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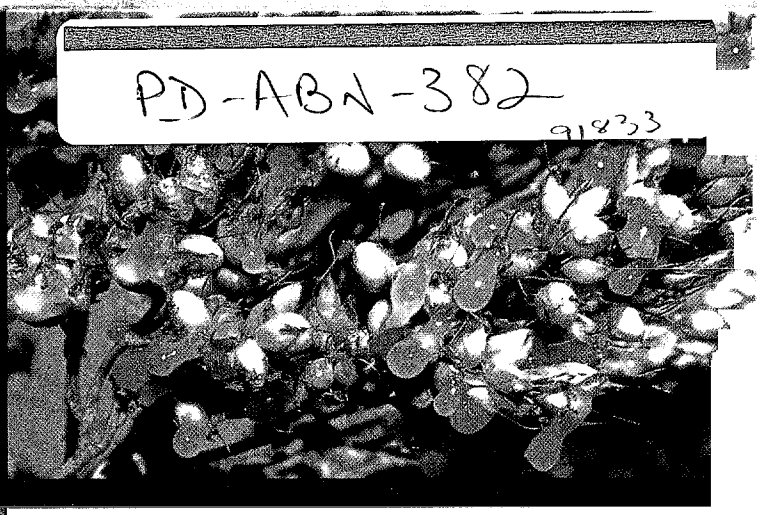

Annual Report 1996

SORGHUM/MILLET COLLABORATIVE RESEARCH SUPPORT PROGRAM (CRSP)

Fighting Hunger with Research ... a team effort

Funding support through the Agency for International Development

Grant No: DAN 1254-G-00-0021-00

Cover Photographs
(top to bottom)

1. Ergot on sorghum at the Good Hope Station in Southern Botswana.

2. Plant Pathologist Esther Mtisi (right) with RSS in Zimbabwe and Agricultural Assistant Kevin Garutsa in a sorghum disease nursery at the Panmure Station north of Harare.

3. Left to right, all with DAR, Botswana, Plant Pathologist Phoebe Ditsipi, Entomology Assistant Motsweri Obipile, and Entomologist Chris Manthe in a late-planted seed increase plot of Phofu sorghum at the Sebele Station near Gaborone.

4. Dr. Yacouba Doumbia, IER Entomologist on left with three field technicians in a sorghum head bug nursery, Sotuba Research Station, Bamako, Mali.

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INTSORMIL

1996 Annual Report

Fighting Hunger with Research . . . A Team Effort

Grain Sorghum/Pearl Millet Collaborative Research Support Program (CRSP)

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The Sorghum/Millet Collaborative Research Support Program (CRSP) is an initiative of the Agency for International Development, Grant No. DAN-1254-G-00-0021-00, Title XII and the Board for International Food and Agricultural Development (BIFAD), the participating U.S. Universities and other collaborating institutions.

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INTSORMIL Publication 96-3

Report Coordinators
John M. Yohe, Program Director

Joan Frederick and Dorothy Stoner

A

For additional information contact the INTSORMIL Management Entity at:

INTSORMIL
113 Biochemistry Hall
University of Nebraska
Lincoln, Nebraska 68583-0748

Telephone (402) 472-6032 ***** Fax No. (402) 472-7978**
Internet: SRML002@UNLVM.UNL.EDU

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INTSORMIL INSTITUTIONS

Kansas State University
Mississippi State University
University of Nebraska
Purdue University
Texas A&M University

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INTSORMIL Management Entity

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Dr. Daniel T. Walters, Acting Associate Program Director
Ms. Joan Frederick, Administrative Technician
Ms. Dorothy Stoner, Illustrator
Ms. Marilyn McDonald, Staff Secretary

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Dr. Darrell Rosenow, Texas A&M University
Dr. George Teetes, Texas A&M University
Dr. Aboubacar Touré, IER, Mali

C

Contents

Introduction and Program Overview vii

1995 Project Reports 3

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet - L.E. Claflin (KSU-108A) 3

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet - J.F. Leslie (KSU-108B) 9

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum - Henry N. Pitre (MSU-105) 17

Role of Polyphenols in Sustainable Production and Utilization of Sorghum and Millet - Larry G. Butler (PRF-104B and PRF-104C) 22

Disease Control Strategies for Sustainable Agricultural Systems - R.A. Frederiksen (TAM-124) 25

Pest Management Strategies for Sustainable Sorghum Production - George L. Teetes (TAM-125) 33

Biological Control Tactics for Sustainable Production of Sorghum and Millet - Frank E. Gilstrap (TAM-125B) 40

Development of Plant Disease Protection Systems for Millet and Sorghum in Semiarid Southern Africa - G.N. Odvody (TAM-128) 45

Sustainable Production Systems

Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries - John H. Sanders (PRF-105) 51

Cropping Systems to Optimize Yield, Water and Nutrient Use Efficiency of Pearl Millet - Stephen C. Mason (UNL-113B) 55

Nutrient Use Efficiency in Sorghum and Pearl Millet - Jerry W. Maranville (UNL-114) 59

Germplasm Enhancement and Conservation

Breeding Sorghum for Increased Nutritional Value - John D. Axtell (PRF-103A) 67

Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, *Striga*, and Grain Mold - Gebisa Ejeta (PRF-107 and PRF-107B) 76

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity -Darrell T. Rosenow (TAM-122) 82

Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems - Gary C. Peterson (TAM-123) 89

Breeding Pearl Millet for Stability of Performance Using Tropical Germplasm - David J. Andrews (UNL-118) 98

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet - Bruce R. Hamaker (PRF-112) 105

Food and Nutritional Quality of Sorghum and Millet - L.W. Rooney (TAM-126) 110

Host Country Program Enhancement

INTSORMIL Collaborative Sites 122

Honduras and Central America -Francisco Gómez 123

Mali - Darrell Rosenow 132

Niger - John D. Axtell and Ouendeba Botorou 138

Southern Africa (Botswana, Namibia, Zambia and Zimbabwe) - David J. Andrews 144

Horn of Africa - Gebisa Ejeta 147

Training

Introduction 157

Year 16 INTSORMIL Training Participants 159

Appendices

INTSORMIL Buy-Ins 163

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1996 166

Acronyms 167

Introduction and Program Overview

The Collaborative Research Support Program (CRSP) concept was created by the U.S. Agency for International Development (USAID) and the Board for International Food and Agriculture Development (BIFAD), under the auspices of Title XII of the Foreign Assistance Act, as a long term mechanism for mobilizing the U.S. Land Grant Universities in the international food and agricultural research mandate of the U.S. Government. The CRSPs are communities of U.S. Land Grant Universities working with USAID and USAID Missions, other U.S. Federal Agencies, developing country National Agricultural Research Systems (NARS), developing Country Colleges and Universities, International Agricultural Research Centers (IARCs), private agencies, industry, and private voluntary organizations (PVOs). The Sorghum and Millet Collaborative Research Support Program (CRSP) is one of eight CRSPs currently in operation.

The Sorghum and Millet Collaborative Research Support Program (i.e., INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. University scientists and scientists of the National Agricultural Research Systems (i.e., NARS). INTSORMIL is programmatically organized for efficient and effective operation and captures most of the sorghum and millet research expertise in the United States. ***The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production and utilization for the mutual benefit of U.S. and LDC agriculture.*** Collaborating NARS and U.S. scientists jointly plan and execute research that mutually benefits developing countries and the United States. Prime sites will be maintained in the agroecological zones of western, southern, and eastern Africa, and in Central America. These sites support the general goals of building NARS institutional capabilities, creating human and technological capital for solving sorghum and millet constraints with sustainable global impact, promoting economic growth, enhancing food security, and encouraging entrepreneurial activities. The universities which are active in the INTSORMIL CRSP are Kansas State University, Mississippi State University, University of Nebraska, Purdue University, and Texas A&M University.

Sorghum and millet are important food crops in moisture stressed regions of the world. They are staple crops for millions in Africa and Asia which, in their area of adaptation, cannot be substituted by other cereals. The development of food sorghums and sorghums with improved feeding properties such as increased digestion and reduced tannin content has contributed to sorghum becoming a major feed grain in the U.S., and in other countries in South America. Pearl millet is becoming an important feed source in poultry feeds in the southeastern U.S. The new food sorghums produce grain that can be used for special ethnic and dietary products as well as for traditional food products. Special white sorghums in Mali have the potential for allowing farmers wives to process sorghum into high value food products for sale in village and urban markets which can compete with wheat and rice products. The traditional types of sorghums cannot make effective food products that can compete with wheat and rice products. Pearl millet also has great potential for processing into high value food products which can be sold in village and urban markets that can compete with wheat and rice products. These developments have occurred because of the significant interaction that INTSORMIL scientists, U.S. and Host Country, have from grain production through processing and marketing.

Although significant advances have been made in improvement and production of sorghum and millet in the regions which INTSORMIL services, population continues to exceed production capacity. There remains an urgent need to continue the momentum of our successes in crop improvement as well as our efforts in strengthening the NARS.

INTSORMIL has maintained a flexible approach to accomplishing its mission. In preparation for the 1996-2001 grant extension proposal, INTSORMIL has implemented several critical recommendations made by the External Evaluation Panel and an Internal/External Committee, with input from the INTSORMIL Technical Committee (TC) and Ecogeographic Zone Council (EZC).

The success of the INTSORMIL program can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities.

- **Developing institutional and human capital**: INTSORMIL will promote educational outcomes in collaborating host countries. The outcomes include institutional strengthening, development of collaborative research networks, promoting and linking to technology transfer and dissemination infrastructure development, and enhancing national, regional, and global communication linkages. ***A major innovative aspect of the INTSORMIL focus is to maintain continuing relationships with collaborating host country scientists upon return to their research posts in their countries. They become members of research teams of INTSORMIL and NARS scientists who conduct research on applications of existing technology and development of new technology. This integrated relationship prepares them for leadership roles in regional networks in which they collaborate.***

- **Conserving biodiversity and natural resources**: Research outcomes of the collaborative research teams include development and release of enhanced germplasm; development and improvement of sustainable production systems; development of sustainable technologies to conserve biodiversity and natural resources and to enhance society's quality of life, and enlarge the range of agricultural and environmental choices. Thus, INTSORMIL promotes conserving millet and sorghum germplasm, conserving natural control of sorghum and millet arthropod pests and diseases, developing resource-efficient cropping systems, developing integrated pest management programs, developing cultivars with improved nutrient and water use efficiencies, and evaluating impacts of sorghum/millet technologies on natural resources and biodiversity.

- **Developing research systems**: Collaboration in prime sites have been strengthened by using U.S. and NARS multi-disciplinary research teams focused on common objectives and unified plans. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and millets. The output from these disciplinary areas of research are linked to immediate results. Biotechnology and other tools of science integrated with traditional science will contribute to alleviating production and utilization constraints in sorghum and pearl millet within the medium term of 5-10 years. New technologies are then extended to farmers' fields in developing countries and the United States through further collaborative efforts. In addition, INTSORMIL plays a part in initiating consideration of economic policy and processing constraints to regaining the competitiveness of sorghum and millet as a basic food staple.

- **Supporting information networking**: INTSORMIL research emphasizes working with existing sorghum and millet networks to promote effective technology transfer from prime sites to local and regional institutions. Technology transfer is strengthened by continued links with regional networks, International Agricultural Research Centers, and similar local and regional institutions. Emphasis is placed on strong linkages with extension services, agricultural production schemes, private and public seed programs, agricultural products supply businesses, and nonprofit voluntary organizations, such as NGOs and PVOs, for efficient transfer of INTSORMIL generated technologies. Each linkage is vital to development, transfer, and adoption of new production and utilization technologies.

- **Promoting demand driven processes**: Development of economic analysis for prioritization of research and farm-level industry evaluation and development of sustainable food technology, processing and marketing systems, are all driven by the need for stable markets for the LDC farmer. INTSORMIL seeks alternate food uses and new processing technologies to save labor and time required in preparation of sorghum millet for food. Research products transferred to the farm will seek to spur rural economic growth and provide direct economic benefits to consumers. INTSORMIL assesses consumption shifts and socioeconomic policies for reducing effects of price collapses, and addresses methods for reducing processing for sorghum and millet. Research outcomes seek to reduce effects of price collapse in high yield years, and to create new income opportunities. INTSORMIL socioeconomic projects measure impact and diffusion and evaluate constraints to rapid distribution and adoption of introduced new technologies.

The INTSORMIL program addresses the continuing need for agricultural production technology development for the developing world, especially the semiarid tropics. There is international recognition by the world donor community that the developing country agricultural research systems must assume ownership of their development problems and move toward achieving resolution of them. The program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits back to the U.S. agricultural sector and presents a win win situation for international agricultural development.

Administration and Management

The University of Nebraska (UNL) is the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID. UNL subgrants are made to the participating U.S. Universities for the research projects between individual U.S. scientists and their host country counterparts. Country project funds, managed by the ME and U.S. participating institutions, flow to the country program in support of the research activities at the host country level. The Board of Directors (BOD) of the CRSP serves as the top management/policy body for the CRSP. The Technical Committee (TC), External Evaluation Panel (EEP) and USAID personnel advise and guide the ME and the Board in areas of policy, technical aspects, collaborating host country coordination, budget management, and review.

Several major decisions and accomplishments were made by the ME, BOD, and TC during the past year.

- The INTSORMIL Five Year Grant Extension Proposal was completed and submitted to USAID.

- INTSORMIL made its presentation for a new five year grant and was recommended for continuation, March 1996.

- The major publications organized and published by the ME office during the year included:

* INTSORMIL Annual Report 1995, INTSORMIL Publication No. 95-1

* INTSORMIL Annual Report 1995, Executive Summary, INTSORMIL Publication No. 95-2.

* INTSORMIL CRSP Directory, INTSORMIL Publication No. 95-3

* INTSORMIL Grant Extension Proposal, 1996-2001, INTSORMIL Publication No. 95-4

* INTSORMIL CRSP Directory update, INTSORMIL Publication No. 95.5

* Sanders, J., Shapiro, B.I., and Ramaswamy, S. 1996. The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa. The Johns Hopkins University Press. 301 pp.

- The INTSORMIL Board of Directors appointed Dr. Oumar Niangado, Director General, IER, Mali to a two year term to the INTSORMIL Board of Directors.

- The Board of Directors approved the temporary appointment of a UNL faculty member, Dr. Dan Walters, at one quarter time to, fill the position of Associate Director.

- The 1995-96 Technical Committee (TC) was elected. The TC members are: Dr. Stephen Mason, University of Nebraska, Dr. George Teetes, Texas A&M University, Dr. Lloyd Rooney, Texas A&M University, Dr. Darrell Rosenow, Texas A&M University, Dr. John Axtell, Purdue University, Dr. Gebisa Ejeta, Purdue University, Dr. Aboubacar Touré, IER/Mali and Dr. Franciso Gomez, EAP/Honduras.

- The announcement for the "International Conference on Genetic Improvement of Sorghum and Pearl Millet", in Lubbock, TX, September 23-27, 1996 was distributed world wide. ICRISAT, INTSORMIL, Rockefeller Foundation and the ODA/Great Britain are cosponsors for this event.

- The USAID/Africa Bureau entered into an agreement with the IPM CRSP and the CRSP Council for implementation of an Inter-CRSP Natural Resource Management regional project for West Africa. The IPM CRSP was designated the lead CRSP for development of this effort. The starting date for this initiative was September, 1995.

- INTSORMIL has entered into an Memorandum of Agreement with the Institute of Agricultural Research (IAR) of Ethiopia.

Training

Training of host country scientists contributes to the capability of each host country research program to stay abreast of environmental and ecological changes which alter the balance of sustainable production systems. The strengthening of host country research institutions contributes to their capability to predict and be prepared to combat environmental and ecological changes which affect production and utilization of sorghum and millet. A well balanced institution will have to be prepared to prioritize and blend its operational efforts to accomplish the task of conserving and efficiently utilizing its natural resources. To this end training is an extremely critical component of development assistance.

During 1995-96, there were 57 students from 18 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. This was a decrease of 24% from the previous year. Approximately 77% of these students came from countries other than the U.S., which illustrates the emphasis placed on host country institutional development. INTSORMIL also places importance on training women which is reflected in the fact that 23% of all INTSORMIL graduate students were women.

The number of students receiving 100% funding by INTSORMIL in 1994-95 totaled 21. An additional 16 students received partial funding from INTSORMIL. The remaining 20 students were funded from other sources but are working on INTSORMIL projects. The number of students receiving 100% funding from INTSORMIL has dropped from a high of 71 in 1986 down to a low of 17 in 1993-94 and then 21 in 1995-96. This is, in part, due to training taking place under other funding sources, but an even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished due to reductions in our overall program budget and because of inflationary pressures.

In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Several host country scientists were provided the opportunity to upgrade their skills in this fashion during 1995-96.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as research newsletters, publications, the exchange of scientists, and the exchange of germplasm. The INTSORMIL Global Plan is designed for research coordination and networking within ecogeographic zones and where relevant between zones. The Global Plan:

- Promotes networking with IARCs, NGO/PVOs, Regional networks (ROCAFREMI, SADC and others)

private industry and government extension programs to coordinate research and technology transfer efforts.

- Supports participation in regional research networks to promote professional activities of NARS scientists, to facilitate regional research activities (such as multi-location testing of breeding materials), promote germplasm and information exchange, and facilitate impact evaluation of new technologies.

- Develops regional research network, short-term and degree training plans for sorghum and pearl millet scientists.

