Fighting Hunger with Research ... a team effort

INTSORMIL

the first five years,

1979-1984

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INTSORMIL (Sorghum/Millet CRSP) is a research program aimed at improving human nutrition and well-being through improved production and utilization of sorghum and millet.

The United States Agency for International Development, Host Countries and the following U.S. Land Grant Institutions participating:

University of Arizona
Florida A&M University
Kansas State University
University of Kentucky
Mississippi State University
University of Nebraska
Purdue University
Texas A&M University

Cooperating International Agricultural Research Centers

ICRISAT - International Crops Research Institute for the Semi-Arid Tropics
Hyderabad, India

IRRI - International Rice Research Institute
Los Banos, Philippines

CIMMYT - International Center for the Improvement of Maize and Wheat
El Batan, Mexico

CIAT - Center for International Tropical Agriculture
Cali, Colombia

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FOREWORD

The Sorghum/Millet Collaborative Research Program, INTSORMIL, combines the resources and research talent of host country research institutions, eight Land Grant Universities, and the Agency for International Development, to improve world-wide sorghum and millet production and utilization. This report stresses only "highlights" of the research. It does not cover all research activity underway nor is it intended to be a technical report.

Sorghum and millet are basic food grains for millions of people. Most live in the poorer nations of the world where economic, human capital, soil, and water resources are limited. The research is challenging since most of the sorghum and millet production and utilization in the less developed countries is impeded by heat and drought stress, insects, diseases, storage, and other problems. INTSORMIL views the challenge as one that must be met head-on with a collaborative program of research, technical assistance, training, and institution building. The impacts of INTSORMIL research are multiplied through workshops, newsletters, information exchange, scientist exchanges, and an international exchange of sorghum and millet germ plasm.

INTSORMIL's research program is consistent with the goal of the Agency for International Development and the Board of International Food and Agricultural Development — to move as rapidly as possible to alleviate world hunger. At the same time, INTSORMIL provides mutual benefits with research results applicable to all farmers in the world where sorghum and millet are grown.

INTSORMIL appreciates grant support by the Agency for International Development and the cooperation of a large number of host country and U.S. institutions and scientists—the "team" is large. The cooperation of the International Agricultural Research Centers, particularly ICRISAT, CIAT, CIMMYT and IRRI, and the USAID Missions also is appreciated. USAID Missions' interest in being a member of the "team" has proved a vital link in host country collaboration and research success.

Significant research results are evolving and research institutions have been strengthened by INTSORMIL collaborative research and the training of host country scientists. This is only a beginning to what can be done as INTSORMIL "Fights Hunger with Research."

Glen J. Vollmar
Program Director

COLLABORATION AROUND THE GLOBE ... SOME EXAMPLES

AFRICA

INTSORMIL's help in Africa ranges from collaborative research on sorghum and millet in Sudan to the effects of grain price policy on production in Burkina Faso (formerly Upper Volta). INTSORMIL also has collaborative research underway in Mali, Niger and Botswana.

Farming Systems in North Kordofan, Sudan

An INTSORMIL team from the University of Kentucky conducted a two-year study of farming systems in the general area of El Obeid, North Kordofan. Millet was found to be of primary importance as a food crop and sesame as a cash crop. Average landholdings are fairly large (over 25 acres) by standards in less developed countries, but production and returns are marginal because of low soil fertility and erratic moisture supply.

Rainfall averages about 350 mm annually, most of it coming between July and October. The amount and distribution of rainfall is variable from year to year. The area is in a transitional zone between the clayey sand soils to the south and the "goz" soils (stabilized sand dunes) to the north. These two soil types are associated with differences in cropping patterns and livestock rearing. Both types are characterized by low fertility. Fallowing is the principal means for restoring soil fertility. The natural propagation of *Acacia senegal,* a native shrub of the region, allows farmers to gain an income from their fallow land through the collection of gum arabic produced by these trees.

The household is the basic consumer unit, but agricultural production is typically in the hands of more than one decision maker in the household. A common pattern is for husband and wife to manage separate farms. Unmarried sons and daughters who are old enough are also given land to manage if it is available. Besides farming, virtually every household has members who work in secondary occupations, usually on a seasonal basis. Nearly two-thirds of all household members are productive in some way during a part of the year.

Most farmers cultivate more than half of their total land each year. This is twice the amount of cultivation in relation to fallow as is usually recommended, and is probably a major reason that soil fertility in the region may be declining. Also, much of the cultivated lands are rented rather than owned by farm managers. Most

INTSORMIL scientists are using seed from the United States and other countries in a collaborative effort to improve sorghum and millet yield and quality.

Socio-economic research includes studies on price policy, markets and sorghum consumption. Here, sorghum is being cleaned before milling in a grain market in Gedaref, Sudan.

Women in Africa and other parts of the world play a key role in sorghum/millet production, harvesting and food preparation.

of the rented land is leased by better-off farmers from the poorer farmers in the villages.

Millet, sorghum, sesame and groundnuts are the most common crops. The cereals are primarily subsistence crops though surpluses are sold to other farmers and at local markets. Millet is the preferred staple of the rural diet, and millet stalks are used as a building material for houses. Almost every household grows some millet. Sorghum is a much less important crop, although most farmers do grow some. Local varieties of sorghum are often planted in the same hill with sesame. Aside from being used in making bread, porridge and beer, sorghum is an important animal fodder. Both seed and stover are used for this purpose.

Sesame is the dominant cash crop in the area, being grown by more than 90 percent of the farmers. It is often intercropped with sorghum, cowpeas, watermelon or *karkadee* (roselle). Most of the sesame is sold at regional markets and processed into oil which is consumed in the urban centers. Groundnuts are the second most important cash crop. They are grown primarily for the export market. Price instability of the world market has made groundnuts a higher risk crop for farmers than sesame.

There is a variety of other crops. Roselle is usually sold for cash or traded in kind. Cowpeas and okra are intended for domestic consumption but may be sold or traded. Watermelon is grown for both human and animal consumption. It is a water source and fodder for livestock during the dry season, and sold in local markets. These minor crops are frequently interplanted with sesame and sorghum.

