela)

Far East
(China, Japan, Korea)

Temperate America

Oceania
(Australia)

SOURCE: ICRISAT (International Crops Research Institute for the Semi-Arid Tropic 1982.

Table 3. Average yields, area under cultivation, and percentage of world area in the five geographic functional regions for sorghum production showing where ICRISAT scientists are located.

Functional region	Average yield (kg/ha)	Area (thousand ha)	Percent of sorghum-growing total world area
Indian subcontinent and Southeast Asia	840	16,672	35
West Africa and Sudan	755	11,697	24
East Africa and Yemen	917	2,970	6
Southern Africa	805	1,295	3
Central America and Mexico	2,238	1,723	5
Mean	1,111	-	-
Total	-	34,357	73

SOURCE: FAO (Food and Agriculture Organization of the United Nations). 1982.

biochemistry, and genetic resources programs have responsibility across all ICRISAT's mandate crops. Scientists in the farming systems and economics programs are also actively involved in sorghum research.

It is visualized that the Center program, apart from coordinating all regional activities, will serve the Indian subcontinent and Southeast Asia. In our other collaborative programs, several scientists were placed in countries in West Africa and it is hoped to have a multidisciplinary regional team for this region in the near future. A regional program for Southern Africa (Southern African Development Coordination Conference (SADCC) countries) has just been funded and the first sorghum scientist is in post. A breeder stationed in Kenya serves as coordinator of the Consultative Advisory Committee on Semi-Arid Food Grain Research and Development (SAFGRAD) sorghum and millet trials for Eastern and Southern Africa.

In Central America, our regional program is comprised of two scientists—a breeder and an agronomist—based at the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) in Mexico and serving Central America and the Caribbean.

As the center and regional programs develop, a research strategy has evolved which identifies four stages in sorghum improvement (Table 4). In keeping with the priorities of the Ten-Year Plan (ICRISAT, 1982), the first five years of the 80's will be largely devoted to establishing and perfecting screening procedures to handle large numbers of germplasm and breeder lines.

Table 4. Stages in sorghum improvement.

1. Identification of yield-limiting factors
2. Development of screening methods
3. Development of products of research (i.e., varieties and hybrids)
4. Transfer of technology to national programs and farmers

Sorghum germplasm

Before going on to the specific objectives of the disciplines within the program, it is vitally important to introduce sorghum germplasm. It is our most valuable resource and forms the nucleus of all our research activities. There are now more than 22,000 accessions from 70 countries in the world collection of sorghum maintained by the Genetic Resources Unit at ICRISAT Center (Table 5).

To make the collection more useful to scientists involved in crop improvement, both conversion and introgression activities involving selected entries are undertaken. The conversion program has been developed using the Texas A&M University/United States Department of Agriculture (USDA) program model of back-crossing to introduce genes contributing to photoperiod insensitivity and shorter plant height. ICRISAT has participated on a joint committee with the International Board for Plant Genetic Resources (IBPGR) to develop and publish a descriptor list (IBPGR/ICRISAT, 1980) for characterizing sorghum germplasm. All information is now being stored on computer and is available to users. This list is useful to a crop improvement program and needs to be more widely distributed in Latin America. Scientists who collect sorghum in Latin America are encouraged to send seed and related biological and environmental data to ICRISAT for inclusion into the world collection. This is clearly an important area for collaboration. It will also be appreciated if, as you evaluate and use these accessions, you will send your results to the Genetic Resources Unit at ICRISAT Center.

Table 5. Status of sorghum germplasm collection at ICRISAT.

Cultivated lines	Wild relatives	Countries represented	Evaluated at Patancheru	Distributed	Recipient countries
22,553	345	79	20,355	214,950	73

Specific objectives

The specific objectives of the disciplines concerned with alleviating abiotic and biotic stress are essentially the same, viz., within the priority areas of research, to develop techniques capable of screening large numbers of the germplasm and breeder lines, and to get these sources of resistance through breeding into the national programs.

For this reason, I propose to give detailed examples of our approach to our objectives in only one of the three concerned disciplines, that of physiology. I have chosen physiology for two reasons: it is one of the principal disciplines underlying this workshop; and as a physiologist I am better qualified to discuss the research of my own program. Notwithstanding this, I shall outline the priority areas of research within entomology and pathology and conclude by describing how sources of resistance, identified from the germplasm, have been utilized in our breeding program and disseminated to the national programs of the SAT.

Abiotic stress

The overall objectives of research on abiotic stresses are to assist the sorghum improvement program develop sorghums that are more stable and higher yielding under environmental stress. Since 1980, under this broad objective, we have confined our research activities to two priority areas:

Factors affecting crop establishment; and

response and adaptation to water, temperature, and nutrient stress, or what largely manifests itself as "drought" in farmers' fields.