Over the years, established networking activities have been maintained with ICRISAT, SADC/ICRISAT, SAFGRAD, ICRISAT Sahelian Center, ICRISAT West Africa Sorghum Improvement Program, ROCAFREMI, EARSAM of ICRISAT, ICRISAT/Mexico, CIAT and CLAIS of Central and South America. There has been excellent collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long term training. INTSORMIL currently cooperates with the ICRISAT programs in East, Southern, and West Africa, and the ROCAFREMI (Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger) of West/Central Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL plans to strengthen linkages among the NARS it works with, as well as international and regional organizations and networks. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Benefits to Host Countries

Realized Benefits of Program

INTSORMIL can document a wide range of benefits to host countries, U.S. agriculture, and the broader scientific community. Many of these benefits have reached fruition with improved programs, economic benefits to producers and consumers, and maintenance or improvement of the environment. Others are at intermediate stages ("in the pipeline") that do not allow quantitative measurement of the benefits at present, but do merit identification of potential benefits in the future. The collaborative nature of INTSORMIL programs has built positive long-term relationships between scientists, citizens and governments of host countries and the United States. This has enhanced university educational programs and promoted understanding of different cultures enriching the lives of those involved, and hopefully making a small contribution to world peace, in addition to sustainably improving sorghum and pearl millet production in developing countries and in the United States.

International

Scientific by Technical Thrust

Germplasm Enhancement and Conservation

Germplasm exchange, movement of seeds in both directions between the U.S. and host countries, has involved populations, cultivars, and breeding lines carrying resistances to insects, diseases, *Striga,* drought, and soil acidity, as well as elite materials with high yield potential which can be used as cultivars per se or used as parents in breeding programs. Specific germplasm releases (including breeding lines) for host country use include the following.

- Improved yield (for all host countries)

- Improved drought tolerance (Africa and drier areas of Latin America)

- Acid soil tolerance

- *Striga* resistance (West, Eastern Africa, and Southern Africa)

- Midge and Greenbug resistance (Latin America)

- Downy mildew resistance (Latin America and Botswana)

- Anthracnose resistance (Latin America and Mali)

- Charcoal rot and lodging resistance (Africa and drier areas of Latin America)

- Head smut and virus resistance (Latin America)

- Foliar disease resistance (for all host countries)

- Improved grain quality characteristics for food and industrial uses (for all host countries)

The hybrid sorghum success story in Sudan traces to ICRISAT/INTSORMIL/ARC collaboration in which they developed, produced seed, and popularized the first hybrid sorghum, Hageen Dura-1 (Tx623 x K1567), for this country. The female line Tx623 was used due to its wide adaptation, high yield potential and drought resistance. It currently is produced on about 12% of the sorghum area in the Sudan Gezira Irrigation Scheme, the largest in the world under one management. The Hageen Dura-1 success story provides an example of the potential economic gains possible through plant breeding research, followed by seed production/marketing activities. Impact studies show that the internal rates of return to this research without further extension of the production area in Hageen Dura-1 were 23% for low fertilizer levels, and 31% for high fertilizer use levels. With the present rate of diffusion, the investment on this research would pay approximately $1 million of annual benefits. The

line Tx622 (a sister line to AT623 in Hageen Dura) has been introduced to China, and is used in hybrids planted on tens of thousands of hectares.

In Honduras, three food-type high yielding sorghum maicillo cultivars have been tested and released. These are Tortillero (CS3541 Sel.), Catracho (Tx623 x Tortillero), and Sureño [(SC423 x CS3541)E35-1]-2-2. Sureño, in particular, has widespread acceptance by Honduran farmers because of its superior grain quality, high yield potential, disease resistance, and dual purpose use for both forage and grain. It is the first sorghum cultivar released by the MNR that has found its way into informal seed markets in Honduras. INTSORMIL's socioeconomic research has also shown that in Honduras the internal rate of return to the development of two new sorghum cultivars, Sureño and Catracho, which are in diffusion, is estimated at 32% or, on annuity basis, $0.7 million annually for the next 30 years. These new sorghum cultivars have economically benefited small farmers dependent on small-acreage hillside farms, the poorest farmer segment in Honduras. Seed production continues to be a problem, however, this is expected to be resolved through the assistance of the new seed processing plant at Escuela Agricola Panamericana (EAP). This linkage will assure production of good quality, certified seed.

The INTSORMIL/Honduras sorghum project has been cooperating with the "Poligono Industrial Copaneco", a religious NGO funded by the Belgium and Canadian governments. The sorghum project has been providing technical advice on agronomic management and marketing of broom corn fibers. The NGO project is producing broom corn fiber and selling it to "Broom and Mops", a broom export factory located at San Pedro Sula in Honduras. Traditionally broomcorn fiber is either imported from Mexico by two or three companies in Central America or produced by small farmers using seed removed from the imported fiber. The result is an increase in costs due to imported fibers and poor fiber quality produced by the small farmers. INTSORMIL/Honduras has developed a new long fiber variety of "broom corn" sorghum which will compete more successfully with imported fibers from Mexico. Seed increase of this new variety was made in 1995. In January, 1996 another field was planted to produce approximately 200 kg of basic seed which will be used to produce certified seed for use by the broom corn producers. Cost benefit analyses indicate this to be a profitable business for small producers to participate in.

Honduras plays a unique role in conservation of local landrace sorghum germplasm (maicillo or photoperiod sensitive sorghum). Central America is the only location in the world where sorghum has evolved to fit the cropping systems of the steepland hillsides. The INTSORMIL/Honduras sorghum project has assumed the responsibility for conserving this sorghum gene pool. The goal of the conservation effort is to create a mosaic of maicillo, enhanced maicillo, and improved variety fields in which genes flow freely among these different kinds of sorghum. Ostensibly, an informal network of village level landrace custodians will care for this germplasm as they have cared for maicillo. The creation of enhanced maicillo cultivars and their subsequent deployment on-farm, not only is intended to increase genetic diversity *in-situ*, but to stave off maicillo's replacement by introduced cultivars. Two new improved varieties, Gigante Mejorado and Porvenir Mejorado have shown outstanding performance across five testing locations in Honduras. Other new enhanced cultivars are being tested on farmer's fields through the on-farm demonstration system in 1966.

In Central America sorghum utilization patterns are shifting as the demand for poultry rapidly increases (8.4% annually in Honduras). For the time period of 1990-1993 sorghum production in Central America grew 18 percent, at a rate of 4.42% per year. Seventy six percent of the sorghum was utilized for animal consumption and 17% for human consumption in Honduras in 1994. For human consumption 6% was for on-farm use and the other 11% was sold. With the rapid expansion of poultry feeding, sorghum has been fillling much of the increased demand for feed grains. Of the cereal component in Honduran commercial feeds, sorghum increased its share from 4% in 1985 to 26% in 1993. All over Central America there has been a rapid growth of hybrid sorghum seed sales for use in production of sorghum grain for feed. It is estimated that 35% of the sorghum area was planted to hybrids in 1995. Sorghum is successfully replacing maize in animal feed and releasing an equivalent amount of white maize for human consumption.

The principal objective of an impact assessment activity completed in July, 1996 was to measure the impact of the new cultivars and associated technologies developed in the SRN/EAP/INTSORMIL program in Honduras. Secondly, the assessment team looked at the impacts and production systems in other principal sorghum producing countries in the region, El Salvador, and Nicaragua. The primary research output in all three countries was the selection of new higher yielding white seeded varieties of sorghum. Conclusions reached from this impact assessment of the Sorghum/Millet CRSP research in Central America indicate that benefits from the varietal research in the three countries ranged from $437,000 per year in Nicaragua, $600,000 in Honduras (low side estimate), to $1,900,000 per year in El Salvador. The two new cultivars introduced in El Salvador were introduced with more extension and public policy support for improved seed production and credit. Estimates include only the benefits accruing from the adoption of cultivars developed by the public research systems. Note that only the Honduras benefits can be totally credited to the SRN/EAP/INTSORMIL program. In Honduras improvements in the quality and availability of seed of varieties will continue to be critical for small-and medium-scale farmers.

A new drought tolerant sorghum hybrid designated NAD-1 (NAD-1 = Tx623 x MR732) has proven to be highly productive and well adapted in Niger. The grain quality is acceptable for local food preparations and the yields reported from 100 on-farm demonstration plots in 1992 were approximately twice the yields of local varieties. Overall,

the average yield of NAD-1 between 1986 and 1994 is 2758 kg/ha on-station, ten times the average yield of the farmer in Niger (273 kg/ha). In 1993 the farm level plots showed the average farmer yield for the Konni and Jirataoua region was 2365 kg/ha for NAD-1. In 1994, NAD-1 yielded an estimated 1725 kg/ha (Say), 3500 kg/ha (Jirataoua), 3800 kg/ha (Cerasa), and 4600 kg/ha (Konni) for an overall farmer yield of more than 3000 kg/ha. This is compared to the national average of 273 kg/ha. In 1995 farmer demonstration trials were conducted in an area extending from Konni to Zinder eastward and as far north as Dakora. The 1995 trials compared the NAD-1 hybrid yields to one of the best local landraces, Mota Maradi (MM). The objectives were to check the extent of NAD-1 superiority over locals under as diverse conditions as possible with farmer management, and assess its area of best performance. A preliminary yield analysis showed that, overall, NAD-1 yielded an average of 1.6 t/ha compared to 1.1 t/ha for MM. This is about 50% better yield for the hybrid. This is especially important because 1995 was not a good year. Farmer interest has been very high. Head size and grain yield have been impressive. This is the first sorghum hybrid that has actually reached farmer fields. In early 1996 a seed program consultancy sponsored by INTSORMIL was put into place. The draft report indicates that the Hybrid NAD-1 and the country of Niger fulfill three basic requirements for the establishment of a seed industry, i.e, (1) it is important that a cultivar be identified that has significant yield, good grain quality and is not more susceptible to pest than local varieties; (2) the area in the country should be large enough to support a seed industry and this exists in Niger (area sown to sorghum is in excess of one million hectares); and (3) the cultivar involved should be a hybrid to permit the establishment of a suitable market and the hybrid should be readily produceable. Results of Regional Trials indicate a wide adaptation of NAD-1 in other countries of the region indicating the opportunity for an international market. The experience of developing a private seed industry in Niger would be immediately valuable to other countries of the region with the production and marketing of hybrid seeds as they realize superior hybrids from their research.

Through the integrated cooperation of sorghum breeders and food scientists we now understand many of the factors necessary for improving the nutritional value of sorghum through local village processing. Sorghum flour is less digestible than most cereal flours unless it is processed using local village procedures which have evolved over hundreds of years. We now understand the scientific reasons why processing is important. This knowledge will help modify and improve the traditional processing methods and to develop improved processing methods for utilization in other countries in the world where sorghum is used as a feed for food grain. This annual report notes for the first time that a genetic solution may be possible for the digestibility problem. Dr. Bruce Hamaker, INTSORMIL scientist in the Food Science Department at Purdue University, has been collaborating on studies of new genetic lines of sorghum with protein digestibilities equivalent to maize. Studies are in progress to determine the inheritance of this important newly identified trait in sorghum.

A *Striga* resistant variety, SRN-39, has been identified as promising and released for production in Sudan. In one area alone about 1200 ha of SRN-39 was grown in 1992. SRN-39 and other possible sources of resistance to *Striga* are being used in breeding programs in Sudan, Mali, Niger and other countries to improve adaptation, yield potential and agronomic characteristics. They are being tested in integrated control programs with various cultural practices, fertilizer management, and different mechanical and chemical control strategies. Recently eight tons, one ton each of eight high yielding *Striga* resistant food grain sorghum varieties were released by Purdue University to the PVO, World Vision, for use in nine countries in Africa. During the first eleven months of operation these *Striga* resistant food quality sorghums have been tested on field stations or in farmers fields, or both, in the following countries: Ghana, Senegal, Mali, Niger, Sudan, Rwanda, Mozambique, and Eritrea. Information and data about the impact and potential impact of these varieties will be available by the end of calendar year 1996.

Excellent progress has been made in Mali to develop white-seeded, tan-plant guinea cultivars. F_6 progenies from crosses involving Bimbiri Soumale and CSM388 look very promising. Emphasis is also being placed on intercrosses using the experimental guinea-type white seeded tan-plant cultivar named N'Tenimissa (Bimbiri Soumale x 87CZ-Zerazera) with elite local guineas and with other high yielding non-guinea breeding lines which lack the necessary head bug tolerance. They have good guinea plant, grain, glume, and panicle characteristics, and some have juicy stems. Two new lines were selected in 1995 for on farm farm testing in the rainy season of 1996. Grain of N'Tenimissa will be increased on about five ha in 1996 for use in utilization and value-added product development. The PVO, World Vision, plans to distribute N'Tenimissa in 20 on farm trials in 1996. In Northern Mali, CARE is cooperating with IER and testing new sorghum cultivars at about 20 sites.

Sustainable Production Systems

In agronomy and soil/crop management, a major INTSORMIL impact has been understanding the soil/cropping system/genotype interactions. Rotation with cowpea in Mali increased pearl millet grain yield by 19,17,31,27,and 30% in 1991,1992,'993,1994, and 1995 respectively, while application of 40 kg/ha N fertilizer increased grain yield 8,20,16,35,and 6%. All cropping system plots had lower ph, N,K, and Mg levels than the fallow after four years, suggesting that all continuous, rotational, and intercrop systems studied were mining nutrients. Research in Mali has shown that small nitrogen (N) additions are beneficial and necessary to sustain sorghum grain yields. In 1994, the increase in pearl millet yield due to N application was 31% and 66% with 20 kg/ha N and 40 kg/ha N, respectively, in monoculture and 64% and 66% for 20 kg/ha N and 40 kg/ha N, respectively, in millet-cowpea rotation. Crop rotation (mil-

let-cowpea) alone without N increased millet grain yield by 74%. The legume effect appears worth 30 to 40 kg N/ha. This information has been compiled and is being used by extension personnel in their recommendations to farmers.

In both Mali and Niger, increasing the production level through use of manure and fertilizer, higher plant population resulted in increased grain yield of all pearl millet cultivars, suggesting that differential production practices are not required. However, in both locations, cultivar grain yield differences were large among cultivars, indicating the importance of cultivar selection.

INTSORMIL research results have demonstrated 18 to 203% yield enhancement of pearl millet and grain sorghum yields in Africa by use of crop rotation with legumes, and a 20 to 50 kg/ha N equivalent contribution to cereals following legumes. In Mali and Niger, intercropping has shown land use efficiency increases of 14 to 48% over sole crops, and also enhanced yields of succeeding crops when intercrop legume yields are high. Obviously legume production, no matter the system, is important to producing optimal sorghum and pearl millet yields when N fertilizer is limiting, especially for improved cultivars.

In Mali crop residue management research with residues removed, left on the surface, and incorporated had no effect on pearl millet or cowpea yield or stover yield. Similar results have been recently reported by the ROTOPHOS project, University of Hohenheim, Germany, on Nigerien sites that were not degraded and that had medium to higher soil P levels.

New research on production practices for improved pearl millet genotypes was initiated. Advanced, recently released, and improved local cultivars were produced at different fertilizer levels (manure and N) and plant populations. No cultivar by production practice interaction was found, suggesting that the cultivars respond similarly to these practices. The advanced cultivars "Benkadinio" and "Sanioba 03" yielded 100-300 kg/ha better than the other cultivars. Increasing the fertilizer rate to the highest level (15 t/ha manure plus 100 kg/ha N) increased grain yield from 1246 to 2475 kg/ha and stover yield from 3178 to 5067 kg/ha. Increasing plant population slightly decreased grain yield.

In Botswana, the benefits of single element fertilizer have been determined and demonstrated to farmers. Water harvesting technology has been evaluated and appropriate recommendations have been extended to farmers. Management practices on water runoff show if additional water could be diverted to a site, better yields resulted. Increased water availability must be coupled with the proper plant population, fertilizer level and pest control to produce high yields. In the event that excess water occurs, the system must be designed to release water without erosion. The National Tillage Trials showed early tillage frequently improved soil water storage. This coupled with 15 kg P ha^{-1} fertilizer increased yield. Due to low sorghum yield potentials, addition of phosphorus (P) was not economical where soil P was greater than 5 mg kg^{-1}. Nitrogen did not increase yields unless rainfall was uniformly distributed during the season, while manure/crop residue additions were effective in increasing water intake and grain yield.

Research in Mali and Botswana has shown that grain yields do not always increase with applied fertilizer N when conditions are extremely dry. However, in the higher rainfall regimes, yield increases are consistently obtained with N application. In Mali, the local varieties such as Tiemarifing have produced higher N use efficiencies than the improved types such as Malisor 84-7. There is a need for P in sandier soils, and this often is the mineral element most limiting in Mali and Niger sorghum and pearl millet production.

Stand establishment problems of sorghum and pearl millet, especially improved cultivars, is common due to heat and water stress, crusting, and due to the small seed size. Pearl millet research indicated that screening for large seed, or producing large seeds by partial head removal, improves stand establishment and often grain yield.

Stand establishment research on sorghum indicates that kernel density is associated with seedling vigor and emergence, and the germination/emergence temperature response varies greatly among genotypes. Emergence potential in crusted soils is associated with large coleoptile diameters, and is a highly heritable trait with additive gene effects.