The cropping cycle begins in the period January to April with land clearing. Then, between May and August all four major crops are planted. Millet is often planted earliest, before the May rains, in the hope it will mature before the season when insects and birds attack the immature candles. If the early plantings do not germinate, the farmer replants after a month. Alternatively he may switch to a shorter maturing crop like sesame or sorghum. Regular planting of sesame, groundnuts and sorghum is generally done in June or early July. These crops, too, may have to be replanted if rains are insufficient for germination or if sandstorms kill the seedlings.

Ideally, all crops are weeded at least twice. However, many poor farmers are forced by their need for cash to sell their labor to other farmers, thus neglecting an adequate second weeding of their own fields. Wealthier farmers, on the other hand, may weed their crops three or four times.

Crops are harvested from late August to January, with the most intense activity in October and November.

Aside from climate, labor is the most important constraint on the cropping system. For many farmers, the cost of hiring agricultural

laborers is the largest expenditure they make. Returns to labor by crop were calculated and it appears that the highest rate of return was for millet, followed by groundnuts, sesame, and sorghum. Sesame is popular among farmers despite its low rate of return because it is less risky than millet, and brings in a cash income.

Improving Pearl Millet in Kordofan

Pearl millet is the major subsistence crop in North Kordofan, but production usually is not sufficient to provide a full year's food supply, and some grain (usually sorghum) must be purchased.

Following the Kentucky farming systems study, INTSORMIL stationed a millet agronomist in El Obeid to bring the results of the Kansas State University pearl millet improvement program to this marginal cropping area. First attention in 1983 was given to the major constraints on yield, which were perceived by the project leader as being:

1. Poor genotypes.
2. Poor seedling vigor and establishment.
3. Poor soil fertility.
4. Inefficient cultural practices.
5. High incidence of insect pests and diseases.

The quick implementation and rapid progress of this project were made possible by the cooperation and logistic support provided by the Western Sudan Agricultural Research Project (WSARP) and the Agricultural Research Corporation (ARC).

Other organizations cooperating fully with INTSORMIL include: USAID/SUDAN; ICRISAT; Ministries of Agricultural Services, Kordofan Region; and Cooperative for American Relief Everywhere (CARE/SUDAN).

The following research projects are underway:

Effect of seed size and seed weight on seedling vigor. Previous research at Kansas State University indicated correlation of seed size and weight with seedling vigor. Better seedling vigor would aid crop production.

Effect of mix-cropping legumes with cereals on concurrent and following crops. Earlier research indicated advantages for mix-cropping with sorghum and millet.

Millet Genotype Screening Nursery.

Effect of Temperature on Germination of Sorghum and Millet Seeds. This project involves cooperative effort with a Kansas State University micrometeorologist. Preliminary results show that early-maturing millet strains escape the usual late-season drought damage and give superior yields. It has been found that the high soil temperatures at planting adversely affect the emergence of millet and sorghum. Screening continued in 1984 to determine which types are best suited to the Kordofan area.

African farmers living in the Sahel (edge of the desert) rely on sorghum and millet for food, forage and building materials.

Stimulating the Sudanese Seed Program

As Africa's largest country and leading producer of sorghum grain, Sudan has a special role in food supply for the region. Land and facilities are available to produce a regular surplus of this traditional food grain. But until recently, Sudan has not had access to improved technology for raising yields.

INTSORMIL has collaborated for several years with ICRISAT and Sudanese sorghum research to develop modern hybrid types adapted to Sudanese growing conditions and food tastes. By 1983, this research partnership had produced a hybrid, Hageen Dura, which meets high standards and is suited for seed production in Sudan.

At the request of the Sudanese Government and ICRISAT, INTSORMIL assumed the leadership, and financed and participated in a November 1983 workshop on hybrid sorghum seed production. This workshop, held at Wad Medani and including field visits to seed production trials, was aimed at rapidly stimulating the development of an effective commercial seed industry in Sudan.

Persons having hands-on experience with hybrid sorghum seed production in India, Africa and South America were on the program. Also participating were leaders from sorghum research agencies, seed enterprises, and the private commercial sector.

INTSORMIL is continuing efforts to improve the Sudan's capacity for hybrid seed production. In 1984, these efforts were concentrated on supply of needed foundation seed and on technical assistance in seed production processes.

Understanding Soil Problems in Mali

The sub-Saharan African country of Mali depends largely on sorghum and millet grain for its food supply. Because soil fertility is generally low, INTSORMIL and TROPSOILS (Tropical Soils CRSP) collaborative research with Malian researchers concentrates on fertilizer use to fit special Malian conditions.

A large part of the agricultural soils in Mali are in an undulating (ridge-valley) topography. The ridges have an ironstone cap at the surface. Some grasses, trees, and shrubs grow in these ironstone areas, but they are almost always unsuitable for cultivation. Just over the crest of the ridge, the soils are sandy and acid (pH 5.0-5.5). Progressing down the slope, the soils become heavier in texture and are silt loams in the valley with reaction near neutral, or even alkaline. The distance from ridge to ridge is frequently on the order of 1,000 yards, thus significant soil changes occur in short distances.

The soils are dry more than 90 days a year, yet during the rainy season (June to September) will be waterlogged at depths of 8 to 24 inches. These soils are deficient in nitrogen and phosphorus, have

low exchange capacities, and the acid soils have relatively large amounts of exchangeable aluminum.

Millets are grown on the acid sandy soils on the upper part of the slope and sorghum on the lower parts of the slope and in the flat areas. Both nitrogen and phosphorus availability limit yields when rainfall is greater than 12 inches. Native rock phosphates can be used on the acid soils, but not on those near neutral in pH. Since all the soils have low exchange capacities, they are very fragile chemically and must be treated with care.

Nitrogen fertilizers available in Mali are acid-forming and will rapidly aggravate the acidity problem in the low exchange capacity soils. This results in declining rather than enhanced production unless a suitable system of use is devised. Research must be directed toward solving this problem, since it is obvious that one of the most rapid methods of significantly increasing production in Mali will be through correction of soil fertility deficiencies.

More Consistent Sorghum Production for Botswana

Sorghum, along with white maize, is the staple food grain of Botswana. Since rainfall and growing conditions in that country tend to vary from year to year, production of food grains tends to vary correspondingly.

Data from the past several years show national average sorghum yields varying from just over 400 kg/ha to less than 100 kg/ha. At the higher level, domestic needs for sorghum grain can nearly be met, but poor yields mean food shortages and an urgent need to import food grains. Unfortunately, in the last two years, the neighboring countries of South Africa and Zimbabwe, normally the source of grain imports, also have had very short crops. This has resulted in an acute food grain shortage in Botswana.