During this period our specific objectives were as follows:

To develop simple, repeatable, inexpensive techniques capable of screening large numbers of the germplasm and breeder lines, and to get these sources of resistance (either directly or inderectly through breeding) into the national programs.

To ensure that these sources of resistance, together with sources of susceptibility, are freely available to physiologists working outside of ICRISAT in order that important basic research on these materials continues in parallel with our screening.

To better understand the physiological basis of existing management practices, and with the agronomists, to improve on these systems.

To train those working in the national programs in the SAT in screening techniques and management practices.

In the area of crop establishment, a number of screening techniques have been developed. The two examples highlighted here relate to screening for emergence at high soil-surface temperatures. The first method, which uses different soil surface treatments to modify soil temperature (Wilson et al., 1982), has shown that there is genetic variation in the ability of sorghum to emerge at high soil temperatures, and that some lines emerged even when soil temperatures were as high as 55°C.

Similar studies have been conducted using the second technique. Long clay pots (300 mm) filled with soil are placed in a water tank. Seeds are sown in the pots and temperatures between 35 and 50°C can be maintained by varying the heights of infrared lamps. Genotypic differences in emergence were most evident at 45°C. The advantage of this technique, although not as simple as the former, is that screening can be done while water is not limiting or the soil crusted.

In the area of drought, I will comment on two approaches. The first is the well known line source sprinkler irrigation system (Hanks et al., 1976), which exposes the crop to a gradient of soil water during different stages of growth. This technique allows us to test a number of genotypes under a continuous range of water levels. Figure 2 shows typical response curves for two contrasting sorghum lines and serves to illustrate the need to match varieties and hybrids to particular environments. Type 1 (continuous line) clearly does better in higher rainfall areas but fails completely in the dry zone. Type 2 (broken line) obviously has a much lower yield potential but will yield under severe stress.

Another approach has been to make up collections of material which are from a wide range of taxonomic groups, geographical regions, and climates and to screen these for particular phenological, morphological, and physiological traits under severe environmental stresses. An example would be our rainfall collection which, in addition to the above listed variability, is stratified into three rainfall zones, viz., those with an annual rainfall of 250-600 mm, 600-900 mm, and 900+ mm.

Each collection comprises about 200 lines and is sown in the summer season at Patancheru, India. Severe stress is imposed from about 30 days after sowing. Maximum temperature during this rainfree period exceeds 40°C, with pan evaporation rates reaching 16 mm/day. One important trait we are looking for is the ability of the growing leaves to avoid desiccation (Figure 3). A number of resistant and susceptible lines were selected in 1983

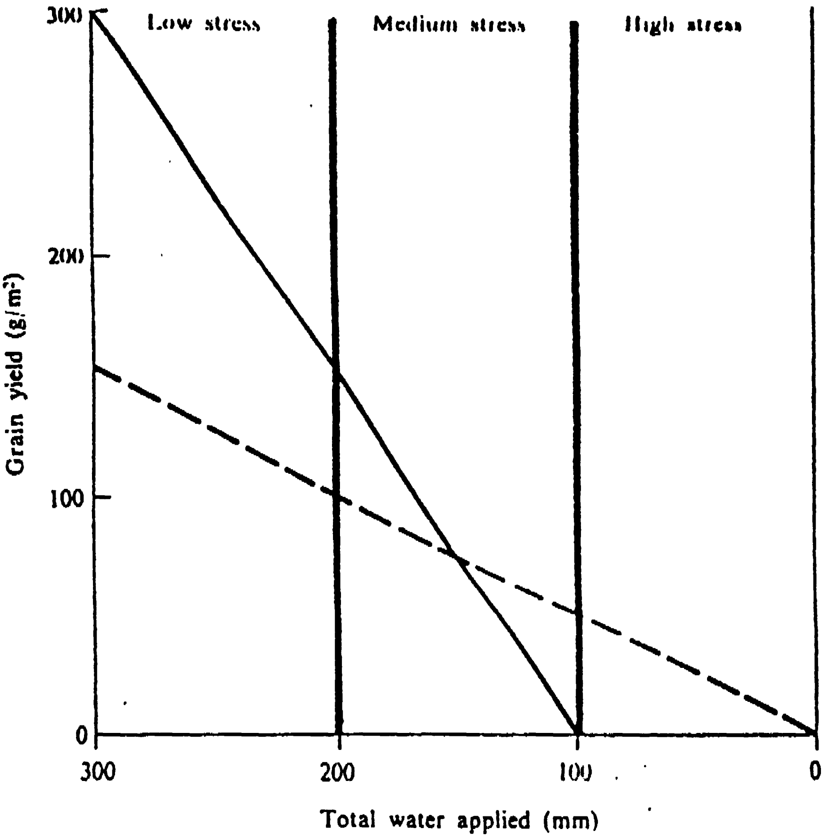

Figure 2. *Relationship between water applied and grain yield in two contrasting sorghum lines.*

and, in accordance with our second major objective, seed from these lines have been sent to other physiologists working outside of ICRISAT who are interested in the underlying mechanisms.