Sustainable Plant Protection Systems

In crop protection, a wide range of sources of resistance for insects, diseases, and *Striga* have been identified and crossed with locally adapted germplasm. This process has been improved immensely by INTSORMIL collaborators developing effective resistance screening methods for sorghum head bug, sorghum long smut, grain mold, leaf diseases and *Striga*.

INTSORMIL scientists and their collaborators identified sorgoleone, a group of chemically reactive oily quinones exuded from the root hairs of sorghum, as the first natural germination stimulant identified from a *Striga* host. Sorgoleone has other properties, including herbicidal and antibiotic, and is a powerful contact allergen. In the field, *Striga* germination is not controlled by sorgoleone but by a different set of compounds exuded by host roots. These compounds are more stable and more water soluble than sorgoleone.

The INTSORMIL PIs have studied each stage of the *Striga* life cycle separately. They are characterizing the host-parasite interaction at each stage, particularly the chemical signals exchanged. For each stage, simple ways to detect ineffective interactions are sought such as an agar gel assay for germination stimulant production. These screening methods are being used to identify crop genotypes

bearing the resistance-conferring traits, and to map the traits on the sorghum genome.

The necessity of coordinating the life cycle of *Striga* with that of its host has led to the recognition of the tight integration of the *Striga* life cycle with growth and development of the host by means of a series of chemical signals exchanged between the two. INTSORMIL scientists have played an important role in the identification of the first signal, germination stimulant, and have provided evidence for later signals exchanged in both directions between *Striga* and its host by means of vascular connections, rather than through the soil medium as for germination stimulant and haustorial initiator.

The collaborative research on African sorghum head bugs in West Africa, especially in Niger and Mali has quantified damage (yield and quality loss); identified resistant genotypes, including practical methodology to screen for resistance; and described bug species composition, biology, and population dynamics. Research activities have studied the bio-ecology of head bug (*Eurystylus marginatus*) and the identification of new resistance sources to be used in integrated pest management programs. The larva and adult populations of head bugs vary naturally across years. During 1995/96 field observations at Sikasso and other areas south of Bamako, Mali, especially where sorghum had not been grown extensively for many years, head bug infestations were observed to be low. At Cinzana experiment station, bug infestation was very severe. Bug infestation at Sotuba was low. The lateness of planting at Sotuba could have caused bug infestations to be lower than usual. There was evidence that bug infestation levels were increasing, and this was especially true at Samanko (ICRISAT) where bug infestation was beginning to increase to very severe levels. Progress is being made by Malian sorghum breeders to develop improved sorghums, especially the improvements to Guinea-type sorghums. It also, is now apparent that resistance to panicle-feeding bugs can be transferred to elite varieties. The important possibility is that if improved Guinea sorghums have moderate levels of resistance and bug severity is less in farmers' fields, panicle-feeding bugs may pose little production constraint to sorghum in Mali.

Sorghum lines resistant to sugarcane aphid have been identified in Botswana and Zimbabwe, and the mechanism of resistance assessed. Genes for resistance have been identified, confirmed, and initially utilized. Efforts are now being made to move the resistance genes into parental lines which are used in hybrid combinations for combine height, early maturing genotypes with acceptable agronomic trans..

Work continues on identification of the most important disease constraints and for design of disease control strategies. This includes continued studies on the variability of *Colletotrichum graminicola* (anthracnose) and genetic resistance of sorghum grown in Honduras to anthracnose. INTSORMIL pathologists continue to collaborate with ICRISAT on growing, distributing, and evaluating the Sorghum Anthracnose Virulence Nursery. The program continues to monitor the major downy mildew screening program run by the Honduran National Program to evaluate disease and host plant resistance.

In Mali, efforts are being continued toward the establishment of a National Sorghum and Millet Disease program. This includes evaluation of INTSORMIL nurseries for reaction to the prevalent pathogens in Mali. INTSORMIL pathologists (NARS and U.S.) are collaborating with program entomologists to study the interaction of head mold and insects (head bug) on grain deterioration in the field.

In Niger, INRAN/INTSORMIL pathologists are continuing to monitor for resistance to long smut, and evaluation for resistance to head smut, Acremonium wilt, and anthracnose. The Niger program has reported the infestation of nematodes on pearl millet for the first time. The species found belong to the genera, *Helicotylenchus, Criconemella* and *Tylenchorynchus.* Preliminary results do not prove that nematodes are a serious threat to pearl millet, but they do give some indication of their relative importance. Pearl millet does serve as a good host for many species of plant parasitic nematodes. Until now, there have been no reports on the importance of nematodes on pearl millet in the Sahel. This lack of research on nematodes on millet and sorghum in the Sahel may be partly explained by the assumption that nematodes cannot survive in an environment which is to dry and hot. These species of nematodes plus *Pratylenchulus spp.* were also found on sorghum in the Konni area where the level of infestation was much higher and threatening. This is the first time that nematodes have been shown to infect sorghum in Niger. This finding is very important because the Konni area is the sorghum belt in Niger.

In Honduras and Niger, INTSORMIL entomological collaboration has resulted in development of sustainable biological control strategies for stem borers, and information on pest and natural enemy biologies has contributed improved approaches to IPM. For whorlworms in Honduras, techniques were developed to manipulate key natural enemies; for stem borers. An efficient natural enemy was imported, released in Honduras and established; for stem borers in Niger, natural enemies have been demonstrated to occur in greater densities in natural vegetation than in millet, a suggestion that the substantial changes in pearl millet production practices is interfering with biological controls.

MHM, Pearl millet head miner *(Heliocheilus albipunctella)* is a serious insect pest of West Africa, and has been found to be an excellent candidate for biological control since it has a predictable habitat, consistent annual habits, produces one generation per year, and has several natural enemies. Two major predators and two commonly encountered parasites have been identified, and are being studied. During 1995/1996, two NARS scientists from West Africa were admitted as graduate students in the Department of Entomology at Texas A&M University. In 1996 they will

begin their graduate degree research at the ICRISAT Sahelian Center. Their research objectives and results will build on findings for MHM biological control reported by INTSORMIL scientists in 1994 and 1995 Annual report. When this research is complete, the key mortality sources, including natural enemies of MHM, will be identified and methods of manipulation will be described for those that can be effectively managed for optimal mortality to MHM populations. The INTSORMIL MHM research continues to coordinate closely with the West Africa ROCAFREMI millet network. INTSORMIL participated in the three ROCAFREMI network meetings during this program year.

Derivatives of SC326-6 continued to show good adaptation and resistance to anthracnose and other foliar pathogens in Zambia and Zimbabwe but a few did show some vulnerability to sooty stripe disease. These lines are being utilized as parental lines in breeding programs. A virus apparently similar to MDMV-A again caused high infection in a late planting of A-lines of released hybrids at one location in Zambia and it (or another virus) was also present in several sorghums in the Pandamatenga and Southern regions of Botswana including a newly released sorghum variety. Live virus samples collected from Zambia and Botswana and sent under a special import permit are being characterized by Dr. S. Jensen at the University of Nebraska.

A bacterial disease of pearl millet first observed in Southern Zimbabwe in 1995 has been tentatively identified as *Pseudomonas syringae* by D. Frederiksen at the University of Zimbabwe. If confirmed this would be the first report of *P. syringae* on pearl millet outside of the United States.

In Honduras insect pest control developed for one species or a complex of species involves the integration of specific management tactics, possible applied throughout the crop growing season, in a holistic crop management system. This holds true for insect pest management in subsistence farming, as it does for high technology crop production. Host plant associations have been identified and ecological relationships have been identified and ecological relationships defined for three of the "langosta" defoliator species. These investigations have provided the information for design of integrated insect pest management programs for designated crop production areas. The use of cultural methods (e.g., planting dates and weed management in production fields), crop varieties with insect resistance, and limited and judicial use of insecticides, as previously identified will benefit sorghum-maize production in Honduras and other areas in Latin America having similar crop production problems.

Crop Utilization and Marketing

In Mali a survey on "Sorghum Diversification of Processing and Utilization" was done using the new white-seeded, tan-plant variety N'Tenimissa. Two hundred 500 gram packets of sorghum grits and flour were placed in a supermarket. Results indicated that 80% of the people that brought the samples liked the products very much, and the other 20% did not respond. This test will be expanded in 1996/97 to about 10 supermarkets.

Major economic changes in Mali relate to the price and availability of wheat for bread and biscuits. There is an economic demand for sorghum, millet or maize flour to extend wheat flour in biscuits (cookies) and French breads. Industry personnel wanted to use maize because they had reports discouraging the use of sorghum because the local sorghum flour has been of poor quality. This poor image of sorghum and millet as a food item is a major problem.

The Cereal Quality Laboratory (LQC) at INRAN in Niger has conducted several surveys to determine the effect of crop selection and pearl millet varieties on couscous preparation in Niger. Sorghum, pearl millet, and durum wheat all produced acceptable couscous in this study. Work continues with INRAN/Niger scientists on sorghum and millet-based couscous. A couscous processing unit has been put into place at INRAN, with funding assistance from the Niger USAID Inter-CRSP initiative. The processing unit consists of a decorticator/mill, agglomerator/siever (designed by CIRAD, France), steamer, solar drier, and packaging sealer. This will be used for research purposes, and also as a demonstration and testing unit to encourage local entrepreneurs to commercialize millet or sorghum couscous. A commercial-type product will also be tested in the market place.

MILEG, a prepared weaning food from dehulled pearl millet and cowpea flours (3:1 blend), is being produced and sold by a small food company in Bamako, Mali. The product prototype was developed cooperatively by the Institute of Rural Economy food technology laboratory, with assistance from INTSORMIL/Texas A&M University food scientists. The businessman, who formerly worked as a technician in the IER Food Technology Laboratory, was financed by a loan from a Canadian agency. The product has been in production for nearly two years. It is being prescribed by medical staff for children suffering from malnutrition. It is not a complete weaning food, but it definitely has improved nutritive value at a reasonable cost compared to other more completely balanced imported weaning foods.

Benefits to the U.S.

Germplasm Enhancement and Conservation

INTSORMIL PIs have developed numerous germplasm lines resistant to biotype C, E, and/or I biotype greenbug which have been distributed to private seed companies for use in their breeding programs. Testing of advance B-line selections resistant to biotype E greenbug continued in 1995. Lines identified for release, with their experimental designations are GR107090M17, GR108-90M23, GR134A-90M50, and GR127-90M21. Each line produces hybrids with excellent yield. Increased emphasis was given in 1995 to development of new germplasm lines resistant to both greenbug biotypes E and I. Two excellent sources of resis-

tance have been identified for biotype I resistance, PI550607 and PI550610. To diversify the germplasm base of greenbug resistant germplasm, PI550607 is used exclusively in R-lines and PI550610 primarily in B-lines. Gene mapping has shown that genes conferring resistance to different greenbug biotypes are slightly different, but probably control the same resistance process.

INTSORMIL research has confirmed that sorghum midge abundance the subsequent year is reduced when sorghum residue containing overwintering larvae is shredded, disked, and deep plowed after harvest compared to when residue is only shredded or shredded and disked. Sorghum midge resistance in sorghum is caused by morphology of spikelets and asynchrony between time of flowering during the day and the presence of sorghum midges. Germplasm resistant to sorghum midge, developed through INTSORMIL support, has served as the foundation for many similar breeding programs throughout the world. Experimental sorghums with female parents A91-6, A92-3, and A93-6 produced superior hybrids during the previous two years and will be released to the commercial seed industry. Hybrid seed has been distributed to commercial seed companies and extension personnel to evaluate hybrid performance in a large range of environments with or without sorghum midge present. The lines will be released to other breeders during the fall of 1996. These will be the first sorghum midge resistant A/B pairs with the traits needed to produce commercially acceptable resistant hybrids.

Materials from the INTSORMIL/USDA/Texas A&M University Sorghum Conversion Program and selected breeding cultivars from other projects are evaluated regularly for resistance to internationally important diseases and insects in a cooperative/collaborative program throughout the sorghum growing world. INTSORMIL PIs have cooperated in the release of 360 converted exotic sorghum lines. The releases were made in three groups: 240 lines in 1986, 110 in 1992, and 50 fully converted exotic lines and 253 partially converted bulks were released in 1994/95. Sets of the 50 converted lines and the 253 partially converted bulks released in May, 1995 have been distributed to 11 private companies and 4 public sorghum breeding programs.

In January 1995, INTSORMIL/Purdue University reported a breakthrough in sorghum digestibility research. Irregularly shaped protein bodies discovered in sorghum kernels under the electron microscope may signal improved human nutrition in some developing countries and higher quality livestock/poultry feed worldwide. In 25 experimental genetic lines of sorghum, two have been identified with significantly faster protein digestion. These two genetic lines of more highly digestible sorghum fall right between maize and wheat in digestibility. The more digestible lines maintain 80 percent digestibility, even after cooking. Most sorghum varieties lose digestibility in cooking; some drop to as low as 46 percent. That makes sorghum potentially competitive with other cereal grains as a source of dietary protein for humans and livestock/poultry. Poultry feeding tests have been initiated to verify the findings.

Sustainable Production Systems

Research in the area of mineral stress, particularly nitrogen, has shown that certain genotypes cope with low soil nitrogen better than others by a rapid mobilization of that element to actively growing tissue which sustains whole plant photosynthesis and thus growth. Also, certain sorghum genotypes have higher photosynthesis rates at lower tissue nitrogen concentrations than others, which allows continued growth at low nitrogen supply. Sorghum varieties having known N use efficiency (NUE) characteristics were studied to determine the physiological basis for superior NUE. The study clearly demonstrated the superiority of two sorghum lines from China for CO2 assimilation capacity when leaves were experiencing N stress (deficiency). Analysis of the data indicated that the enzyme of particular interest is most likely phosphoenol pyruvate carboxylase, the first catalytic enzyme in the CO2 capture process in cells.

Studies to develop an agronomic production practices package for dwarf pearl millet as a new alternate crop for the U.S. have been initiated. Narrow row spacing, nitrogen application, and good weed control were identified as important practices, although pearl millet appeared to be more competitive with weeds than grain sorghum.

Sustainable Plant Protection Systems

INTSORMIL PIs developed an International Anthracnose Virulence Nursery which is used to monitor the pathogen. This nursery is now managed in cooperation with ICRISAT. The system of networking includes the growing of several uniform nurseries in locations where sorghum/millet diseases are important, such as the International Sorghum Anthracnose Virulence Nursery, which is grown where anthracnose is endemic. Other nurseries include a uniform nursery for head smut, sorghum downy mildew, sorghum viruses, and grain mold. Growing of these nurseries permits a quick evaluation of pathotype differences among locations and the severity of the problem. INTSORMIL also evaluates and distributes elite sorghums in nurseries for evaluation of the multiple resistance of sorghum. These are international nurseries and represent a means of distributing elite germplasm from different breeding programs in INTSORMIL.

INTSORMIL PIs have developed a dot immunobinding assay (DIA) to distinguish different bacterial pathogens of sorghum and millet. The test is easy to perform, inexpensive, requires limited equipment and chemicals, and was designed with LDC laboratory conditions in mind. It has been shown that the causal agent of bacterial leaf streak is seedborne and can remain viable in the seed for more than two years.

International collaborative research programs with NARS and ICRISAT scientists have resulted in the devel-

opment of sustainable insect management strategies and identification of sorghums resistant to sorghum midge, greenbug (biotypes C, E, and I), African sorghum head bugs, sugarcane aphid, and yellow sugarcane aphid. Mechanisms and inheritance of resistance have been determined, and genes conferring resistance have been introgressed into elite parental lines that have been evaluated alone and in hybrid combinations. Levels of resistance have been quantified, and economic injury levels established for most of them.

INTSORMIL research has employed a holistic approach to identify, evaluate, and deploy sorghum midge, greenbug, and yellow sugarcane aphid resistant sorghums as a component of IPM, and develop and validate sorghum plant and sorghum midge dynamics computer models.

Significant advances were made in developing the technology to allow farmers to manage these sorghum insect pests. Significant advances have been made in biological control and these advances contribute to improved IPM of sorghum and millet, and to improved concepts for using biological control in annual crops. For aphids attacking sorghum in the U.S., predators were demonstrated as key natural enemies for effective biological control of these pests. In the U.S., phytoseiid predators have been demonstrated as an effective alternative to pesticides for control of spider mites and parasites, and were shown to be effective on the American sugarcane borer attacking sorghum.

Biological and ecological relationships and insecticide susceptibility for fall armyworm for Florida, Mississippi, Honduras, and Jamaica have been determined. This provides a basis for understanding infestations and developing control strategies for this migrating insect pest of economic importance in the U.S.

The impact of insect resistant germplasm in sorghum production of the U.S. has been dramatic. For example, insecticide use on sorghum in Texas was at an all-time high at the initiation of this CRSP. In 1978, nearly 60% of the sorghum acreage in Texas was treated with insecticide, while in 1990 only about 24% of the acreage was treated. The savings gained from not using insecticide were $6,000,000 per year, and this does not consider the ecological or environmental benefits, or benefits from reduction in insect pest resurgence or secondary pest outbreaks. During this project, the economic benefit to Texas farmers has been at least $90,000,000.

Crop Utilization and Marketing

INTSORMIL scientists originally addressed the tannins as antinutritional factors. They developed methods, now widely used by others, for assaying and characterizing these materials. They also developed a simple method for detoxifying and improving the nutritional value of high tannin sorghum. They are elucidating the biochemical mechanisms by which tannins exert their antinutritional effects. They are also characterizing the role of tannins and related materials in resistance to birds, molds, and leaf diseases. Methods for polyphenol analysis, purification and characterization have been widely adopted and used by nutritionists and ecologists studying tannins in other crops and range plants.