To reach a higher and reasonably consistent level of domestic sorghum production, an accelerated sorghum research program has been started in Botswana. INTSORMIL is participating by providing germ plasm, training Botswanian researchers, and by stationing two experienced INTSORMIL research staff members and a graduate student in Botswana for on-site collaborative research.

Crop Rotations with Sorghum

Research at the University of Nebraska has shown that sorghum benefits from a previous crop of soybeans at a rate equivalent to about 40 kg nitrogen/ha. Similar studies in Botswana are also showing a good nitrogen equivalent response benefit to sorghum following cowpeas or groundnuts. These results are promising for less developed countries where foreign exchange must be used to buy fertilizer.

Cropping practices and research on fertility and drought resistance are important to sorghum and millet improvement in extremely hot and dry areas.

Rotation of sorghum and soybeans lowers the bulk density of the soil. This increases aeration and water percolation. A greater number of nodules were present on soybean roots when soybeans were grown in rotation as compared to monoculture soybeans, indicating higher nodulating efficiency in a rotation.

Legumes generally do not require additional nitrogen fertilizer because they are equipped to fix atmospheric nitrogen by nitrogen fixing bacteria present in root nodules. There has been much research concerning the efficiency of this system with respect to the legumes. However, there is usually a beneficial effect on yields of the subsequent cereal crop.

INTSORMIL's goal is to define the mechanisms associated with rotations and to increase the efficiency of cereal-legume systems. This information will be used to increase soil fertility without using applied nitrogen, which should be especially useful for low income farmers in less developed countries.

Nutrient Use Efficiency

In many less developed countries, at rainfall levels of about 12 inches, soil fertility is the first limiting factor in crop production. Since fertilizers are scarce and expensive, they must be used to maximum efficiency. In addition to changing cultural practices, one way to attack this problem is by using plants that are most efficient in use of the nutrients available at low native soil levels and that respond most efficiently to small amounts of applied fertilizer.

In field trials, collaborating INTSORMIL scientists have identified sorghum breeding lines that consistently produce more grain at low soil nitrogen levels than others. They have also identified within this more efficient group, lines that respond well to fertilizer ap-

plication. Currently, they are conducting research to determine which plant factors responsible for grain yield are most active in efficient conversion of nutrients to grain. The field screening program for nutrient use efficiency is being expanded to include phosphorus.

As breeding lines are identified as more nutrient use efficient, they will be incorporated into the breeding program to produce agronomically acceptable elite breeding lines with this characteristic.

How Does Grain Price Policy Affect Production?

In many West African countries, millet and sorghum are the principal staple crops. For total cereals, however, imports are increasing. Africa is the only region of the world where per capita food production declined during the 1970's and 1980's. This trend has been attributed to "cheap food" policies which subsidize urban consumption and tax the agricultural sector. Studies have clearly demonstrated that farmers are responsive to price incentives. This problem has been made worse because wheat and rice have become popular, substituting for millet and sorghum in urban diets, and are cheaply available through food aid programs.

Burkina Faso (Upper Volta) provides a classic example of this problem. An official grain trading agency, OFNACER (Office National de Cereales), attempts to provide cheap and stable food supplies to urban areas, intervening substantially in grain markets. Significant quantities of wheat and rice are imported, partially commercially and partially as food aid. Cereal imports constitute over 10 percent of Burkina Faso's import bill at a time when foreign exchange is in extremely short supply. The government of Burkina Faso attempted to solve this problem by allowing grain prices to rise to international market levels. This action led to internal unrest, made worse by the recent drought.

In better times and in the longer run, farmers in Burkina Faso and other African nations are likely to respond to improved price signals. Linear programming studies of farmer behavior indicate that new technologies require labor at high opportunity costs during peak periods. At sufficiently high grain prices, farmers can afford to purchase animals and labor remains on the farm rather than migrating to urban areas, since gains are possible through use of the new technologies. The key to this decision for the farmer is the value of the production increase relative to his labor cost.

Preliminary results of INTSORMIL studies indicate that markets efficiently transmit price signals to farmers. Hence, policies aimed at urban grain prices and grain import decisions will have an effect on the adoption rates for new technologies being developed for millet and sorghum.

LATIN AND SOUTH AMERICA

The potential place of sorghum in Latin American cropping systems is under intensive study because maize, the staple cereal food of much of this area, is in short supply. INTSORMIL scientists are studying both cultural practices and sorghum types to determine the best fit of the crop to Latin American farming systems.

Sorghum Instead of Maize for Subsistence Farmers

Modern sorghum technology has been transferred to many areas of Mexico in the past 25 years. Sorghum production there has increased from almost nothing to more than 5 million metric tons in the early 1980's. It is now the third leading crop, behind maize and wheat.

Farther south in Central America, subsistence farmers often grow small areas of sorghum and use it instead of maize for food.

Field research in Southern Honduras during 1981-83 studied farming methods, social and economic factors, and the nutritional condition of subsistence farm families in localities where grain sorghum is a staple food. Because of limited land resources and the nature of production and consumption systems in subsistence economies, these families often lead a precarious existence with respect to the food supply.

A systematic analysis was made of the capabilities of subsistence farming in Southern Honduras to provide adequate nutrition. The analysis showed that the average crop yields of maize, sorghum and beans grown on farms that averaged 1.1 manzanas (1.9 acres) in size can provide the minimum recommended amounts of calories and sufficient protein, but are deficient in several essential nutrients including vitamins A and C. Women appeared to be especially affected by these shortages.

In drought years, such as 1982 and 1983, sorghum was a much more reliable producer than maize. Sorghum consistently produces well in South America with lower moisture and with less fertilizer input than do crops like maize. However, large areas of Latin America (cerrado and the llanos) have highly acid soils which are a major constraint to sorghum production.

Sorghum genotypes vary extensively in their tolerance to the acid soil problem. Screening techniques to evaluate germ plasm for tolerance to toxic and deficiency levels of mineral elements have been developed in nutrient solutions. These screening procedures have correlated well or are being tested for relationship with field responses. (See *Finding Aluminum-Tolerant Sorghum Genotypes.*)

Aluminum-susceptible and high yielding aluminum-tolerant varieties of sorghum.