One example of this collaborative research is a project being conducted at the Welsh Plant Breeding Station (WPBS) in the United Kingdom where scientists have shown that emergence at high temperature is highly correlated with its embryo protein synthesis (WPBS, 1983). The research has not only led to the development of a screening method which will screen a large number of lines, but has attempted to establish the underlying biochemical processes associated with poor crop establishment.

Existing projects with organizations such as the Indian Council of Agricultural Research (ICAR), International Development Research Centre (IDRC), International Sorghum and Millet Program (INTSORMIL), and Official Development Assistance

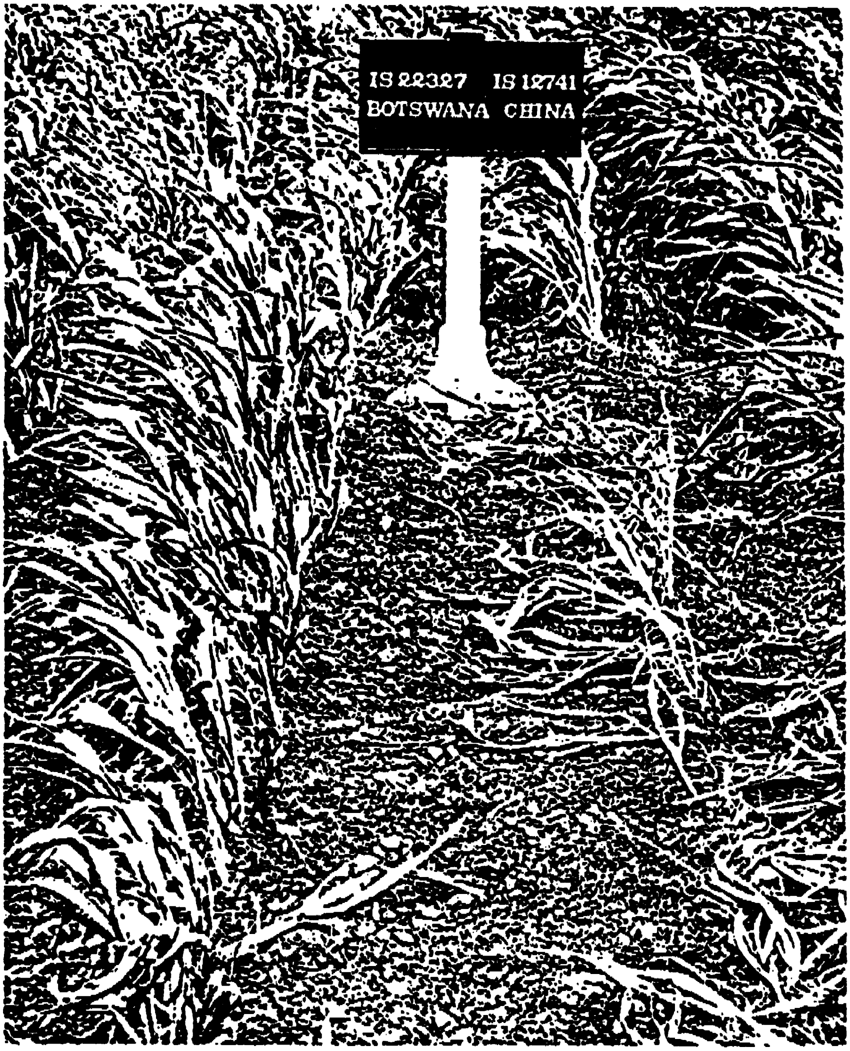

Figure 3. *The effect of extreme heat and water shortage on sorghum cultivars grown at Patancheru, India. The leaves of the line from China are severely desiccated in contrast to the line from Botswana whose leaves have remained green.*

(ODA) are proving to be very effective and we must strive to encourage further projects and strengthen existing links.

I believe that the problem of acid soils in Latin America lends itself very much to this approach, and I hope that in the course of this week, concerned scientists and organizations will have worked out an effective research strategy to deal with one of the most serious problems of sorghum production in Latin America.