The most significant finding of late concerns the poor protein digestibility of sorghum. In screening 25 selected sorghum genotypes for *in vitro* protein digestibility they found a range from 66 to 88% for uncooked values and 48 to 81% for cooked values. Two sorghum lines had notably higher digestibilities compared to the other sorghums tested. Perhaps more important, digestibility of these two sorghums did not decrease appreciably on cooking, which is commonly seen with sorghum. This was verified using two *in vitro* enzyme systems. Chemical studies showed that in the two highly digestible sorghums the major storage protein (about 65% of total protein), α-kafirin, was digested much earlier than the other sorghum samples. Also, a group of high molecular weight proteins, that usually restrict the digestion of α-kafirin, was digested very rapidly. This group of sorghums is now being grown to determine if this is a heritable trait. If this proves to be so, we believe that a rapid screening assay for digestibility can be developed based on chemical differences between genotypes.

The chemistry, composition, structure and nutritional value of sorghum kernels has been related to genes that control pericarp thickness and color and the presence and absence of a pigmented testa. From this knowledge, several white, tan plant sorghum inbreds have been released to the seed industry and are being grown in the United States. These food hybrids have improved quality for use in livestock feed as well as ingredients in food systems.

New prototype food products including noodles, ready-to-eat breakfast foods, weaning foods, granolas, instant porridges, baked products and others have been developed from 100% sorghum and millet for potential utilization in several countries. Products have been made with sophisticated techniques like extrusion and micronizing and also with simple, low-technology methods appropriate to targeted countries. The major constraint limiting their application is the lack of a consistent supply of good quality sorghum and pearl millet grains at a competitive price.

Sorghum has been used to produce tortilla chips, tortillas and related products from alkaline cooking. Several new cultivars with improved tortilla making quality have been or are near release in Central America because of collaborative work within the breeding programs. A simple test to evaluate tortilla potential of sorghums has been successfully utilized.

New waxy and heterowaxy sorghum cultivars and hybrids have been developed with unique properties for use in food systems. A white, tan waxy sorghum produced flakes for granola using micronizing. These JOWAR flakes have excellent potential for use in a wide variety of products. The same grains have excellent steam flaking properties and may

have improved feed efficiency when fed to ruminants and swine.

The adverse effects of molds and weathering on sorghum quality significantly limit the use of sorghum for foods in many areas. Major progress to understand the factors affecting grain deterioration has been made. Work continues to secure mold resistant sorghum cultivars. New information on the role of antimicrobial proteins is being developed.

The structure and processing properties of pearl millet has been evaluated. A white pearl millet grain had excellent acceptance when cooked like rice. The milling properties of pearl millet were mainly affected by kernel size, shape and hardness. Parboiled pearl millet did not develop the off-flavor that occurs in pearl millet products.

Future Directions

INTSORMIL will continue to jointly plan and execute collaborative research that benefits developing countries and the United States. These collaborative relationships are keys to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are envisioned to be in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds a finite scientific capability on sorghum and millet, and creates technological and human capital that has a sustainable and global impact. INTSORMIL will use five specific strategies to maintain its current momentum, build on its record of success, and accomplish a new set of goals. These strategies are (1) sustainable research institutions and human capital development, (2) conservation of biodiversity and natural resources, (3) research systems development with focus on relevant technology generation, (4) information and research networking, and (5) demand driven processes.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-108A
L.E. Claflin
Kansas State University

Principal Investigator

Dr. Larry E. Claflin, Department of Plant Pathology, Kansas State University, Manhattan, 66506

Collaborating Scientists

Mr. Xu Xiude, Sorghum Research Institute, Liaoning Academy of Sciences, Shenyang, China
Dr. Elhamy El-Assiuty, Plant Pathology Research Institute, Agricultural Research Center, 9 Gamaa Street, Giza, Egypt
Dr. C. J. Kedera, Head, Plant Quarantine Station, KARI, P. O. Box 30148, Nairobi, Kenya
Dr. Debbie Frederickson, Department of Biological Sciences, University of Zimbabwe, P. O. Box MP167, Mt. Pleasant, Harare, Zimbabwe
Dr. Paula Bramel-Cox, ICRISAT, Patancheru 502 325, Andhra Pradesh, India
Dr. John Leslie, Department of Plant Pathology, Kansas State University, Manhattan, KS
Dr. Darrell Rosenow, Texas Agricultural Experiment Station, RR 3, Box 219, Lubbock, TX
Dr. R. A. Frederiksen, Department of Plant Pathology, Texas A & M University, College Station, TX 77843
Dr. G. A. Odvody, Texas A&M Research and Extension Center, Route 2, Box 589, Corpus Christi, TX 78406
Dr. D. J. Jardine, Department of Plant Pathology, Kansas State University, Throckmorton Hall, Kansas State University, Manhattan, KS 66506

Summary

Fusarium subglutinans, F. proliferatum and *F. moniliforme* were found to cause disease symptoms in grain sorghum similar to pokkah boeng, a disease of uncertain etiology. Additional research is in progress to ascertain the seedborne role and the concentration of inoculum that will increase disease incidence.

The potential role of *Fusarium* spp. serving as endophytes in grain sorghum plants as a biological control agent and plant growth promoting fungus is under field investigation.

The causal agent of sooty stripe, *Ramulispora sorghi*, produced abundant conidia when grown *in vitro* on sorghum leaf extract, dandelion extract, and potato dextrose agar at 20-24 C. Germplasm accessions that possessed tolerance to natural infections of sooty stripe included B1, 82BDM499, 86EON328, 87BH8606-6, BTxARG1, BTx638 and BTx2755.

Teliospores of *SporIsorium sorghi* (covered kernel smut) were mixed with seeds of grain sorghum and were also infiltrated into seed with a partial vacuum prior to sowing. These were the most effective techniques for increasing the incidence of covered kernel smut. Injection of germinated teliospores into the growing point at the boot stage of growth and incubating seedlings in a sporidial suspension were ineffective in screening protocols for determining the genetic variability of various grain sorghum accessions to covered kernel smut. The accessions, B35 and SC414, were immune to *S. sorghi.*

Isozyme banding patterns of *Sporosorium sorghi* revealed that 10 monomorphic loci and one polymorphic locus were present. All isolates of *S. sorghi* from Kansas, Mali, Sudan, two locations in Egypt and Senegal, and from three locations in Kenya had the same isozyme banding patterns except the isolate from Tambacounda, Senegal.

Objectives, Production and Utilization Constraints

Objectives

a. Determine the causal agent(s) of pokkah boeng disease of pearl millet and grain sorghum.

b. Ascertain the potential of plant growth promoting fungi in sorghum production.

c. Develop an effective screening protocol for sooty stripe (*Ramulispora sorghi*) under greenhouse and field conditions.

d. Screen sorghum accessions from the Texas A&M University All Disease and Insect Nursery (ADIN) for genetic variability to covered kernel smut, rust, bacterial, and other diseases of sorghum.

e. Develop efficient and reliable screening protocols for *Sporosorium sorghi* (covered kernel smut) and determine the inheritance of resistance to this disease.

f. Provide pure cultures of plant pathogenic bacteria and antisera to LDC Scientists to expedite diagnoses of bacterial diseases of pearl millet and sorghum.

Constraints

Pokkah boeng disease is observed every year in all sorghum production areas of the world and the cause has been attributed to chemical injury, calcium deficiency and a fungal pathogen, *Fusarium subglutinans*.

Several *Fusarium* spp. produce gibberellic acid (GA) and a closely related species in Asia, *Fusarium fujikuroi*, is utilized in fermentation protocols to commercially produce GA. *Fusarium* spp. that are known to be avirulent (saprophytes) and produce GAs in lesser quantities will be added to pearl millet and grain sorghum seeds and evaluated for promotion of plant growth and biological control of seedborne and soilborne diseases.

Sooty stripe occurs in most sorghum production areas in the world. Screening protocols for ascertaining variability in sorghum germplasm have not been developed because the fungus grows slowly or not at all *in vitro*.

The Texas A&M ADIN contain a wide array of sorghum germplasm. These entries are sent to diverse regions in the world to be evaluated for various diseases. Some accessions have been found to be tolerant or immune to various diseases and, therefore constitutes a valuable resource in breeding programs.

Covered kernel smut is one of the more important diseases of grain sorghum in LDCs. The disease is easily controlled by chemical seed treatments but these chemicals may not be available or the cost may be prohibitive for purchase by farmers. Incorporation of resistant or immune germplasm into acceptable cultivars would partially alleviate concerns about covered kernel smut.

Research Approach and Project Output

Research Methods

Determining the causal agent of the pokkah boeng disease involves placing diseased tissue or extracts of the tissue in petri plates containing various media. The resulting colonies of microorganisms on the media are examined morphologically and microscopically. Those suspected or known to cause plant diseases are inoculated into host plants. If the disease symptoms are similar then recovery of the inoculated organism(s) from tissue is repeated to complete Koch's postulates.

Fusarium proliferatum, F. subglutinans and *F. moniliforme* obtained from the our collection and from other collections will be screened for pathogenicity to pearl millet and grain sorghum and for GA production by utilizing the HPLC protocol. Pathogenicity will be determined by adding 10^6 propagules/ml to seeds and/or inoculating plants at the 6th leaf stage of growth with the same concentration.

The techniques have been fully described and amendable for our research. Isolates determined to be high, mid, and low producers of GA will be used to infest pearl millet and grain sorghum seed at concentrations of 10^2, 10^4, and 10^6 propagules/ml. Seeds will be dried and then planted at various depths (1, 2, and 3 inches) to ascertain the effect of GA on emergence. Controls will consist of adding autoclaved fungal suspensions to seeds, hot water treatments (55 C for 5 minutes) to destroy microorganisms, planting seeds that were treated with Captan, and planting untreated seeds. The statistical design of field experiments will consist of a strip plot randomized complete block with a 4-way factorial. Data on emergence, height at flowering, and yields (if possible) will be taken.

Biological control activity of the *Fusarium* spp. will be ascertained under greenhouse conditions. Soil will be obtained from fields where pearl millet and grain sorghum was grown continuously for at least three years. Pearl millet and sorghum seeds will be infested with the *Fusarium* spp. and planted. Sterilized soil will serve as a check and the controls are the same as listed above. Results on emergence, incidence of diseased roots and isolation of the causal agent(s) should indicate biological control activity. The degree of colonization of pearl millet and grain sorghum roots can be monitored by using mutants of the *Fusarium* spp. used to infest seeds. This would include selecting isolates resistant to benomyl or hygromycin B resistant transformants, ß-D-glucuronidase (GUS) marked strains and other techniques like restriction fragment length polymorphism (RFLP) analysis of total DNA after hybridization with a random probe and the polymerase chain reaction (PCR).

Techniques for evaluating screening protocols for covered kernel smut will be evaluated under greenhouse and field conditions. Cultivars B35, SC414, TX7078, QL3 and TX2767 were selected as based on previous tests for genetic variability.

Inoculation Techniques

Smutted heads from the previous year of research were threshed and the teliospores screened through sieve sizes of 100 and 400 to eliminate debris. Spores were stored at 4 C until needed.

Sorghum seeds will be disinfested in a formalin/water (1:300 v/v) solution for 1 hour and then washed in running tap water for three minutes, air-dried for 24 hours and then stored in paper envelopes. Seeds will be infested with teliospores of *S. sorghi* (0.6% w/w).

Partial Vacuum

Seeds were mixed with teliospores (0.2% w/w) and water was added to cover the seeds in small flasks. The seed-spore mixture was placed under partial vacuum (180-200 mmHg) for one hour except when the vacuum was released at 15 minute intervals. Seeds were then dried overnight and the procedure was repeated the following day.

Teliospore Inoculation

At the boot stage of growth, plants were inoculated (0.1 - 0.2 ml) with a sporidial suspension. Sporidia were obtained from a mixture of 20 teliospores that had been maintained on water agar.

Isozyme Analyses of Sporosorium sorghi

Covered kernel smut infected panicles were collected from Kansas, Mali, Sudan, two locations in Egypt and Senegal, and from 3 locations in Kenya and stored at -20 C. Teliospores were threshed and sieved through 100 and 400 mesh screens. Spores were soaked for 3-5 minutes in 0.5% copper sulfate solution for disinfesting the spores from bacterial contaminants. Ten-fold serial dilutions were made in sterile distilled water until the final spore concentration was 10^1. The aliquots (1 ml) were placed in petri plates containing water agar.

The single-spored teliospores were grown on PDA at 24 C until the colony diameter reached 2-4 cm (8-10 days). The mycelia and sporidia were extracted with enzymes following recommended procedures and placed on the surface of sterile cellophane dialysis membrane that was layered on the surface of PDA in petri plates. About 1 to 1.5 mls of the mycelia suspension of each isolate was placed in the center of the cellophane tubing and then incubated at 24 C for 7-8 days. The cellophane with the mycelia was frozen in liquid nitrogen. The mixture was then ground in a fine powder with grinding buffer. The homogenate was centrifuged for 5 minutes at 10,000 g (4 C). The protein extract was placed in 0.5 ml microtubes and stored at -20 C until isozyme analyses.

Starch Gel Electrophoresis

Twenty five enzyme and five buffer systems were evaluated on starch gels. The gels, enzyme and buffer systems, and electrophoresis was performed as previously described by other journal articles. Gels were electrophoresed at 35 MA for 3 hours (Soltis No. 6 buffer), 25 mA for 12 hours (Amine-morpholine buffer), 90 Ma for 3 hours (Steiner buffer), 75 mA for 3.5 hours (May's modification of Selander buffer), and 50 mA for 4 hours (lithium-borate buffer).

Research Findings

a. Pokkah boeng is a Javanese term for diseased plants that have damaged top shoots or distorted tops. The causal organism was reported as *Fusarium subglutinans*, a fungus that is reported on numerous hosts throughout the world but seemingly is more important on corn, grain sorghum, and sugar cane. Most farmers and agricultural scientists would prefer to term the disease "onion-leaf" or "rat-tail" due to the characteristic appearance of infected plants as the individual leaves appear to be glued together and fail to unfurl in a normal pattern from the whorl. Other symptoms associated with pokkah boeng include "knife-cut" in which it appears that a knife was drawn transversely across the leaf leaving a cut appearance. Another symptom includes discolored elliptical lesions on leaves near the stalk. Calcium deficiency will mimic the cut-leaf symptom and a layby application of herbicide can result in the onion-leaf symptom.

Pokkah boeng is observed in all sorghum growing areas of the world and a high incidence is noted if favorable weather conditions persist. The disease was particularly severe in Upper Egypt on the cultivar, Giza 15, which is the leading cultivar in that region.

This disease has been poorly researched and even many plant pathologists are unaware of the symptoms. In preliminary experiments we observed that several closely related fungi, *F. moniliforme* and *F. proliferatum* also can incite pokkah boeng symptoms under greenhouse conditions. In addition, severity of disease on grain sorghum was influenced by inoculum concentrations.

b. Numerous bacterial and fungal species have been described that are capable of promoting plant growth. Unfortunately, most are very fastidious and may not tolerate low ph soils, hot or cold conditions, nor colonize certain crops like pearl millet and grain sorghum. *F. subglutinans* occurs on numerous crops throughout the world, tolerates harsh environmental conditions and has the ability to colonize grain sorghum plant tissues. In addition, some strains of *F. subglutinans* produces appreciable quantities of GA. Although *F. subglutinans* is recognized as a plant pathogen, virulence levels vary within this species from being aggressive to avirulent (saprophytes). Our results show that some isolates are virulent at 10^1 propagules/ml whereas other isolates are avirulent at populations exceeding 10^7 propagules/ml.

It is anticipated that applying *F. subglutinans* to seed will result in plant growth promoting and biological control of some seedborne and soilborne microorganisms. Promotion of plant growth will primarily result in an increase in seedling emergence especially if seeds are planted too deep, in cold soils and/or in soils that tend to crust. *F. subglutinans* has not been reported to produce antagonistic compounds against other seedborne or soilborne organisms. As *F. subglutinans* readily colonizes plant tissue (primarily the roots and coleoptile), the expected biocontrol mode of action is exclusion of other microorganisms since the tissue is already colonized. It is also possible that systemic diseases such as smut could be reduced due to the enhanced growth spurt

provided by GA that was produced by *F. subglutinans*. Although *F. subglutinans* is considered a plant pathogen, assays for virulence will be conducted for all strains and only those that are shown to be saprophytic will be tested.

Gibberellic acid was used in experiments as a potential growth promoter for numerous crops including grain sorghum. Beneficial effects such as emergence, increases in yields and promotion of flowering in sorghum were inconsistent. In most cases, where seeds were treated with GA and coupled with 4-5 foliar applications, the costs incurred were prohibitive. As pearl millet and grain sorghum kernels are devoid of chaff (palea and lemma tissue), limited amounts of GA are absorbed by the seed coat. At most, GA would remain on the seed for only 1-3 days before being absorbed by the soil or broken down by microorganisms. In crops such as oats, barley, and rice in which the seed is enclosed by the lemma and palea, more chemical is absorbed by the seed. Approximately one-half million acres of rice in Arkansas and Texas are planted with seeds treated with GA to enhance emergence in those soils that tend to crust. If GA is applied at rates exceeding 10 parts per million (ppm), the emerged seedlings are often tall and spindly.