INTSORMIL - Mexico Collaboration in Sorghum Improvement

Collaboration between INTSORMIL workers and Mexican researchers is proving vital both to the Mexican sorghum improvement program and to INTSORMIL's activities elsewhere in Latin America. Because of the broad base of germ plasm being infused into Mexican programs, many lines of research are being developed with INTSORMIL involvement.

Sorghum is grown in Mexico from sea level to elevations above 1,500m, in high rainfall areas and in semiarid regions, and in different seasons of the year. Because maize commands a higher price in the market place, farmers are producing that crop for sale and saving less for home use, while supplementing food resources with high quality sorghum.

Many recipes and methods of preparation have been developed for sorghum. Sorghum continues to have the reputation of "poor man's food", but it is becoming recognized as a means to reduce hunger when maize yields are limited. Sorghum also has a major role in providing livestock feeds in place of maize and for food uses where maize is not capable of meeting the needs of the people.

Because there is a close mutual interaction between scientists in INTSORMIL and the Mexican Instituto Nacional de Investigaciones Agricolas (INIA), there has been a good exchange of useful sorghum germ plasm and information. New sorghum breeding stocks developed in the INTSORMIL program have been provided to Mexico so that a broader base of resources can protect the developing industry. Basic inbred lines, F_2 and advanced generation materials form the base for new hybrids for high yield areas and for the drought-prone regions of that diverse country.

Perhaps one of the more significant results of INTSORMIL involvement in Mexico has been the establishment of a hybrid de-

Because maize commands a higher price in the market place, Mexican farmers are producing that crop for sale and saving less for home use. They are supplementing home food resources with high quality sorghum.

velopment and release program. In 1983, Mexico released two hybrids — BJ-83 and BJ-85 — arising from INTSORMIL materials introduced previously. More hybrids are in final stages of testing in preparation for release. Mexico is making good use of INTSORMIL sorghum in complementing ongoing programs. At the same time there has been a major improvement in yield, disease resistance, and quality of sorghum resulting from INTSORMIL collaboration.

Four major Latin American sorghum workshops have been held in Mexico during the past four years. These have emphasized sorghum diseases, grain quality, breeding, and farming systems. About 110 participants from throughout Latin America have attended each of these workshops. The workshops have been a collaborative effort of INIA, CIMMYT, ICRISAT and INTSORMIL. They have proven useful to both Latin American sorghum researchers and INTSORMIL workers who were unfamiliar with tropical disease and insect problems, the obstacles of photoperiod and temperature sensitivity, and constraints of adaptation. A research network has been established for the Caribbean, Central and South America, and Mexico.

Through INTSORMIL involvement and stimulation, the first sorghum conference ever held solely by Mexican workers in all related disciplines occurred September 26-29, 1983, at Irapuato. Approximately 140 scientists participated. Interest was intense in all aspects of sorghum quality and nutrition research and in the capability of breeders to incorporate desirable traits.

Because of the close association and strong program developed in Mexico and because of the wide and varied sorghum production regime there, Mexico can develop the technology of sorghum culture and utilization needed to become a strong focal point for the rest of Latin America.

Better Sorghum Varieties for Central America

Traditionally, sorghums grown by the small farmers in Central America are tall, late-maturing, and generally give a low but reliable grain yield. White or cream-colored types which make acceptable tortillas are preferred.

The INTSORMIL collaborative sorghum improvement program for Central America, based in Southern Honduras, is striving to develop high-yielding types with grain quality satisfactory for the preferred regional food products. Local *maicillo criollo* types have much to offer. Using the disease and insect resistance, food quality and intercropping tolerance of the locals and the high yield potential of other INTSORMIL germ plasm, significant gains are possible.

As a first step in this program a new sorghum variety, Tortillero, which possesses grain quality equivalent to local varieties but high-

A Texas A&M graduate student in plant pathology helps with research on sorghum diseases in Honduras.

er yield potential and earliness, has been developed and distributed in Honduras. This development resulted from a joint effort by the Honduran National Sorghum Program, a part of the Ministry of Natural Resources, and INTSORMIL. The original selection work was by Rigoberto Nolasco, presently head of the Honduran program. Tortillero was selected from the introduction into Honduras of CS3541. This sorghum cultivar was developed by India's sorghum program and distributed by ICRISAT.

An INTSORMIL sorghum breeder stationed at Choluteca, Honduras, was the catalyst for the release, seedstock increase, and distribution of this variety. Most of the seed increase work has been done on the recently restored La Lujosa research station.

The variety Tortillero and the tropical adapted female, Tx623, developed by Texas A&M University INTSORMIL sorghum breeders, is playing a key role in the introduction of improved food type sorghum hybrids in Honduras and other Central American countries and in Mexico. The F_1 hybrid, ATx623 x Tortillero, has been tested in Central America and performs well. Seed of the hybrid was placed into extensive farmer testing throughout Honduras in 1984.

Much potential remains for sorghum improvement in Honduras and nearby El Salvador and Eastern Guatemala. The release of Tortillero is significant because of the stimulation and interest it has generated in breeding, development, and the use of new improved sorghum varieties and hybrids among Honduran government officials and farmers. There is also considerable interest in other countries.

Tortillero has a cream colored grain and is an early maturing, photoperiod insensitive, short statured type adapted to both hand and mechanical harvesting. The demand for this type of sorghum

in Southern Honduras is not yet as extensive as for the tall, late maturing local varieties which are interplanted with maize. Still, the release and use of Tortillero provides immediate benefits to the farmer and enhances the food grain production of the area.

Adapted hybrids are expected to be the next generation of types released, and can be expected to produce significantly higher yields even than Tortillero. The drought tolerance and consistency of the yield will allow the crop to enhance food resource production and reduce hunger in much of the semiarid areas of Central and South America.

Finding Aluminum-Tolerant Sorghum Genotypes

Large areas east of the Andes in the llanos and cerrado, mostly in Colombia and Brazil, have acid soils that reduce production of most plants, including sorghum. These soils have high aluminum toxicity, phosphorus deficiency, and a related series of problems associated with mineral nutrition.

Two INTSORMIL scientists — a plant physiologist and a plant breeder — are working with South American counterparts in an attempt to identify sorghum genotypes that will adapt to the acid-soil complex of both countries. The research is centered at CIAT with field testing at other locations.