Biotic stress

Disease stress (including *Striga*).

Priority diseases of global importance on which research is conducted at the Center and locations in India are:

Grain mold (preharvest biodeterioration of grain) caused by a complex of fungi;

root stalk rots that usually result in plant lodging, caused by *Macrophomina phaseolina* and *Fusarium* spp. (ICRISAT, 1984b); and

downy mildew caused by Peronosclerospora sorghi.

Research is also conducted on diseases of regional importance if they also occur in India. These include anthracnose and rust. The establishment of multidisciplinary regional teams will facilitate research on diseases of regional and local importance (such as viruses in Central America, leaf blight, grey leaf spot in eastern Africa, and sooty stripe and smuts in West Africa) for which screening opportunities do not exist in India.

Striga is a parasitic weed which is a major problem in India and West Africa. The Center program works on *S. asiatica* and scientists in the program in Burkina Faso work on *S. hermonthica*. Fortunately, *Striga* is not found in Latin America. Two information bulletins are available from ICRISAT on the identification of sorghum and pearl millet diseases and *Striga* (Williams et al., 1978; Ramaiah et al., 1983).

The specific research areas are:

Biology of pathogens and epidemiology of the diseases they cause. This information is essential for the development of meaningful resistance screening techniques.

Development of resistance screening techniques;

Identification of resistance both in source material and in breeding progenies.

Multilocational testing of identified resistance at "hot spot" locations for stability of resistance.

Nature of resistance and its utilization in breeding projects.

Pest stress

The priority insects of global importance are stemborers, shoot fly, midge, and head bugs. There are several important stemborers, viz., Chilo, Sesamia, Eldana, Busseola, and Distreae. The latter is found in the Americas. In India, 90% of sorghum damage is caused by the head bug, *Calorcoris angustatus*. An Information Bulletin is available from ICRISAT on sorghum insects (Teetes et al., 1983).

The specific areas of research are:

To develop reliable screening methods;

to identify sources of resistance; and

to incorporate this resistance into agronomically good backgrounds.

Breeding for yield, stability, quality, and resistance

The overall objective of breeding is to develop high-yielding cultivars that will increase and stabilize sorghum production in the SAT. This is achieved by breeding for improved yields, agronomic eliteness, incorporation of good grain quality characteristics, and resistance to abiotic and biotic stress. Both conventional and population breeding methods are used in the development of varieties and hybrids.

At ICRISAT, populations were developed from original populations from Nebraska and Purdue Universities, USA; Serere, Uganda; and Samaru, Nigeria. In the future, these populations will be merged into five populations in which a broad range of germplasm and sources of resistance will be utilized (Table 6).

Several high-yielding varieties have been developed (Table 7) and distributed to national programs mainly through the Sorghum Elite Progeny Observation Nursery, the International Sorghum Variety Adaptation Trial, and the International Sorghum Drought Observation Nursery. In addition, several hundred breeding lines in various stages of development have been distributed to breeders in national programs for further selection and incorporation in their programs.

Table 6. Planned multifactor resistant (MFR) sorghum populations.

Population designation	Origin	Traits[a] to be incorporated and selected	Monitored traits
ICSP1-R/MFR	US/R Rs/R	Improved grain yield[b]. Resistance to grain mold, stemborer, shoot fly and midge.	Charcoal rot, stand establishment[c], *Striga*, food quality.
ICSP2-B/MFR	US/B Rs/B	Improved grain yield. Resistance to grain mold, stemborer, shoot fly and midge.	Charcoal rot, stand establishment, *Striga*, food quality.
ICSP3-R/MFR	US/R	Improved grain yield. Resistance to grain mold and *Striga*, and improved stand establishment.	Charcoal rot, stemborer, shoot fly, midge, food quality.
ICSP4-B/MFR	US/B	Improved grain yield. Resistance to grain mold and *Striga*, and improved stand establishment.	Charcoal rot, stemborer, shoot fly, midge, food quality
ICSP5-BR/MFR	WAE	Improved grain yield. Resistance to stemborer, shoot fly, *Striga*, and high food quality.	Charcoal rot, grain mold, midge, stand establishment.

a. Highly heritable traits such as disease resistance to downy mildew, rust, anthracnose, etc., to be fixed during population development by mass selection.

b. Grain yield evaluation would include tests under optimum management, low fertility, and moisture-deficient conditions.

c. Stand establishment includes several components: emergence through a soil crust, emergence through a hot soil-surface, seedling vigor, and seedling resistance to moisture stress and/or recovery from moisture stress.

specific objectives of the sorghum physiology, pathology, entomology, and breeding programs; and lists the lines and techniques which are now being utilized in different countries.

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