For unknown reasons, bacteria have been the choice in selecting organisms that have potential in promoting plant growth and biocontrol activities. However, they have only been successful in a particular niche and in selected geographical regions. They are notorious for being fastidious with slow growth and they often fail to colonize plant tissue. In preliminary tests with corn during the 1995 growing season, one fungal strain enhanced emergence over 30% and another strain increased grain weight per ear over 26% of the control.

Plant diseases such as pokkah boeng where the causal agent has not been ascertained creates problems in the seed and feed grain export trade. Importing countries become alarmed as they are not certain that the pathogen is present in their country. Hopefully, research that is being proposed will alleviate fears about sanctions against two important farm commodities in domestic and international trade.

Nearly 100% of hybrid grain sorghum seed used in North America is treated with chemicals. These chemicals have been reviewed in the past for environmental and toxicology reasons and will likely be reviewed in the future. Seed treatment are often unavailable or are too expensive for farmers in LDCs to purchase. This project evaluates other viable options for chemical seed treatments that potentially offers promotion of plant growth and biocontrol activities. If successful, it is conceived that less seed will be planted and problems with crusted soils will be partially alleviated. This would certainly contribute to increased sustainability for farmers involved in production of pearl millet and grain sorghum.

c. *Ramulispora sorghi* produced optimum conidia when grown on sorghum leaf extract, dandelion extract and potato dextrose agar media. The optimum temperature for conidial production was between 20 - 24 C at a pH of 4.5. Conidial production and mycelia growth was enhanced at a temperature of 28 C. Sclerotia formed on sterilized sorghum grain, wheat kernels and sorghum leaf tissue and matured in about 50 days.

d. ADIN germplasm was evaluated under both inoculated and natural infection plots in 1995 (Table 1). All entries that were inoculated with *R. sorghi* conidia had relatively high ratings. Those accessions determined to possess resistance to sooty stripe under natural infection included B1, 82BDM499, 86EON328, 87BH8606-6, BTxARG1, BTx638, and BTx2755 (Table 1).

e. *Sporisorium sorghi*. Significant differences ($p<0.05$) were found among cultivars, inoculation procedures, and cultivar by inoculation interactions in research involving a screening protocol for covered kernel smut. Infiltrating teliospores of *S. sorghi* into seed by partial vacuum (PV) and mixing teliospores with seed prior to planting were not significantly different under greenhouse and the second (June) field planting. Both techniques produced the highest disease incidence and the cultivars SC414 and B35 remained immune to *S. sorghi*. Disease incidence was higher in the greenhouse and the second field planting than in the first (May) planting. Differences in the field plantings for smut incidence is probably attributable to weather conditions during and after planting. Unusual cool soil temperature and prolonged rainfall conditions persisted which likely reduced the smut incidence for the May planting. In June, average soil temperature at planting was 19.1 C and did not drop below 21.7 C. The soil had low to medium moisture during preemergence of the seedlings in June. TX2767 was the most susceptible followed by QL3 and Tam 428. TX 7078 was not significantly different from SC 414 and B 35 which are immune to our race of *S. sorghi*..

Injection of germinating teliospores into the growing point at boot stage of growth was not effective. The failure to produce smutted plants is attributed to inability of the sporidia to establish infection, unfavorable weather conditions for disease development and establishment, and the failure of the pathogen to colonize the floral tissues of the plant and initiate infected florets.

Incubating seedlings in suspensions of sporidia resulted in no infected panicles. Saprophytes in the water agar seed mixture may have been more competitive and the teliospores may have been ineffective. However, infection may have taken place but *S. sorghi* failed to colonize the floral tissues.

The enzymes, Aspartate aminotransferase, Aconitase, Glucose phosphate isomerase, and isocitric dehydrogenase produced two bands on the starch gels which were always present with all isolates with at least one of the buffer systems. Malate dehydrogenase produced 2-3 bands in all

Table 1. Reaction of All Disease and Insect Nursery Accessions to *Ramulispora Sorghi*

Entry	Inoculated[A] First Reading September 1	Inoculated[A] Second Reading October 5	Natural Infection[C]
B35	2.67[B]	4.47	2.90
SC326-6	2.27	3.43	2.63
SC414-12E	4.00	4.33	3.23
SC630-11E (II)	3.30	4.36	1.77
R.9188	3.00	4.20	3.40
B1	4.17	4.90	1.73
82BDM499	3.00	3.57	1.16
86EON361	3.85	3.63	1.87
87EON366sis	3.37	3.90	4.07
90EON328	3.93	3.57	2.03
90EON343	4.20	4.87	4.47
91BD1319	3.20	4.20	2.07
91BE7414	4.20	4.37	3.90
92BD1016	3.73	4.30	3.43
87BH8606-6	3.10	4.30	1.16
88BE2668	3.83	3.77	2.30
92BD1982-4	3.47	4.37	4.40
94CW5045	3.80	4.20	3.93
94BE6109	4.07	4.60	4.53
89CC443	3.20	3.77	2.80
90CW8147	3.93	4.40	3.60
85OG4300-5	4.07	4.17	4.17
93CW3768	3.73	4.13	3.23
GR108-90M24	3.30	3.77	2.20
92LG10314	4.10	4.67	4.40
94EON149-151	3.93	4.43	3.83
95BRON397	3.80	4.70	2.97
MB104-B92NF9	1.83	4.67	2.97
MB110-B93NF6	3.87	4.93	3.30
94MLT66	3.00	4.50	3.50
GB112-B9INF18	3.70	4.53	3.70
MB110-1	3.40	4.47	4.30
GR127-90M41	3.27	3.77	4.10
Tx2880	3.37	3.87	4.30
Tx2862	3.97	4.67	4.60
MB108B	4.00	4.13	4.10
R.9112	2.43	3.77	2.83
R.9204	3.43	4.27	2.30
R.9120	3.10	3.97	2.63
R.9007	2.90	3.17	3.30
R.9210	3.80	4.47	4.03
ICSV112	3.87	4.37	3.17
R.9117	2.77	4.50	2.20
Tx2896/R8903	4.27	4.43	3.63
91B2978	2.97	4.47	4.16
90B2662	3.57	4.20	3.16
87EON109	3.33	3.93	2.50
88B1016	3.90	4.07	3.97
88B924	3.70	4.23	3.56
88B928	3.00	4.10	3.97
88B943	3.70	4.37	4.43
Tx2908/R.8503	4.30	4.80	4.40
Tx2894/80C2241	4.40	4.67	4.33
Sureno	3.67	4.20	4.60
Malisor 84-7	3.40	3.90	3.16
SRN39	2.97	4.30	3.70
RTx436	3.87	4.47	4.00
BTx635	3.60	3.83	4.03
BTxARG1	2.93	3.57	1.60
BTx638	2.80	3.97	2.07
Tx2767	3.30	4.27	2.67
Tx2783	4.10	4.70	4.30
BTx2755	3.53	4.90	1.86
BTx623	3.87	4.40	2.50
BTx631	3.43	3.57	3.03
QL3 (India)	3.50	3.80	3.30
TAM428	3.67	4.30	3.56
Tx430	3.47	3.97	3.36
BTx378	3.50	4.47	3.23
Tx7078	4.07	4.93	4.50

[A] - Plants were inoculated August 2, 1995 and maintained under high moisture regimes with overhead irrigation.

[B] - Scale 1-5; 1 = 0-2%; 2 = 2.1-10%; 3 = 10.1-25%; 4 = 25.1-50%; 5 = > 50.1%

[C] - Observed in covered kernel smut nursery under natural infection.

isolates, however bands 1 and 3 were always present and band 2 was unstable.

Of the 11 putative loci observed, 10 were monomorphic and one was polymorphic. All isolates tested had the same isozyme banding patterns for each loci except the isolate from Tambacounda, Senegal which differed in the glucose-6-phosphate dehydrogenase locus. As only 12 isolates were available, the extent of genetic variation in *S. sorghi* or the usefulness of isozyme analysis as a promising technique for characterizing single teliospore isolates is only partially known. Enzymes and buffer systems have been identified to detect loci in *S. sorghi* and additional research should concentrate on evaluating more isolates from diverse regions.

Networking Activities

Research Investigator Exchanges

Mr. Xiude Xu from the Sorghum Research Institute, Shenyang, China spent the time interval of November 1, 1994 until December, 1995 under the auspices of UNDP working in my laboratory on developing screening protocols for sooty stripe disease of sorghum.

Germplasm and Research Information Exchange

Ms. Aimen Wen, University of Queensland, Australia, was furnished bacterial cultures from sorghum and antisera to detect these pathogens for her Ph.D. program.

Dr. Debbie Fredericksen, University of Zimbabwe was given bacterial cultures isolated from pearl millet, antisera to detect these bacterial pathogens, specialty chemicals, supplies, research journal articles and suggestions for diagnosing a bacterial disease affecting pearl millet in Zimbabwe.

A visit was made to Egypt (December, 1995) to confer with Dr. Elhamy El-Assiuty on publishing manuscripts of collaborative projects. Considerable time was spent with Mr. Abu-Serie Ishmael, Ph.D. candidate, University of Cairo and Dr. El-Assiuty is his Major Professor. Immunoelectrophoresis gels for determining the antigenic determinants of *Pseudomonas andropogonis* (causal agent of

bacterial leaf stripe of sorghum) were interpreted; photographs of the gels were taken and the film was processed at Kansas State University; journal articles were provided for the literature citation of the thesis and a portion of the thesis was edited for Mr. Ishmael.

Sorghum germplasm from the Kenyan breeding program and the ADIN (Texas A&M) was evaluated for disease incidence at Kiboko and Katumani (Kenya) with INTSORMIL collaborators, Dr. Chagema Kedera and Dr. Wilson Songa in November, 1995.

It is anticipated that a collaborative project will be initiated with sorghum researchers in Ethiopia. Bacterial leaf streak (*Xanthomonas campestris* pv. *holcicola*) is a constraint to sorghum production in several areas of Ethiopia. We have furnished cultures and antisera in the past. Contacts will be established with Mr. Tarekegn Geleta, Alemaya University in Dire Dawa; Dr. Mengustu Hulluka, Alemaya University, and Dr. Girma Tegegne, Sorghum Research Center, Nazreth, Ethiopia.

Publications and Presentations

Abstracts

Muriithi, L.B., L.E. Claflin, and B.A. Ramundo. 1995. Survival of *Pseudomonas andropogonis* in Grain Sorghum Debris. Phytopathology 85:1164.

Xu, X., L.E. Claflin, B.A. Ramundo and D.J. Jardine. 1995. Optimizing Production for *Ramulispora sorghi*. Phytopathology 85:1169.

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Journal Articles

Muriithi, L.B., L.E. Claflin and B.A. Ramundo. 1995. Reaction of All Disease and Insect Nursery (ADIN) Accessions to *Pseudomonas andropogonis*. Proc. 19th Grain Sorghum Res and Util. Conf. 19:105-107.

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Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-108B

John F. Leslie
Kansas State University

Principal Investigator

Dr. John F. Leslie, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506-5502

Collaborating Scientists

Drs. Elhamy El-Assiuty and Hamed Mazyad, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt
Drs. Osman El-Nagouly and Rashad A. Abo-Elenien, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt
Dr. Chagema J. Kedera, Plant Quarantine Unit, KARI, Nairobi, Kenya
Dr. Baharuddin Salleh, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia
Dr. Walter F. O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa
Dr. Anaclet S. B. Mansuetus, Department of Biological Sciences, University of Swaziland, Kwaluseni, Swaziland
Dr. Maya Piñeiro, Mycotoxins Unit, Laboratorio Tecnologia del Uruguay, Montevideo, Uruguay
Drs. A. E. Desjardins and R. D. Plattner, USDA National Center for Agricultural Utilization Research, Peoria, IL
Dr. G. Ejeta, Department of Agronomy, Purdue University, West Lafayette, IN
Dr. P. J. Bramel-Cox, Department of Agronomy, Kansas State University, Manhattan, KS
R. Thakur and Dr. J. S. Smith, Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS
Drs. R. W. Bowden, L. E. Claflin and D. J. Jardine, Department of Plant Pathology, Kansas State University, Manhattan, KS
Dr. K. K. Klein, Department of Biological Sciences, Mankato State University, Mankato, MN
Dr. M. B. Dickman, Department of Plant Pathology, University of Nebraska, Lincoln, NE
Dr. P. E. Nelson, Department of Plant Pathology, The Pennsylvania State University, University Park, PA
Dr. R. A. Frederiksen, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX
Dr. G. Odvody, Texas Agricultural Experiment Station, Corpus Christi, TX
Drs. G. Peterson and D. Rosenow, Texas Agricultural Experiment Station, Lubbock, TX

Summary

In *Fusarium* section *Liseola*, the sexual stage (teleomorph) is used to identify mating populations that represent different biological species. The *Gibberella fujikuroi* mating populations to which strains of *Fusarium* section *Liseola* belonged were determined for isolates from sorghum grown at Ifakara, Ilonga, and Kachiri, Tanzania. The frequency of the different mating populations was similar at all three sites with A (21%) and F (49%) being the most frequent and C and E the least frequent, if they were recovered at all. The relative proportions of mating populations A and F in the population were significantly different from each other at Ilonga, but were not significantly different at Ifakara or Kachiri. Based on grain mold scores, at least some strains belonging to the F mating population appear to protect against grain mold, and some strains from the A mating population may be preferentially responsible for the grain mold.

Female sterility has recently been recognized as a significant factor limiting the effective population size of a fungal pathogen. In an analysis of global composite populations of the biological species in the *G. fujikuroi* species complex, polymorphism for female-sterile/hermaphrodite status occurs and female-sterile mutants may compose more than 50% of the population. These female-sterile strains can function as males in sexual reproduction. The female-sterile mutants are at a selective disadvantage every time sexual reproduction occurs. To overcome their disadvantage during sexual reproduction, these mutants must have an advantage during vegetative propagation. When a high frequency of female-sterile strains is observed, it indicates that vegetative propagation is a significant component of the fungus's natural history. Depending on the mutation rate to female sterility and the selective advantage of the female-sterile strains during vegetative propagation, the ratio of sexual:asexual generations can range from 1:15 to 1:2300 for

some species in the *G. fujikuroi* species complex. The relative rarity of sexual reproduction may permit the accumulation of female-sterile strains to such a level that some populations could completely lose sexuality and would appear to be an asexual (imperfect) species. Within the Tanzanian population, female-fertile strains were more common within mating population A than within mating population F. The inbreeding effective population size for the A and F mating populations, respectively, were 69% and 91% of count based on mating type, and 88% and 53% of count based on male/hermaphrodite ratios.

Objectives, Production and Utilization Constraints

Objectives

Increase collection of *Fusarium* samples from sorghum and millet.

Develop characters for assessing genetic variability in fungal populations.

Provide pure cultures of fungi from our extensive collection to U.S. and LDC investigators to expedite diagnoses of fungal diseases of sorghum and millet.

Constraints

Fusarium spp. associated with sorghum and millet do obvious damage as stalk rot, grain mold and pokkah boeng. All of these diseases can cause intermittently heavy losses in the United States and in developing countries. Breeding for resistance to *Fusarium* associated diseases is limited because the strains responsible for disease often cannot be accurately identified and used repeatedly in field challenges.

Mycotoxin contamination limits the uses to which harvested grain can be put, and creates health risks for both humans and domestic animals. *Fusarium*-produced mycotoxins are among the most common mycotoxins found in cereal grains, yet have not been effectively evaluated in sorghum and millet. Since contamination often occurs on apparently sound grain, merely discarding obviously molded grain is not sufficient to avoid the mycotoxicity problems.

Research Approach and Project Output

Research Methods

Tanzanian sites and sampling of sorghum grain. Sorghum grain was collected after physiological maturity from plants grown in the SADC/ICRISAT grain mold resistance nurseries during the 1990/91 cropping season at Ifakara Agricultural Research Institute and Ilonga Agricultural Research and Training Institute. These nurseries consisted of 32 sorghum cultivars grown in single rows and replicated twice. Nine cultivars common to both nurseries were selected (Table 3). Grain mold was rated on a scale of 1-5 where 1=0-20%, 2=21-40%, 3=41-60%, 4=61-80%, and 5=81-100% of the grain surface molded. Four heads were selected per row per replication and 2-3 g of grain (70-100 kernels) was sampled from each head and placed into paper bags containing silica gel as a desiccant. Grain from eleven sorghum heads, selected on a random basis, was collected from a farmer's field in Kachiri; the cultivar/genotype of this local land race was unknown.

One gram of sorghum grain from each head was placed in a 250-ml Erlenmeyer flask containing 100 ml sterile distilled water and swirled at 200 rpm on a rotary shaker for 30 minutes at room temperature. This suspension was diluted 1:9 in sterile distilled water, mixed for an additional 5 min., and a 0.5 ml sample spread on a petri dish containing a peptone/PCNB medium. The plates were incubated under a 12:12 hr light:dark cycle at 22°C for five days; colonies were subcultured from this medium before they coalesced. Two colonies were obtained from each head from Ifakara and Ilonga, and six colonies were obtained from each head from Kachiri. Colonies were purified by isolating single spores through a dilution technique. Colonies resulting from the single spores were grown on complete medium slants, and resulting spore suspensions stored in 15% glycerol at -80°C.