Technology has now been developed and is being used to screen plants in the laboratory and field for tolerance to aluminum toxicity and phosphorus stress. Laboratory results have been shown to relate to field response.

One project goal is to screen and evaluate approximately 2,000 lines from the World Collection of Sorghum. Other goals are to learn why some genotypes are able to adapt, and how to correct acid soils with a minimum input of lime and phosphorus. The most aluminum-tolerant cultivars are being evaluated in yield trials in the llanos and cerrado to determine minimum inputs required for economic returns.

After testing, aluminum-tolerant cultivars are and will be crossed to improved materials or other materials that have these desirable qualities. The pedigree breeding approach is being used with different aluminum-tolerant sources.

Advanced breeding lines, random mating populations, World Collection lines, and new U.S., INTSORMIL and ICRISAT releases are being made available to interested breeders in Brazil, Colombia, and other areas where acid soil problems occur.

Dr. Bruce Maunder, chair of INTSORMIL's external evaluation panel, in a sorghum research plot at CIAT.

Latin American nations are looking to sorghum for tortillas to meet future food needs.

Northern South American scientists are being instructed in the use of effective breeding and screening methods for the adaptation of sorghum to acid tropical soils through workshops, staff visits, traineeships in host countries, and training at U.S. universities.

Results of this INTSORMIL project will also be applicable in Peru, Venezuela and the vast acid-soil areas in other parts of the world, including central Africa and eastern Asia, as well as southeastern and eastern United States, eastern Australia and New Zealand.

Tortillas from Sorghum

Tortillas—flat, unleavened bread usually made from lime-treated maize—are the staple cereal food in Mexico and much of Central America. Increasingly, the white maize usually preferred for tortilla making has become short in supply and expensive. Interest has developed in substituting grain sorghum for maize, either totally or in mixtures.

INTSORMIL researchers at Texas A&M University, collaborating with their counterparts in Mexican research organizations, have been studying ways of maximizing sorghum substitution in tortillas, while retaining acceptable quality. Color, texture, and taste are important to consumers. In many cases, a sorghum tortilla which is nutritionally as good as one from maize is considered unacceptable because of defects in one or more of these characteristics.

The easiest and most effective solution to the quality problem appears to be an alteration by breeding of sorghum grain color and textures. The model for this approach on a scientific basis has already been provided by the *maicillo criollo* sorghum types of Southern Honduras and southeastern Guatemala. These types, which have been grown and used for food in their regions for a long time, have white seeds of a texture which makes acceptable tortillas even when 100% sorghum flour is used. Flavor also appears acceptable to local consumers.

Using these or similar types as a source of grain quality, collaborating plant breeders and food scientists believe they can produce high-yielding sorghum varieties and hybrids which will combine high grain quality with other desired characteristics.

It must be recognized that something beneficial is likely to be lost when white-seeded high grain quality characteristics are incorporated into high yielding varieties and hybrids. They may be less resistant to certain insects or disease pathogens, for example.

INTSORMIL researchers are also attempting to identify the undesirable pigments which discolor the grain, and possibly find ways to eliminate them.

THE FIGHT AGAINST PESTS

Disease, weed and insect pests of sorghum and millet pose tough problems for farmers and scientists, but progress is being made. For example, research has reduced damage from sorghum downy mildew, and biological control methods promise help against stemborers and millet head girdler in West Africa.

Can Striga Be Controlled?

The parasitic weed *Striga* is one of the most serious limiting factors for sorghum and millet yields in Africa. One species also is a severe problem in India.

Despite considerable research by a variety of agencies, damage from *Striga* is reported to be increasing. INTSORMIL recently undertook collaborative work on this problem with the help of scientists in North and South Carolina who have had experience in *Striga* control.

Striga does its chief damage underground by parasitizing roots of host plants. Once it appears aboveground, it flowers and sets seed. The tiny, numerous seeds have a long life in the soil, and usually germinate only when a favorable host plant grows nearby.

Ordinary weed control methods, such as cultivation or herbicides, do not work well with *Striga* because its main damage is done before these controls can be applied. Successful control requires such measures as long-term growing of nonsusceptible crops, measures to cause *Striga* seeds to germinate harmlessly, and planting highly resistant crop varieties. None of these methods has yet proven economically practical in less developed countries.

A combination control effort, involving genetic, agronomic, and biochemical approaches is planned for trial in Sudan and Niger. Close cooperation between laboratory and field studies and the U.S. experience with integrated *Striga* control in the Carolinas is expected to help.

Stopping the Downy Mildew Threat

Sorghum downy mildew can cause crop failure either in individual fields or whole regions. The fungus causing downy mildew in sorghum, while similar to many other tropical downy mildews, differs in that it attacks both sorghum and maize.

During the 1960's and 1970's, sorghum downy mildew spread rapidly throughout the sorghum growing world. Its striking ap-

Researchers in Latin America discuss anthracnose situation.

pearance and ability to cause complete destruction of affected plants created alarm and concern. Some areas proposed drastic quarantine measures, which were not always effective and also greatly hindered germ plasm exchange by breeders.

At first, downy mildew could be controlled only by breeding for resistance. Research has now made it possible to control the disease with new systemic fungicides, crop rotations, and other cultural practices. Cultural controls such as deep plowing reduced the disease by 75%. In one test, a three-year crop rotation had an 85% reduction in sorghum downy mildew. Biological control agents are known, but their manipulation under field conditions remains a mystery. These alternative controls, along with host resistance, are expected to extend host plant resistance when genetic resistance succumbs to new types of the pathogen.

New research utilizing biological control and serology for identification of physiologic races is being developed. This research network includes South American, Asian, and African workers.

INTSORMIL programs have sponsored key workshops on integrated control of downy mildew; this information was presented to sorghum workers worldwide. A regional sorghum downy mildew screening nursery was developed in Honduras. Sorghum breeders and pathologists from various Central and South American countries are screening material for resistance to this disease.

Combatting Sorghum Leaf and Smut Diseases

Anthracnose, caused by *Colletotrichum graminicola,* may be the most important disease of sorghum in the more humid sorghum growing regions of the world. To reduce losses from this disease, INTSORMIL institutions have initiated collaborative programs to monitor pathogen variability, select and breed for resistance, and evaluate losses. The work is done by graduate students from less developed countries at Purdue, Texas A&M University, and Mississippi State University.