Sexual crosses and mating population identification. Standard tester strains from each of the six mating populations were used as one of the parents in all of the crosses. Crosses were made on carrot agar following standard protocols. Field isolates were initially used as males with the standard tester as the female parent. Once mating population and mating type were identified, the roles in the crosses were reversed to determine if the field isolate was female fertile. Fertile crosses produced perithecia that exuded a cirrus of ascospores. Sterile strains were not fertile in crosses with any of the standard testers in either the original or a replicated set of crosses.

Effective population number (N_e)*:* The size of a population relative to an ideal population in Hardy-Weinberg equilibrium is found by calculating the effective population number. As N_e decreases, the effects of drift and of clonal reproduction become more important. Two common types of effective numbers are often used: (1) the inbreeding effective population number ($N_{e(f)}$), which is based on the probability of identity due to common ancestry, and (2) the variance effective population number ($N_{e(v)}$), which is based on the amount of allele frequency drift per generation as measured by its variance. We have derived equations that can be used in the application of these concepts to haploid fungal populations that are quite different from the animal and plant populations for which these concepts were originally developed. The equations are based on differences in frequencies of strains of opposite mating type, or on the relative proportion of hermaphroditic strains in the population. The inbreeding and variance effective numbers behave in opposite manners as the relative numbers of female-sterile strains and hermaphrodites change. As the number of her-

maphrodite strains increases, the inbreeding effective number also increases, but the variance effective number decreases. $N_{e(f)}$ is more generally useful than $N_{e(v)}$ in the evaluation of fungal populations.

As the inbreeding effective number decreases, the effect of drift in these populations increases. With respect to fertility, effective population size is much more a function of the number of hermaphrodites than it is of the number of female sterile strains. N_e is also more sensitive to a reduction in the number of female fertile strains than it is to an imbalance in the frequencies of the two mating type alleles. Inbreeding effective population number is a concept that is relevant only to sexually reproducing populations, where it is used to estimate the effects of drift and inbreeding. Drift in asexual populations is a function of the extinction of lineages, rather than the loss of alleles. Selection in asexual populations also effects lineage persistence and the ability of lineages to accumulate deleterious mutations. In an agricultural context, a relatively small effective population number indicates that the population is clonal and that breeding against particular strain types will usually be successful. It also indicates that most, if not all, new gene combinations will be the result of mutation and that sexual recombination to produce new strain types will not often occur.

The frequency of hermaphrodites can also be used to determine the relative number of sexual generations per asexual generation. Selection either for hermaphrodites during sexual reproduction or for female-sterile strains during vegetative propagation can drive the population close to an extreme (all hermaphrodites or all female-sterile strains). If, however, the environment is such that alternating selection favoring first the hermaphrodites and then the female-sterile strains occurs, then a sort of equilibrium should ensue. We conceive of this equilibrium as a cycle (Figure 1). Sexual reproduction increases the relative number of hermaphrodites, while the number of hermaphrodites declines during vegetative propagation due to mutation and the asexual reproductive advantage of the female-sterile strains. Hermaphrodite losses due to mutation (μ) or selection (Θ) during the asexual portion of the life cycle need not be distinguished from one another since the two values are multiplied to give a cumulative loss of hermaphrodites per asexual generation. Thus, the variables (μ, Θ and g = number of asexual generations per sexual generation) affecting this cycle are all primarily associated with the asexual portion of the cycle.

An infinite number of equilibrium cycles are possible, each one representing a different set of reproductive and environmental factors. For a cycle to be stable over the long term, the loss of hermaphrodites during vegetative propagation must be balanced by their replacement during sexual reproduction. h_a is the highest value for hermaphrodite frequency during the cycle and h_b is the lowest. If h_b becomes sufficiently small, then it is possible for all of the

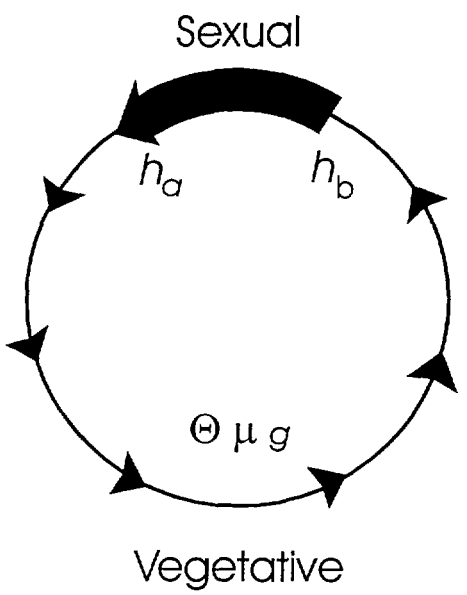

Figure 1. Equilibrium cycle. A single sexual generation alternates with multiple asexual generations to affect the frequencies of hermaphrodites in a population with a mixed reproductive cycle. μ = mutation rate from female fertility to female sterility; Θ = selective disadvantage of hermaphrodites during vegetative propagation; g = number of generations of vegetative propagation per sexual generation; h_a = frequency of hermaphrodites immediately following the sexual generation; h_b = frequency of hermaphrodites immediately preceding the sexual generation.

hermaphrodites to be lost from the population by chance, rendering the population asexual. In general, the greater the frequency of hermaphrodites the more frequently (or recently) sexual recombination occurs. Within a species, μ and θ may be assumed to be constants allowing the comparison of different populations for the relative frequency (g) with which sexual recombination has occurred.

Research Findings

Analysis of Global Populations for Effective Population Number (N_e)

The filamentous ascomycete *G. fujikuroi* (anamorphs in *Fusarium* section *Liseola*) consists of at least six distinct biological species, often referred to as mating populations. The frequency of female sterile strains in globally composite field samples of these fungi ranges from 50 to 90% (Table 1). We had previously noted that the percentage of female sterile strains varies considerably and might be related to the environmental or ecological niche in which each of these biological species thrives. The biological species designated A was collected primarily as a pathogen on maize from temperate regions. Mating population D is found on maize, rice, sorghum, and many other hosts in both temperate and tropical regions. Mating population F is primarily an endophyte of sorghum, and is found with global distribution. Genetic evidence from these mating populations (*e.g.* vegetative compatibility group analysis) is consistent with the hypothesis that there is significant genetic variation within at least some of these species.

Vegetative propagation produces individuals that can be grouped into an equal or smaller number of clones. The number of clones in field samples of *G. fujikuroi* may be inferred from data which categorizes each isolate based on vegetative compatibility group or VCG. Vegetative compatibility is controlled by a large number of loci and/or alleles (probably both) such that members of a single VCG often have very similar, if not identical, genotypes. In field isolates taken from the same population, members of a VCG usually share other genetically determined characteristics such as mating type, spore-killer phenotype and female fertility. In the global populations discussed here, there is a higher degree of clonality among the F mating population than among the D or A mating populations, which had previously led us to speculate that vegetative propagation was relatively more important in species F than in the other two mating populations.

The effective population numbers in the D and the F mating populations are not reduced significantly by the minor discrepancies observed in the relative frequencies of the two different mating types (Table 1). The difference observed in the A mating population is significantly different from 1:1 ($P < 0.001$) and reduces the effective population number to approximately 90% of the count. Thus, even relatively large discrepancies in mating type frequency do not reduce the effective population number to a degree such that drift can play a large role.

All three species have female sterile strains present in frequencies (>50%) well above the mutation rate (Table 1). These data are presumptive evidence for significant levels of vegetative propagation for extended time periods. For mating population A, N_e derived from either the mating type or the female-sterile/hermaphrodite dimorphism is similar (90.6% compared with 88.8%). For mating populations D and F, however, the inbreeding effective population numbers for the female-sterile/hermaphrodite dimorphism, 71.5% and 32.1% respectively, are much smaller than the corresponding values for the mating type polymorphism.

The observed hermaphrodite frequencies can be used to estimate length, in asexual generations, and the range of hermaphrodite frequencies that might occur in an equilibrium cycle (Table 2). The length of the cycle depends on N_h, θ and μ with cycle length increasing as N_h or μ decreases or θ increases. The range and the cycle length also depend on where in the cycle the population is when N_h is measured. For example, if mating population A in Table 2 has just completed the sexual portion of the cycle then N_h would be expected to fall from approximately 50% to 25% before the next round of sexual reproduction. On the other hand if this population was now to go through a sexual cycle then N_h would increase from approximately 50% to 70% after which the asexual decay in N_h would begin once again. The values in Table 2 were calculated based on the assumption that the female-sterile strains and hermaphrodites are equal in their maleness. If the hermaphrodites are not as effective as males as their female-sterile counterparts, then the relative change in the frequencies of the hermaphrodites following sexual reproduction will be reduced and cycle times correspondingly shortened. As noted above, the significance of this

Table 1. Experimental data and effective population size parameters for three biological species in the *Gibberella fujikuroi* species complex.

Biological species	Mating type (+:-)	N_{fs}:N_h	N_e			M
			M.T.[a]	$N_{e(f)}$[b]	$N_{e(v)}$[c]	
A	237: 446	342: 341	90.6	88.8	66.7	0.7
D	72: 63	94: 41	99.5	71.5	76.7	1.2
F	53: 40	84: 9	98.1	32.1	91.2	2.3

N_{fs} - Number of female-sterile male-fertile strains; N_h - Number of hermaphroditic strains; N_e -Effective population number, and M - mean number of female sterility mutations per strain.
[a]Effective population number based on mating type and expressed as a % of the actual count.
[b]Inbreeding effective number based on numbers of males and hermaphrodites and expressed as a % of the actual count.
[c]Variance effective number based on numbers of males and hermaphrodites and expressed as a % of the actual count.

Table 2. Length and range in hermaphrodite frequencies for equilibrium cycles based on observed data from three biological species in the *Gibberella fujikuroi* species complex. Observed frequency of hermaphrodites is from Table 1.

Biological species	Time (h_a)[a]			Hermaphrodites			Time (h_b)[b]		
	0.98[c]	0.99[c]	0.999[c]	Max[d]	Obs	Min[e]	0.98[c]	0.99[c]	0.999[c]
A	17.2	34.4	347	0.706	**0.499**	0.249	34.4	68.8	695
D	29.5	59.0	595	0.551	**0.304**	0.092	59.3	119	1200
F	57.0	114	1150	0.316	**0.100**	0.010	114	228	2300
-	74.2	148	1500	0.224	**0.050**	0.003	148	297	3000
-	114	228	2300	0.100	**0.010**	<0.001	-	-	-
-	130	261	2630	0.070	**0.005**	<0.001	-	-	-
-	172	343	3470	0.032	**0.001**	<0.001	-	-	-

[a]Time, in asexual generations, to cycle from h_a to the observed frequency given the value of $(1-\mu)\theta$.
[b]Time, in asexual generations, to cycle from the observed frequency to h_b given the value of $(1-\mu)\theta$.
[c]$(1-\mu)\theta$.
[d]Value for h_a if the observed hermaphrodite frequency is used as the value prior to sexual reproduction.
[e]Value for h_b if the observed hermaphrodite frequency is used as the value immediately following sexual reproduction.

reduction becomes less important as the proportion of hermaphrodites in the population decreases.

Based on these data, sexual reproduction in mating population A, with the lowest percentage of female sterile strains, is nearly twice as frequent as in mating population D and nearly three times as frequent as in mating population F. Both the D and the F mating populations could cycle to fewer than 10% hermaphrodites (Table 2). Mating population D averages more than one female-sterility mutation per genome and for mating population F, the average is greater than two. In crosses made to develop female-fertile tester strains of mating population F, we previously had obtained sterility: fertility ratios that were consistent with the segregation of female sterility alleles at multiple loci. To further exacerbate the situation in this species, the number of individuals is much larger than the number of clones as measured by diversity in the number of VCGs. The severely reduced inbreeding effective population number (32% of the actual count) increases the tendency for genetic drift. The data are consistent with the hypothesis that the F mating population is moving towards imperfect status and that local populations exist in which hermaphrodites are completely absent. Thus two processes are at work in this species: (1) a reduction in genetic diversity due to clonality, as exemplified by the reduced VCG diversity and the preponderance of female-sterile strains over hermaphrodites, and (2) a reduction in effective population number, as a consequence of the high proportion of the female-sterile strains. There is a kind of synergy in the reduction of population number in these processes, where the effects of drift are felt during both vegetative propagation and sexual reproduction.

Analysis of a Tanzanian Population Associated with Grain Mold

In a collaborative study with Drs. A.S.B. Mansuetus, G.N. Odvody and R.A. Frederiksen we analyzed a *Fusarium* population from Tanzania to determine: (1) The identity and relative frequencies of the mating populations present on sorghum in Tanzania, (2) If mating population is correlated with grain mold, and (3) If mating type or hermaphrodite frequency is reducing the inbreeding effective population size.

Most of our fungal samples originated from grain mold nurseries on two experiment stations. The same cultivars were rated at both locations, but the incidence of grain mold was not the same at both sites, and was more severe in all cases at Ifakara than it was at Ilonga (Table 3). During this growing season, the Ifakara region received more rain and was generally more humid than the Ilonga region.

Isolates of *Fusarium* species in section *Liseola* that we examined were assigned to different mating populations. All mating populations and mating types were represented in our sample, but the A (21%) and F (49%) mating populations clearly dominated. The number of strains that did not cross with any of the standard testers also formed a significant portion of the population (15%) and accounted for most of the remaining strains examined.

There were no significant differences in the frequencies of the A and F mating populations with respect to location. The F mating population was more frequent than the A mating population at all three locations, but only the difference at Ilonga was statistically significant ($P<0.01$). At both Ifakara and Ilonga, isolates belonging to both the A and F mating populations were recovered from all nine cultivars (Table 3). The remaining mating populations were not sufficiently frequent to make meaningful comparisons possible. Of the eleven heads examined from Kachiri, ten were infected by isolates belonging to more than one mating population, and all were infected by at least three genetically different strains. The similarities in the frequencies of the mating populations at the three locations are particularly striking since the host material and the cultural practices in the grain mold nurseries at Ilonga and Ifakara were quite different from that found in the farmer's field at Kachiri.

Female fertile strains were found in all mating populations. Only the A and F mating populations were recovered at sufficient frequency to permit the analysis of these traits in a population context (Table 4). Hermaphrodites were significantly more frequent in the A mating population than

Table 3. Grain mold ratings of and *Gibberella fujikuroi* mating populations recovered from nine sorghum cultivars grown at Ilonga and Ifakara, Tazania.

	Ilonga			Ifakara		
Cultivar	Mold[a]	A[b]	F[c]	Mold	A	F
Serena	1.5 b[d]	3	7	3.5 c	6	4
AIS1683	1.5 b	6	9	3.5 c	6	9
Town	2.0 ab	4	8	4.0 b	6	6
A3244	1.5 b	2	12	3.5 c	8	5
ZSV1-UK-SEL	2.0 ab	1	7	3.0 d	3	7
Marupantse	2.5 a	2	8	5.0 a	6	7
PM10876	2.0 ab	3	8	5.0 a	4	11
FramidaZP	1.5 b	2	10	2.0 e	1	15
PAN337	1.6b	1	9	4.0 b	2	13

[a]Grain mold rating based on a scale of 1-5 where 1=0-20%, 2=21-40%, 3=41-60%, 4=61-80%, and 5=81-100% of the grain surface molded.
[b]Number of strains (from the 16 collected) that were in the A mating population.
[c]Number of strains (from the 16 collected) that were in the F mating population.
[d]Means followed by the same letter within a column are not significantly different by Duncan's multiple range test ($P>0.05$).

Table 4. Female fertility and inbreeding effective numbers for populations of the A and F mating populations recovered from sorghum in Tanzania

	Fertility[b]		N_e[c]		
M.T./M.P.[a]	Male	Herm.	M.T.	Fert.	M[d]
A+	35	24	69	88	0.7
A-	4	13			
F+	94	19	91	53	1.7
F-	48	14			

[a]The base letter indicates the mating population (biological species) within Gibberella fujikuroi and the superscript is indicative of the mating type.
[b]Males function only as the male parent in crosses with the standard testers. Herm = hermaphrodites which can serve as either the male or the female parent in these crosses.
[c]N_e (expressed as a percentage of the count) is the inbreeding effective number for differences in mating type (M.T.) or male/hermaphrodite (Fert.) polymorhisms.
[d]Average number of female sterility mutations per strain assuming a random distribution of the mutations.

they were in the F mating population. In both mating populations the large number of males, 51% in the A mating population and 81% in the F mating population, resulted in large reductions in the inbreeding effective population number relative to the size expected if the entire population had been hermaphrodites, 12% and 47% reductions of the count, respectively. The mating type ratios were significantly different from 1:1 ($P<0.001$) for both mating populations, again resulting in large decreases in the inbreeding effective population number to 69% of the count for the A mating population and to 91% of the count for the F mating population. Hermaphroditic strains of both mating types from both mating populations were recovered from all locations, except at Kachiri where the F^+ hermaphrodite class was absent. In the F mating population, mating type and fertility segregated independently, but these traits were not independent for the A mating population ($P<0.01$).

Our data suggest that there may be differences between test plots on experiment stations and farmers' fields. All mating populations were recovered from sorghum grown at Ilonga. At the Ilonga station, local and foreign germplasm is developed, maintained, and screened. Consequently, the differences in the occurrence and frequencies of the mating populations observed here relative to other locations might be attributable to the introduction of exotic *Fusarium* strains as hitchhikers on asymptomatic seed of sorghum or other crops. In contrast, mating populations D and E were present at higher levels in the sample from the farmer's field at Kachiri than they were in the experimental plots at either Ilonga or Ifakara. The basis for this difference between locations is not known, although some of it may be attributable to the relatively smaller sample size from Kachiri than from the other locations.

In previous work primarily based on samples from the United States, the F mating population has been reported to be dominant on sorghum and the A mating population reported to be dominant on maize, but relatively uncommon on sorghum. Our results are in line with this general finding, particularly with respect to the F mating population, which constituted 49% of the sample in the present study and 55% of the sample in the previous study. The only other mating populations that were present at significant frequencies were the A mating population, which was more common than in previous studies (21% vs. 6%), and the D mating population, which was slightly less frequent (7% vs. 10%). In Tanzania, as previously, the six mating populations are sympatric since they may occur together at the same site and even on the same grain head. The similarity of the composition of these two samples suggests that the fungi that colonize sorghum are relatively constant and that disease expression is a function of the environment and host and/or plant genotypes, rather than the biological species that are present in the interaction or the geographical location in which the interaction is observed. It also suggests that manipulating these variables, as opposed to growing the host in the absence of the fungus, will be necessary to achieve long-term relief from the problems that are associated with these fungi.

With respect to grain mold, we have data (Table 3) on the same host material from a nursery with a relatively low level of grain mold (Ilonga) and a relatively high level (Ifakara). At both locations the number of F mating population isolates was weakly negatively correlated with the grain mold rating

(r = -0.47 at Ilonga and r = -0.23 at Ifakara). The A mating population was not significantly correlated with grain mold at Ilonga (r = -0.18), but was weakly correlated with grain mold at Ifakara (r = 0.39). We pooled the other strain types and found no correlation between grain mold and frequency at Ifakara (r = 0.00) and a weak correlation (r = 0.47) at Ilonga. We interpret these data to mean that at least some strains belonging to the F mating population can protect against grain mold, and that some strains from the A mating population may be preferentially responsible for the grain mold we observed. If grain mold occurs at high levels, then the "other" group has no discernible role. At the lower incidence levels, the "other" group might be expressing the maximum amount of damage that it is capable of inciting under field conditions. Additional explanations for these data can also be proposed, e.g. environmental differences and genetic differences within the mating populations, but at present we do not have sufficient data to evaluate their plausibility. Careful evaluation of individual strains against a battery of host cultivars under different environmental conditions will be necessary to rigorously test this hypothesis.

It has been suggested that the F mating population had originated in Africa and had evolved in concert with its sorghum host, while the A mating population had originated in the Americas and evolved in concert with maize. The data from Tanzania are consistent with this hypothesis. The effective population size of the F mating population in the United States is smaller than its Tanzanian counterpart, while the size of the Tanzanian A mating population is smaller than its U.S. counterpart. For the A mating population, sexual reproduction appears to occur at about the same frequency both in the United States and in Tanzania. The data also indicate that sexual reproduction within the F mating population in Tanzania is more frequent in the United States, although the frequency of hermaphrodites in both locations is consistent with the hypothesis that the two populations are simply at different positions within the same sexual/asexual cycle. The data for both mating populations suggests that sexual reproduction is not common, but widely dispersed clones would be expected to be more common in the F mating population than in the A mating population. The relatively long cycle time (57-1150 asexual generations per sexual generation) would provide sufficient time for the selection and dispersal of clones. On the other hand, if a suitable cultivar or hybrid is developed and deployed, it would be expected to have a relatively longer life if more than a single mutation within the fungus is required to break the resistance gene in the host. Studies of the amount and dispersion of genetic variability within these populations will be needed to answer these questions.

In conclusion, there is a complex dynamic among populations of *Fusarium* spp. associated with grain mold in Tanzania. In many ways, the mix of species parallels that seen in the United States where similar observations have been made. Successful protection of sorghum from fungi associated with grain mold will probably require an approach that combines host-resistance mechanisms with other non-specific controls, including escape. Additional studies on the genetic and epidemiological relationships among *Fusarium* spp. invading sorghum grain may also provide opportunities to use inter-specific competition as a means of biological control.

Networking Activities

Editorial and Committee Service

Editorial Board of *Applied and Environmental Microbiology*

Associate Editor and Editorial Board of *Mycologia*

Member of the International Society for Plant Pathology, *Fusarium* Committee

Editorial Board for the Proceedings of the International Seminar on *Fusarium* Mycotoxins, Taxonomy and Pathogenicity

Research Investigator Exchange

Seminar, Workshop and Invited Meeting Presentations

Department of Biological Sciences, University of Northern Iowa, Cedar Falls, IA - 3/95.

Eighteenth Fungal Genetics Conference, Asilomar, California - 3/95.

American Chemical Society Annual Meeting, Anaheim, California - 4/95.

Fifteenth Eastern Regional Conference on the Ecology of Root-infecting Microorganisms, Columbia, Missouri - 3/95.

International Seminar on *Fusarium* Mycotoxins, Taxonomy and Pathogenicity, Bari, Italy - 5/95.

Departamento de Genética, Universidad de Sevilla, Seville, Spain - 5/95.

Department of Plant Pathology, University of California, Davis - 6/95.

Norwegian Society for Plant Pathology, Ås, Norway - 7/95.

Distinguished Lecture Series in Biological Sciences, Louisiana State University, Baton Rouge, Louisiana - 9/95.

S and G Seeds, B.V., Enkhuizen, the Netherlands - 10/95.

PROMEC, Medical Research Council, Tygerberg, South Africa - 10/95.

Department of Microbiology, University of Capetown, Capetown, South Africa - 10/95.

INTSORMIL/ICRISAT/ASARECA Network Planning Conference, Kampala, Uganda - 11/95.

Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt - 11/95.

Long-term Laboratory Visitors

Dr. Keith K. Klein, Sabbatical visitor 9/94-8/95 (Sponsored by USDA National Research Initiative competitive grant). Present position: Professor, Department of Biology, Mankato State University, Mankato, Minnesota.

Dr. Baharuddin Salleh, Sabbatical visitor 4/96-6/96. Present position: Associate Professor, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia.

1995 Standard FusariumCcultures Provided to:

S. Danielson, CATIE, Turrialba, Costa Rica

Dr. A. Szécsi, Plant Protection Institute, Hungarian Academy of Sciences, Budapest, Hungary

Dr. B. Tudzynski, Botanical Institute, Westfaelische Wilhelms University, Muenster, Germany

Dr. C. J. Kedera, KARI, Nairobi, Kenya

Dr. W. A. J. de Milliano, S and G Seeds, B.V., Enkhuizen, the Netherlands

Z. Chulong, Department of Plant Protection, Zhejiang Agricultural University, Hangzhou, People's Republic of China

Dr. J. Chelkowski, Institute of Plant Genetics, Polish Academy of Sciences, Poznan, Poland

Dr. W. F. O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa

Dr. Javier Avalos, Genetics Department, Universidad de Sevilla, Seville, Spain

Dr. Maya Piñeiro, Mycotoxin section, Laboratorio Tecnologico del Uruguay, Montevideo, Uruguay

Dr. D. G. Gilchrist, Department of Plant Pathology, University of California, Davis, CA

Dr. Claude P. Seletrinnikoff, University of Colorado Health Sciences Center, Denver, CO

Dr. Charles Bacon, USDA Russell Research Center, Athens, GA

Drs. R. D. Plattner, A. E. Desjardins and K. O'Donnell, USDA National Center for Agricultural Utilization Research, Peoria, IL

Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, KS

R. Thakur and Dr. J. S. Smith, Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS

Drs. R. W. Bowden, L. E. Claflin and D. J. Jardine, Department of Plant Pathology, Kansas State University, Manhattan, KS

Dr. M. Stankis, Myco Pharmaceuticals, Cambridge, MA

Dr. P. E. Nelson, Department of Plant Pathology, The Pennsylvania State University, University Park, PA

Publications and Presentations

Abstracts

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Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-105
Henry N. Pitre
Mississippi State University

Principal Investigator

Dr. Henry N. Pitre, Entomologist/Professor, Mississippi Agricultural & Forestry Experiment Station, Mississippi State University, Box 9775, Mississippi State, MS 39762

Collaborating Scientists

Dr. Francisco Gomez, Plant Breeder, Agronomy Department, Panamerican School of Agriculture (EAP), Apartado Postal 93, Tegucigalpa, Honduras

Dr. Ron Cave, Entomologist, Plant Protection Department, Panamerican School of Agriculture (EAP), Apartado Postal 93, Tegucigalpa, Honduras.

Dr. Billy Wiseman, Entomologist, USDA, Insect Biology and Population Management Research Laboratory, Tifton, Georgia.

Dr. David Parvin, Agricultural Economist, Agricultural Economics Department, Mississippi State University, Mississippi State, Mississippi.

Summary

Soil inhabiting insects, stem borers and panicle feeding insects contribute to reduced yields of sorghum and/or corn on subsistence farms in Honduras; however, the major insect pest constraint to production of these crops is foliage feeding insects. A complex of defoliator caterpillars, known to subsistence farmers in Honduras as "langosta", annually damages or destroys the sorghum and corn crops. The pest complex has been identified by MSU-105 to consist of four lepidopterous caterpillars, including three armyworm species and a grass looper.

Aspect of the biology, ecology, behavior and population dynamics of the armyworm species has identified the role of these insects in this complex. This information has contributed to the successful conduct of entomological research designed to evaluate ecological relationships of the pest insects with crop and noncrop plants within various cropping systems, crop planting and management strategies, host plant resistance, influence of insecticides on pest and natural enemy populations, and roll of naturally occurring beneficial agents in regulation of pest populations. Insect pest management tactics have been investigated (usually alone) in crop production systems in areas where the insects are a constraint to crop production. These tactics are under investigation in holistic on-farm crop management systems. Information obtained from MSU-105 research on sorghum and corn will assist subsistence farmers in producing grain crops with increased yield at minimum cost for pest control and with reduced risk to human health.

The entomological investigations in MSU-105 have provided the basis for development of insect pest control strategies for sorghum and corn production in Honduras and surrounding regions in Central America having similar insect pest constraints. The extension of the project into El Salvador and/or Nicaragua in 1997 will expand the scope of MSU-105 activities in this ecogeographic region.

Objectives, Production and Utilization Constraints

Objectives

Determine influence of specific weed management practices on lepidopterous insect pests in the "langosta" complex and natural enemy populations on production farms.

Determine the influence of specific planting dates on the "langosta" pests and natural enemy populations on production farms.

Determine the efficacy and residual impact of insecticide spray(s) on the lepidopterous larvae in the "langosta" complex on production farms.

Conclude studies and prepare manuscripts on aspects of biology and behavior of *Metaponpneumata rogenhoferi*, a lepidopterous caterpillar in the "langosta" complex on sorghum and corn. This insect species is one of the four species responsible for damage or destruction of sorghum and corn seedlings and older plants on subsistence farms in Honduras.

Constraints

Ninety percent of the sorghum acreage in southern Honduras is intercropped with corn because of adverse environment and agronomic conditions. In this area, tall,

photoperiod sensitive, low yielding sorghum, called "maicillos criollos" are intercropped with corn. If the corn crop is lost to drought, farmers substitute sorghum for corn to feed their animals and family. Thus, sorghum is an insurance crop during dry years when the corn crop fails, which occurs in three of every five years. More than 40% of the sorghum harvested in southern Honduras is destined for human consumption.

The lepidopterous "langosta" pest complex is considered by subsistence farmers to be the principal threat to their sorghum-corn crop during the early period of crop development. Biological and ecological studies have been conducted in MSU-105 with the armyworm species (*Spodoptera frugiperda*, *S. latifascia*, and *M. rogenhoferi*) in different crop production areas in Honduras. Insect pest biology, ecology and seasonal population dynamics studies elucidated the role of these three insect species in intercropped sorghum and corn. Noncrop plant "source habitats" and crop plant "sink habitats" have been identified and the biotic potential of the species in the crop production systems has been determined. Crop mortality factors have been partitioned in limited studies in sorghum-corn intercropped systems in southern Honduras, with insects accounting for 65% of the mortality to the crops.

Having previously identified the importance of two of the lepidopterous caterpillar species in the "langosta" complex, studies in 1994-96 emphasized a third species, *M. rogenhoferi*. The relationships of this little researched species with non-crop vegetation and crop plants in sorghum-corn production environments was emphasized. Studies were concluded on the influence of host plants on larval developmental time and adult survivorship. The pest population levels and dynamics of infestations on the crops during the growing season for this species, and others in the lepidopterous complex, assists in developing total insect pest management strategies for the "langosta" in intercropped sorghum and corn in specific regions of Honduras. Aspects of this research is transferable to other areas in Central America.

The international significance of the *Spodoptera species*, as well as *M. rogenhoferi*, particularly in relation to migration and pest control and insecticide resistance, has impact on sorghum production for various regions in the Latin American Ecogeographic Zone, as well as potential impact on crop production in the United States (this is particularly significant for the fall armyworm, a serious pest throughout the Americas).

Alternative insect pest management practices (limiting insecticide use) which are practical for use by the subsistence farmer have been evaluated in MSU-105. Investigations have been further designed to elucidate specific aspects of langosta pest management tactics previously identified as practical for control of the species in this lepidopterous complex that limit crop production. The sorghum breeding program with EAP is designed to develop improved maicillo varieties and photoperiod sensitive hybrids. MSU-105 is active in this program, and has identified antibiosis resistance in the native landrace cultivars, and research has elucidated the antibiosis mechanisms of resistance.

Research Approach and Project Output

Research Methods and Research Findings

Honduras

Weed Management — Influence on the "Langosta" Lepidopterous Pest Complex and Beneficial Agents

Weeds have been shown to have an influence on the biology and behavior of the "langosta" lepidopterous caterpillar species attacking sorghum and corn in Honduras. However, specific and detailed weed management practices have not been evaluated (in comparisons) on subsistence, production farms. In 1995, weed management treatments were tested in on-farm comparisons in southern Honduras to determine the best program to include in on-farm validation and demonstration studies (initiated in 1996). Treatments included different levels of weed control during the growing season. Information was obtained on weed species identification, establishment, buildup, and diversity, as well as weed association with insect pest diversity and density, and weed association with predator-parasitoid diversity and density. Yield data and economic information (cost of on-farm labor, cost of external inputs, and economic investment and return) were obtained for each treatment.

Treatment (T) included:

T1. 100% weed control at planting, plus as needed (control).

T2. 50% weed control at planting.

T3. 100% weed control one week post crop emergence.

T4. 100% weed control two weeks post crop emergence.

T5. 100% weed control three weeks post crop emergence.

Twelve broadleaf weeds were identified in this investigation. The most common species were *Portulaca oleracea* (20% incidence), *Amaranthus* sp. (15% incidence), *Ipomoea* sp. (15% incidence), *Cassia* sp. (10% incidence), *Melanpodium divaricatum* (10% incidence), *Bidens* sp. (10% incidence), *Mimosa pudica* (5% incidence), *Sida acuta* (5% incidence), and unidentified species (10% incidence). The broad leaf weed population dynamics changed due to cultivation during the growing season, thus being replaced to a great extent by grasses. However, the broad

leaf weeds are very important as a source habitat for buildup of the caterpillars and natural enemy populations. These natural enemy populations consist of predators and parasitoids, especially wasps, flies and spiders.

Eighteen grasses were identified in the study area. The most common were Digitaria sp. (25% infestation), *Cynodon dactylon* (10% incidence), *Ixophorus unisetus* (20% infestation), *Cyperus* sp. (10% incidence), *Echinochloa* sp. (10% incidence), *Panicum* sp. (5% incidence), *Cenchrus* sp. (5% incidence), *Setaria* sp. (5% incidence) and other unidentified grasses (10% incidence). The grasses were found to be a good food host for early infestations of *Spodoptera frugiperda* and *S. exigua*, as well as, *Mocis latipes* late in the season. These grasses included *Digitaria* sp. and *Ixophorus unisetus*. *M. rogenhoferi* could not be found, probably because the early rains in April terminated diapause and the emergence and oviposition of the adults could not be recorded during the months of this study. Several generations of *S. frugiperda* were found feeding on the crops during all of the developmental stages. Treatments with 100% weed control two weeks post crop emergence showed less foliage damage to the crops during early crop development than treatments with weed control at planting.

The noncrop vegetation served as preferred oviposition and feeding hosts for the langosta species during the early stage of crop development. With the insects feeding on the preferred weed host plants, damage to the sorghum and corn crop was minimized. The influence of the noncrop vegetation, especially the grasses, during the entire crop growing season could influence yield depending upon when weed removal operations are administered. This relationship in regard to yield in treatments will be determined by economic analysis of data obtained in 1995 and 1996.

The influence of weed management on natural enemies (predators, parasitoids) of the langosta species was considered in treatments. Parasitization of caterpillars in the treatments with 100% weed control post crop emergence was higher (90% parasitization) than that in treatments with weed control at planting (50% parasitization). This may be related to the presence of weeds which serve as a source of refuge and food for the parasites. The most frequently encountered parasites included the tachinid flies *Lespesia archippivora* (10% parasitization), *Archyta* sp. (5% parasitization), and *Chetogena* sp. (5% parasitization). The most common parasitic wasps were the braconid *Chelonus insularis* (25% parasitization) and the ichneumonids *Ophion* sp. (5% parasitization) and *Pristomerus spinator* (10% parasitization). However, the most frequently encountered parasite in all the weed management systems was a nematode, *Hexameris* sp. (40% parasitization). The role of each of the parasites in the population dynamics of each of the langosta pest caterpillars will be ascertained in on-farm experiments during 1996 and 1997. In addition, predation by foliage and soil inhabiting predators will be determined in order to partition the influences of biotic control factors on the pest populations.