Initially, workers at Texas A&M, along with colleagues at Mississippi State University, developed the International Anthracnose Virulence Nursery. Data generated by growing this nursery in various ecological zones of the world clearly indicate that there are striking differences in the pathogen-host reaction from zone to zone. Researchers at Purdue and recently in Brazil have obtained isolates from many different zones which confirm earlier observations that the fungus is a variable species. Few sorghums have universal resistance, but some identified by Brazilian researchers appear to have higher resistance levels.

Further collaboration will encourage integrated disease control programs to selectively reduce the rate of disease development.

Genetic variation in sorghum and millet results in wide differences in height, grain yield and quality, and tolerance to diseases, insects and droughts.

This will be done in part by developing cultivars with "rate" reducing disease resistance, crop rotation, and other cultural controls.

Other significant foliar pathogens include sooty stripe in West Africa, and leaf blight in East Africa. Damage by these similar diseases, caused by distinctly different pathogens, can be reduced by systematic selection of sorghums with moderately high resistance levels. This requires a method of selecting for resistance under natural conditions on an annual basis. While techniques are available, pathologist-breeder teams to conduct these programs in less developed countries need to be developed or expanded.

INTSORMIL pathologists have collaborated with workers in Egypt and Sudan to develop sorghum cultivars resistant to long smut. Normally, this disease is a minor problem in local ("land races") cultivars. However, when land race cultivars are crossed with exotic sorghums, many hybrids are unusually susceptible and must be removed from the programs. To screen these hybrids for susceptibility requires special inoculation techniques. Techniques developed in Egypt for long smut were suggested to Sudanese pathologists who adapted them to their conditions. These techniques are now being transferred from Sudan to Mali by collaborating African sorghum researchers.

Sorghum Midge — Tiny, but Devastating

The sorghum midge is one of the most widespread and devastating of the insects which attack sorghum. The tiny midge larvae, which mature in the sorghum floret, damage the grain by feeding on the ovary and thereby preventing normal kernel development. At maturity a midge-damaged panicle has little or no seed and a "blasted" appearance.

Insects cause large losses in sorghum and millet production throughout the world.

Development of agronomically improved, genetically resistant sorghum by INTSORMIL scientists provides a means to control the midge, either alone or in combination with other measures.

Since all adapted U.S. sorghums were originally susceptible, scientists turned to exotic lines from the Texas A&M breeding program for sources of resistance. Screening about 240 lines as they became available, INTSORMIL plant breeders and entomologists found 13 lines with excellent resistance levels and 20 additional lines with usable resistance levels. The data indicate that of about 214 additional lines presently being screened, 10 possess usable resistance levels. A tall, late maturing introduction from Brazil, AF28, possesses the highest known resistance level.

These sources of resistance have been used to develop a large number of elite, adapted lines. The first known resistant line, SC175, has been the most widely used. New lines are being developed which combine new sources of resistance. Random-mating populations are being developed and improved to provide a source of germ plasm with multiple resistance sources and potential wide adaptation.

Midge resistant hybrids produce no significant yield advantage in the absence of midge. But resistant hybrids produce up to three times as much grain as susceptible hybrids when midge density is sufficient to destroy 75% of the seed of susceptible entries.

Collaborative research on several facets of sorghum midge biology and control are underway in at least eight countries. This collaboration has been particularly productive with scientists in Mexico, Honduras, and Brazil. The lack of sorghum research entomologists in many developing countries continues to be a serious constraint. This has been addressed by an intensive foreign student graduate training program. Technical assistance also has been provided by INTSORMIL upon request. Joint production of a Sorghum Insect Identification Handbook and an International Sorghum Entomology Workshop with ICRISAT are additional evidence of the commitment of INTSORMIL entomologists to help in the fight to reduce host country sorghum and millet losses caused by insect pests.

Potential for Biological Pest Control in Africa

Stemborers and the millet head girdler regularly cause crop losses to sorghum and millet in West Africa. Losses vary in severity depending on location and year. Almost nothing is known about the occurrence, species diversity, or biology of the parasites and predators which attack these pests in West Africa. Prospects are excellent for significant reductions in stemborer and head girdler infestations by biological control. Significant reductions or complete control have already been realized on closely related pests in other parts of

the world.

Initial steps have been taken to begin programs for biological control of the head girdler and selected stemborers on millet. Samples of millet were collected in Niger to determine what parasites attack millet infesting stemborers. All collected borer stages were sent to the quarantine facility at Texas A&M University to protect against accidental introduction of a West African stemborer into the U.S. The sampled millet was heavily infested with stemborers, and the stemborers were in turn heavily parasitized by a complex of parasites. A publication is being developed to report the findings of the stemborer studies. A collaborative research program is being developed to study biological control of the millet head girdler in West Africa. The study has been started in Niger.

How Best to Store Sorghum

Although the major emphasis of the sorghum/millet research program has been to increase production, it is unique in having a storage component. One area of investigation has been traditional methods of millet and sorghum storage, handling, and preservation.

In most developing countries, millet and sorghum grains often are stored attached to a part of the plant, or "in-head", for at least part of the storage period. Laboratory studies show that in-head storage of millet (when compared with threshed millet) reduces damage by weevils.

Millet is traditionally threshed by hand or by "pounding" in wooden mortars. Damage caused by insects which develop inside grain kernels is not affected by the threshing method; however, the damage to seeds caused by both mechanical laboratory and field threshers resulted in greater total insect damage. More species of insects were able to develop in the grain because of the threshing damage.

Many types of "facilities" are used to store millet and sorghum in the developing countries. These range from stacking the grain in-head in the open or in ventilated basket-type units to the storage of threshed grain in sacks or in underground pits. In laboratory trials to compare ventilated and unventilated storage, weevils produced more damage in unventilated storage but *Angoumois* grain moths were favored by ventilated storage.

Although some of the damaging stored-product insects are not able to move freely through threshed millet stored in bulk, localized populations of weevils can damage grain and produce conditions that result in deterioration by mold.

Research indicates that some of the traditional methods of farm storage, handling, and preservation are effective under the conditions where they usually are used. As production levels increase, there probably will be a need to increase on-farm storage capacity.

HEAT AND DROUGHT RESISTANCE

INTSORMIL researchers are using controlled water supply under extreme environmental conditions to screen sorghum and millet breeding materials for resistance to heat and drought. Studies of canopy temperatures, the presence of "bloom" and leaf width may speed up selection of drought-resistant sorghum types.

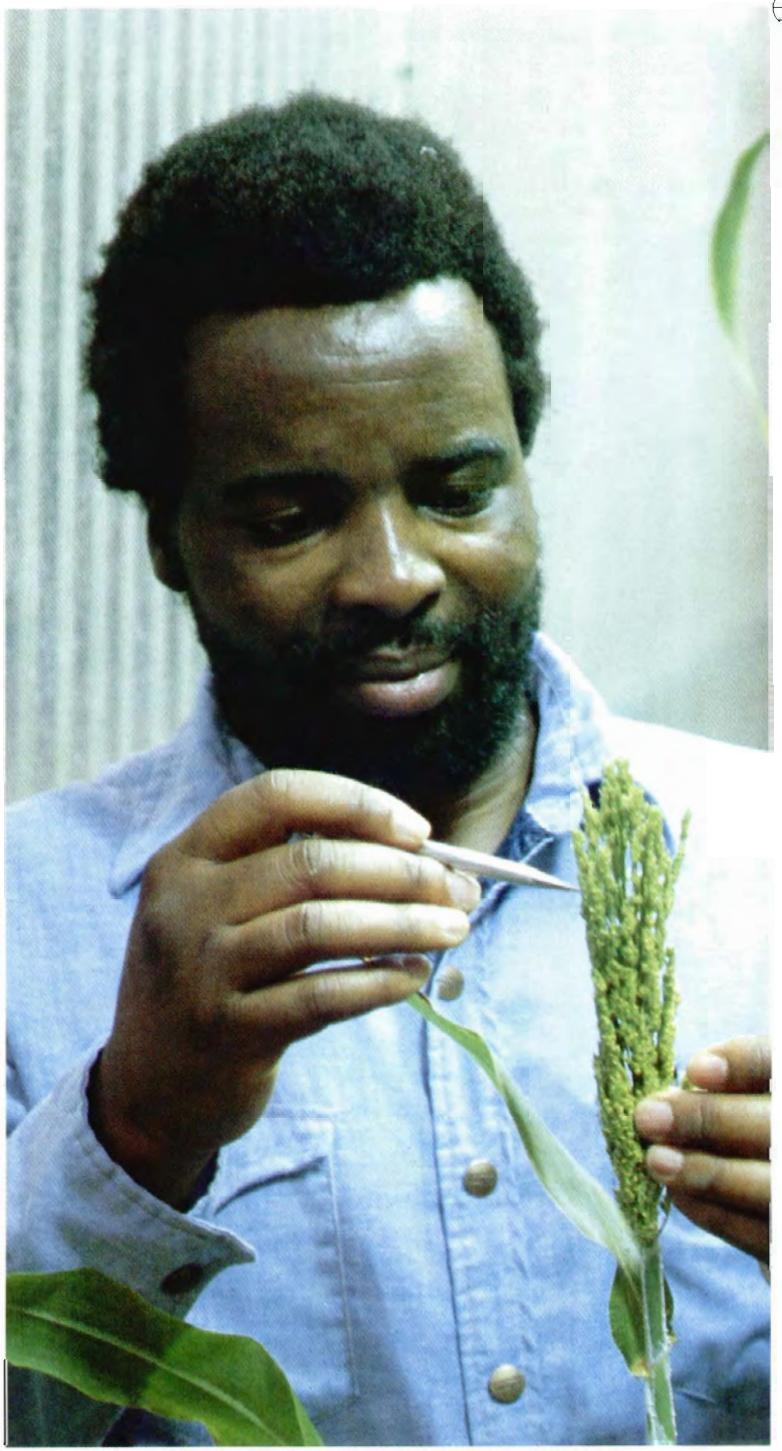
Screening Sorghum and Millet for Resistance

In many regions of the arid and semiarid tropics, drought is the most important environmental stress limiting production of sorghum and millet. Identification and development of plant genotypes with differences in their ability to withstand drought is important in crop improvement programs. By using a sprinkler irrigation gradient system in Yuma, Arizona, where temperatures average over 40° C and there is virtually no rainfall during the growing season, University of Arizona scientists have identified genotypes tolerant to both heat and drought.

Seed samples submitted by cooperators are planted perpendicular to the irrigation pipe. By controlling water application, a gradient in soil water exists outward from the irrigation pipe. Water delivery rates can be manipulated to simulate the rainfall occurring in many arid and semiarid agricultural areas. Physiological and agronomic data collected during the growing season help identify characteristics that are related to drought tolerance. A simple measure of grain production with the lowest amount of water use is used to compare various genotypes with each other. Data on performance of these entries are made available to both U.S. researchers and collaborators in less developed countries for local sorghum and millet improvement programs.

Two sorghum populations and 20 to 30 lines with tolerance to heat and drought have been developed under Arizona environmental conditions. In the dry, hot weather of Arizona, which exceeds the optimums for normal sorghum growth and development, researchers have been successful in detecting genotypes with greater ability to produce heads under these stresses. Some experimental lines exceed the grain yields of some well known hybrids under drought stress, indicating that there is a potential for developing hybrids with heat and drought tolerance.

Research at the University of Nebraska shows that sorghum grain yield reductions from water and temperature stresses are caused mainly by reductions in the seed number component of



Heat and drought studies involve extensive laboratory research. Here, a host country scientist studies sorghum plants for drought resistance.

yield. Successful screening for stability in seed number requires pinpointing the time when seed number losses occur. Research has keyed on the development of sorghum as it relates to seed number.

Research shows that sorghum is surprisingly sensitive to seed number reductions when under modest temperature stress during the approximate 30-day panicle development period. The greatest sensitivity is two to three weeks after panicle initiation, or shortly

Laboratory research is extended to field trials in host countries.

after stamens and pistils are initiated. Most yield differences result from different reactions to stress during that period. Based on this information, an attempt was started in 1981 to develop a field screening technique for drought resistance to seed number reduction and yield loss. Irrigation is withheld between panicle initiation and bloom to learn which genotypes are stable in seed number. Preliminary results show wide differences between genotypes in seed number stability. Further breeding work will be carried out to transfer this character to agronomically useful material.

Physiological Basis for Drought Resistance

Water availability and temperature are closely correlated. Usually, high temperature coincides with drought.

Plants respond positively to soil water availability; however, their response will differ from year to year, location to location, soil type to soil type, and with differing management practices. INTSORMIL scientists working with scientists from African host countries are examining a physiological basis for drought resistance, hoping to characterize genotypes and a management system that will permit stable production in a stressful environment.

Joint U.S.-host country research has examined the use of canopy temperatures for selecting drought resistant genotypes. Researchers have found that genotypes with warm canopy temperatures under well-watered conditions conserve their water and are drought resistant in a stressful environment. Genotypes that have cool canopy temperatures are transpiring and photosynthesizing. These genotypes may be high producers but are high water users. In a dry environment, such as in the Sahel of Africa, they will run out of water and in a severe drought may not yield at all.

Canopy temperatures can be measured rapidly with an infrared thermometer. Thus, this technique offers a potential for screening large numbers of genotypes. The canopy temperature characteristic can be selected and developed with disease and insect resistant characteristics to provide a stable, moderately yielding genotype.

Field evaluation tests of bloom and bloomless sorghum lines under heat and drought have indicated that "bloom" on the sorghum plant contributes to moisture conservation during growth and production. Narrow sorghum leaves also were found to be correlated with higher grain production under moisture stress environments.

INTSORMIL researchers are focusing on several physiological characteristics of the sorghum plant, in attempts to short-cut the process of selecting types with stable, yet fairly high yields of food quality sorghum under stress.

UNDERSTANDING SORGHUM FOOD QUALITY

Laboratory studies are helping to determine differences in preference for various sorghum types when used for different food products. Other research on the basic chemistry and genetic control of tannins may lead to eliminating the "bad" effects of tannins, while keeping the "good."

Identification of "High Quality" Is Difficult

Sorghum ranks along with wheat, rice, and maize as a major cereal food crop in the developing world. The uses of sorghum, as opposed to rice and wheat, are so diverse that no single criterion of quality can be identified. Little is known about the physical and chemical properties that affect the processing and food-making quality of sorghum grain. These factors have hindered the progress of plant breeders in selecting improved sorghum types with acceptable food grain quality.

The influence of certain physical characteristics of the grain, such as hardness, on the quality of traditional sorghum food products has been demonstrated by INTSORMIL researchers and others. Sorghum grain with a high proportion of horny endosperm produces the best quality in porridge-type foods. On the other hand, sorghum with greater amounts of floury endosperm is better suited for fermented breads, popular in East Africa. A simple flotation technique has been developed by INTSORMIL scientists for rapidly measuring grain hardness. This technique provides a useful tool for screening large numbers of sorghum lines for food quality.

Collaborative research has shown that starch components from the horny and floury endosperm of sorghum have an apparent difference in molecular weight. These differences were found to influence the stiffness of alkali porridge foods such as tô (a West African staple sorghum food). In contrast, this may not be important for types of tô stiffened with acid products. Work is continuing in an effort to understand the functional properties of other sorghum grain components as they relate to quality in other traditional food systems.

Tannins: Both Bad News and Good News

Tannins have long been known as naturally occurring materials useful in making leather. Tannins and chemically related materials known as polyphenols are present in certain sorghums which are

Honduran woman prepares sorghum for the family.

resistant to damage by birds. Sorghum tannins are also associated with resistance to preharvest germination and to fungal pathogens.

Thus, high tannin content has likely been developed in many sorghums by natural selection. Unfortunately, the agronomic benefits are offset by diminished nutritional value. High tannin sorghums are less digestible and contribute to other nutritional problems. They also tend to develop undesirable colors during processing.

INTSORMIL researchers are purifying and identifying the many chemically complex polyphenols of sorghum, and are devising simple and specific assays for them. Some of these materials have biological activities not previously associated with sorghum, such as antibiotic activity, inhibition of spore germination of fungal pathogens, and dietary induction of specific tannin-binding salivary protein secretions in the rat, mouse and (presumably) human. Salivary tannin-binding proteins appear to be a defense mechanism against dietary tannins.

Workshops on food quality and other aspects of sorghum and millet improvement provide a network to disseminate scientific information. Workshop instruction is given jointly by U.S. and host country scientists.

Chemical and mechanical techniques for detoxifying or removing tannin from sorghum grain have been developed, but a less highly technical solution is being sought. INTSORMIL researchers have recently found that the polyphenol components which are responsible for the antinutritional effects are different from those which provide the agronomic benefits. Thus, it is feasible to seek a genetic solution, in which the undesirable components will be eliminated and the useful components augmented.

Development of new lines containing only the desirable polyphenols is being tried by advanced tissue culture techniques. The enzymes responsible for synthesizing sorghum polyphenols are being sought in sorghum cells. Ultimately, the gene coding for these enzymes probably can be isolated and manipulated to efficiently produce "bioengineered" sorghums with specifically tailored polyphenol components. Thus, the "bad" character of tannins can be removed while retaining the "good" effects.

SOME SPECIAL INTSORMIL GOALS

Training

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in overseas development work.

The most frequently used training system is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project, or being very closely related to it.

During the five years covered by this report, 399 students (181 U.S. and 218 international) were advised by INTSORMIL principal investigators. Students supported by INTSORMIL funds totaled 199 (103 U.S. and 96 international). The international students came from 27 different countries.

Beginning this year, INTSORMIL is cooperating with ICRISAT on a special training program aimed at the Southern Africa Development Coordinating Conference countries. This program is funded principally by USAID regional funds.

Building Improved Research Systems

INTSORMIL scientists are helping less developed countries improve their research institutions.

Two studies have been conducted. One looked at the international communications system surrounding grain sorghum research. INTSORMIL sociologists identified communication bottlenecks, including a gap between scientists used to working with sorghum as

a feed, and those concerned with food. Scientists who shift from feed to food production must be made aware of the importance of food quality characteristics for successful adoption.

Problems identified in a study of the Sudan Agricultural Research Corporation included the need for improved communication among scientists and with client groups, inadequate diffusion methods and inadequate financial support. Detailed recommendations were offered.

Technical Assistance on Call

The grant authorization establishing INTSORMIL provides for limited "technical assistance." As defined by AID, this means consultant service to a host country or USAID field mission is given on request by a USAID mission. Usually, these are requests to study general or special sorghum/millet research situations and make planning recommendations to the USAID mission and the host country government.

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