Planting Date — Influence on the "Langosta" Lepidopterous Pest Complex and Beneficial Agents

Farmers traditionally plant sorghum and corn as soon as possible after the first rains, typically in late April or early May. Planting time can have an impact on the level of insect pest infestation and crop damage. This is particularly apparent when insect pest infestations are closely associated with environmental factors that influence extreme population establishment and buildup. This appears to be the situation with the "langosta" caterpillar populations.

As with the weed management investigation, different planting dates were tested in on-farm experiments in southern Honduras to determine the optimum planting dates to be included in validation and demonstration studies (initiated in 1996). Treatments included traditional planting system and planting at four plantings at short intervals thereafter. Data was collected as indicated in the weed-management investigations. Weed control was performed manually in order to minimize the interference of external inputs, like herbicides that are not commonly used by resource poor farmers.

Treatments (T) included:

T1. Planting date immediately after the beginning of the rainy season (control).

T2. Planting date 3 days post first planting.

T3. Planting date 6 days post first planting.

T4. Planting date 9 days post first planting.

T5. Planting date 12 days post first planting.

Although the interval between planting dates was short, delayed planting (9 days post first rains) proved to be the best planting date strategy to reduce crop damage by the early season defoliator species in the "langosta" complex. The later plantings experienced less foliage damage to early whorl stage plants than the early plantings. The young crop plants in the early plantings were attacked by the "langosta" caterpillars at the peak of the population, often completely destroying the crops. This early population of pests (consisting mostly of two species) attacks noncrop host plants, before moving to the grain crops during the early part of the crop growing season. If these pests complete most, if not all, of their development on the noncrop plants, damage to the early growth stages of the later planted grain crops is minimized.

Parasites and degrees of parasitization of the langosta caterpillars was similar to that observed in the weed management study. Predators, especially stinkbugs, spiders and earwigs, were more abundant on the early planted crops than on the late planted crops, possibly due to the greater amounts of foliage on the earlier plantings (older crops) than on the

later plantings (younger crops), which provides them with greater refuge area to establish populations. The relationship between predators and parasites with noncrop vegetation and planting dates needs investigation (Studies to be conducted in 1996 and 1997).

Insecticide Evaluations — Influence on the "Langosta" Lepidopterous Pest Complex and Beneficial Agents

Chemical insecticides, when available to the subsistence farmers, are used to suppress the "langosta" complex on sorghum and corn. This approach is often less than acceptable for a variety of reasons, including selection of ineffective materials, poor application methods and improper timing of application. The insecticide evaluations conducted in 1995 were performed to evaluate selected insecticides applied at appropriate times. The different application schedules were evaluated for insect infestation on the crops, material efficacy, reinfestation, impact on predators and parasitoids, and yield and economic returns.

Of the chemicals tested, Lannate provided the highest level of control of the "langosta" species, followed by Lorsban, Curacron and Tamaron. Chemicals were applied when eggs and early larval developmental stages of the pests were observed. Best results were obtained following an intensive sampling program to determine egg infestation level and/or early larval stages. The chemicals reduced parasitism by 30% and foliar damage was less when insecticide was applied to the early larval stages. Tamaron has a low price and can be considered for use depending upon infestation level and age structure of the population, whereas Lannate would be more effective when treatment is required for a variable population of larvae.

Occurrence, Host Plant Relationships and Diapause of *M. rogenhoferi* (Analysis of data and management preparation)

M. rogenhoferi, like *S. frugiperda* and *S. latifascia*, is associated with noncrop vegetation upon which they feed before moving to sorghum and corn. Systematic sampling of vegetation types in and around production fields before planting revealed that this species infested noncrop vegetation of several types beginning immediately after the on-set of the rainy season. Further observations indicate that *M. rogenhoferi* appears to have only one (possibly two) generation on crop and/or noncrop vegetation and then pupates in diapause in the soil in southern Honduras. The following three investigations were completed in 1993 and 1994 and results were analyzed in 1995 for discussion in relation to: 1) the univoltine or multivoltine behavior of the species, 2) host oviposition preference for and larval development on broadleaf plants compared with sorghum, corn and other grass plants, and 3) influence of soil moisture and time on pupal diapause.

Diversity of *M. rogenhoferi* developmental stages and density were used to depict insect occurrence in time and with host plant growth stage. Our observations suggest that sorghum and corn may be sink habitats for this species and that certain noncrop vegetation types are preferred over sorghum and corn.

M. rogenhoferi larvae were first collected on noncrop plants that emerged following the initiation of the rains and prior to crop planting in May of 1995, as in previous years; this further supported earlier observations of a pupal diapause. The ecological relationship of this species with noncrop host plants and the population structure (insect developmental stages) during May-June, as confirmed by intensive sampling in the crop production area, identified the time that this species is potentially destructive to the crops. In most years, *M. rogenhoferi* may be the most damaging species in the "langosta" complex; in other years it may appear as only a contributor to crop destruction by the "langosta". In 1995, this armyworm appeared as a contributor to crop destruction and did not play a major role in damaging the young plants. The biological and ecological relationships of this species in sorghum and corn intercropping systems will be further investigated in various ecogeographic regions and crop production systems to elucidate the specific factors responsible for the occurrence of devastating populations of this defoliator pest species at different times in Honduras.

Diapause in *M. rogenhoferi* during the dry season was investigated in previous on-farm and laboratory experiments. Time that pupae remain in diapause and soil moisture appeared to be closely related to termination of this resting stage. Larvae fed different plant diets were not influenced in termination of diapause. This biological information is useful in understanding the role of crop and noncrop plants, as well as survival potential of the species in the "langosta" complex. This is the type of biological information necessary for design of successful insect pest management methods for the complex of defoliators that is the principal pest constraint to sorghum and corn in many areas of Central America

Integrated Crop Management

Insect pest control developed for one species or a complex of species involves the integration of specific management tactics, possible applied throughout the crop growing season, in a holistic crop management system. This holds true for insect pest management in subsistence farming, as it does for high technology crop production. Host plant associations have been identified and ecological relationships defined for three of the "langosta" defoliator species; these investigations have provided the information for design of integrated insect pest management programs for designated crop production areas. The use of cultural control methods (e.g., planting dates and weed management in production fields), crop varieties with insect resistance, and limited and judicial use of insecticides, as previously iden-

tified in the MSU-105 project, will benefit sorghum-corn production in Honduras and other areas in Latin America having similar crop production problems. The observation of various levels of antibiosis host plant resistance in the maicillo criollos to fall armyworm can have considerable impact on sorghum insect pest control. The subsistence farmers in this region of Latin America use a wide variety of native land race sorghums, many of which may have some levels of insect resistance. The antibiosis resistance characters in these cultivars are desirable for use in the Honduran National Sorghum Breeding Program.

Unfortunately, little Integrated Pest Management (IPM) research has been done in this region in Central America. In order to improve pest control on resource-poor farms in Honduras through the development of multi-tactical IPM programs, on-farm evaluations must be conducted. Validation research activities in 1996 will determine the economic value of control tactics in on-farm experiments. The information provided by the agronomic and pest control practices that contribute to the quantification of yield for each IPM program must be economically evaluated in order to be useful in making recommendations for insect pest management. If farmers respond logically to the economics of on-farm production costs and/or market economics, they will adopt IPM programs that can increase yields and produce a surplus to increase cash flow.

United States

Planting Date - Crop System Examinations

Sorghum planted at early recommended planting dates, as well as delayed plantings were examined for insect pests in northeastern Mississippi in 1995. Observations were made (systematic sampling) on insect pest species diversity and density throughout the crop growing season. Sorghum was planted in monoculture and intercropped with corn (sorghum stripped with corn). Chinch bugs and corn leaf aphids established on early whorl stage plants (both crops-corn preferred), fall armyworm larvae damaged (but not significantly) early to mid-whorl stage plants, southwestern corn borer larvae infested corn stalks (not sorghum) but caused little economic damage, and a complex of lepidopterous larvae infested the sorghum panicles and corn ears. The lepidopterous larvae included sorghum webworm, fall armyworm and corn earworm on sorghum, and fall armyworm and corn earworm on corn. This inventory of pest insects and observations on crop production will continue in 1997 - 1998 to ascertain levels of insect pest infestations and aspects of pest and crop dynamics in the different planting (crop) systems, particularly during years when acreage of the grain crops has increased substantially in the mid-South in the United States.

Networking Activities

Germplasm and Research Information Exchanges

Supplies and equipment required by graduate students in performance of research activities in the laboratory and field in Honduras were supplied (as in previous years) by MSU-105. Some financial support (cash) is provided annually to the students for research expenses while in Honduras.

Publications and Presentations

Journal Articles

Castro, M. T., H. N. Pitre, and D. H. Meckenstock. _____. Fall armyworm (*Spodoptera frugiperda*) (J.E. Smith) (Lepidoptera: Noctuidae) development on Honduran landrace sorghums as a function of plant age. Trop. Agric. (Accepted).

Castro, M. T., H. N. Pitre, D. H. Meckenstock and F. Gomez. _____. Influence of slash and burn and slash and mulch practices on insect pests in intercropped sorghum and maize in southern Honduras. CEIBA. (Accepted).

Lopez, J. I., H. N. Pitre, D. H., Meckenstock, and F. Gomez. _____. Evaluation of Honduran landrace sorghums for antibiosis resistance to Spodoptera frugiperda (Lepidoptera: Noctuidae). CEIBA. (Accepted).

Lopez, J., H. N. Pitre, D. H. Meckenstock, and F. Gomez. _____. Evaluation of a sorghum population for resistance to fall armyworm (Lepidoptera: Noctuidae). Trop. Agric. (Accepted).

Portillo, H. E., H. N. Pitre, D. H. Meckenstock, and K. L. Andrews. _____. Performance of a lepidopterous pest complex (the langosta in Honduras) on sorghum, maizes and non-crop vegetation. Environ. Entomol. (Accepted).

Portillo, H. E., H. N. Pitre, D. H. Meckenstock, and K. L. Andrews. _____. Oviposition preference of *Spodoptera latifascia* (Lepidoptera: Noctuidae) for sorghum, maize and non-crop vegetation. Fla. Entomol. (Accepted).

Portillo, H. E., H. N. Pitre, D. H. Meckenstock and K. L. Andrews. ____. Feeding preferences of neonates and late instar larvae of a lepidopterous pest complex (the langosta in Honduras) (Lepidoptera: Noctuidae) on sorghum, maize, and noncrop vegetation. Environ. Entomol. (Accepted).

Portillo, H. E., H. N. Pitre, D. H. Meckenstock, F. Gomez and J. Lopez. ____. Validation of new agronomic and plant protection technologies in intercropped sorghum and maize in southern Honduras. Trop. Agric. (Submitted).

Role of Polyphenols and Other Defense Chemicals in Sustainable Production and Utilization of Sorghum

Project PRF-104B and PRF-104C
Larry Butler
Purdue University

Principal Investigator

Dr. Larry Butler, Professor of Biochemistry, Biochemistry Department, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Dr. Gebisa Ejeta, Professor of Agronomy, Agronomy Department, Purdue University, West Lafayette, IN 47907
Dr. Abdel Gebbar Babiker, Weed Control Program, Agricultural Research Corporation, Gezira Station, Wad Medani, Sudan

Summary

This project applies biochemical techniques, in an interdisciplinary manner with LDC and other INTSORMIL collaborators, to characterize sorghum's defense chemicals, to elucidate their role in minimizing losses to birds, grain mold, and *Striga* and to overcome their role in limiting nutritional quality. We collaborate closely with our breeder colleagues in developing relatively rapid and simple laboratory assays for screening these chemicals in sorghum germplasm. We also collaborate with animal nutritionists, food scientists and crop protection specialists.

New compounds we have characterized in the past year are caffeic acid esters of complex phenyl ethanol glycosides. These were found in fresh extracts of *Striga asiatica* by a bioassay-directed fractionation procedure. The goal of this aspect of the *Striga* research is the characterization of the so-called "toxin" from *Striga*, which controls and limits host crop growth and productivity. At earlier stages in the characterization of compounds we extract from *Striga*, we confirmed previous reports of high levels of mannitol, which is a relatively unreactive sugar alcohol that contributes to the high osmotic pressure of *Striga* that helps it attract water away from its host, and of polyamines such as spermine. None of the materials identified so far accounts for the "toxin's" activity against host tissue.

Objectives, Production and Utilization Constraints

Objectives

To identify the chemical components of *Striga* plants that control the growth and productivity of *Striga's sorghum host.*

To utilize *in vitro* tissue culture to introduce herbicide resistance into the *Striga*-resistant sorghums recently developed and released by our collaborative research program with Dr. Ejeta.

To develop a screening bioassay for at least one more trait that confers resistance to *Striga*, preferably one that occurs after germination but before much damage occurs to the host.

To determine definitively the role of sorghum polyphenols, including tannin, in feeder cattle nutrition.

To train, establish and encourage a network of LDC collaborators in national agricultural research programs who, with help from INTSORMIL and other sources, will continue to address these problems.

To publish (with Dr. Ejeta) about six journal articles describing work already completed on bird, mold and *Striga* resistance in sorghum, along with a major review for Annual Review of Phytopathology and a non-specialized article on *Striga* for Natural History or a similar publication.

Constraints

The parasitic weed *Striga*

Grain-eating birds

Grain molds and leaf diseases for which polyphenols play a defense role

Antinutritional effects of tannins

Research Approach and Project Output

Research Approach

This is an integrated interdisciplinary research program coordinated closely with that of Dr. Ejeta. Our general approach is on sorghum improvement by enhancement of its resistance to pests, but we also contribute new basic

knowledge about sorghum and its pests and nutritional constraints. The specific approach we often use is to collect and/or identify by screening superior sources of resistance (to birds, mold, *Striga*, etc), establish in the laboratory the biochemical mode of resistance, develop a simple method of screening for the resistant trait, screen genotypes in the laboratory for the trait, confirm their resistance in the fields of our African collaborators, and use them in breeding improved sorghums. The major emphasis we place on developing pest resistant crops (rather than chemical or technological "fixes" of the pest problem) is consistent with the current thrust toward low input sustainable agriculture, and is particularly appropriate for African subsistence farmers with limited access to inputs.

Project Output

Research methods development: In the past year we have considerably refined our bioassay for the "toxin" produced by *Striga*. We are still seeking a simple and reliable chemical assay for dhurrin.

Research Findings

Striga: The necessity of coordinating the life cycle of *Striga* with that of its host has led us to the recognition of the tight integration of the *Striga* life cycle with growth and development of the host by means of a series of chemical signals exchanged between the two. We have played an important role in the identification of the first signal, germination stimulant, and have provided evidence for later signals exchanged in both directions between *Striga* and its host by means of vascular connections, rather than through the soil medium as for germination stimulant and haustorial initiator.

We are also attacking the problem of how *Striga* controls growth and development of its host plant. We have shown that crude extracts of *Striga* plants are toxic to host plants, and have developed a bioassay for this apparent *Striga*-derived "toxin." We have extracted and isolated from *Striga* several candidates for the *Striga* toxin, including several polyols and polyamines as well as a series of unique phenolic glycosides, with complex sugar structures. None of the components extracted and identified from *Striga* so far account for the activity of the toxin. Our bioassay-directed separation produces two fractions with quite different properties which together seem to be responsible for the toxin activity.

Bird resistance: We have continued to address the development of a convenient chemical assay for dhurrin, which we have shown contributes significantly to bird resistance of the grain of certain sorghums. Our best assay still requires the use of HPLC technology, which is too slow and costly for routine analyses.

Nutritional quality: We are initiating an extensive study of the role of sorghum tannins and other polyphenols in the diets of feeder cattle.

Networking Activities

Workshops

L.G. Butler, Eastern Africa Regional Sorghum and Millet Workshop, November 6-9, 1995, Kampala, Uganda.

L.G. Butler, Sixth Parasitic Weed Symposium, April 16-18, 1996, Cordoba, Spain.

L.G. Butler, ICRISAT Sector Review for *Striga* Control in Sorghum and Millet, May 27-28, 1996, Bamako, Mali.

Research Investigator Exchanges (all done at Purdue)

Helio T. Prates, Research Scientist, EMBRAPA/CNPMS (Brazil), July 2-31, 1995.

Betty Bugusu, Food Scientist, KARI (Kenya), August 29-October 6, 1995.

Nivea Medina, Summer research student from the U. of Puerto Rico, June 4-July 30, 1995.

Abdellah Mohammed, Dr. Babiker's assistant at ARC, Sudan, is currently studying for his Ph.D. under Dr. Ejeta in Agronomy, and is using our *Striga* containment facility for the research, along with other students from the laboratory of Dr. J. Bennetzen, Biology.

Germplasm and Research Information Exchange

Distribution of *Striga*-resistant sorghums in Africa: see G. Ejeta's report.

Provided research supplies for B. Siame, former student, at the U. of Botswana.

Research information has been exchanged with virtually all the cooperating scientists.

Cooperating Scientists

Dr. Ann Hagerman, Department of Chemistry, Miami University, Oxford, Ohio 45056.

Dr. Adolf Nahrstedt, Institut fur Pharmazeutische Biologie und Phytochemie, Westfalische Wilhelms-Universitat, Munster, Germany

Drs. Athene Lane and John Bailey, IACR-Long Ashton Research Station, University of Bristol, Bristol, UK.

Dr. Sam Mukuru, ICRISAT Sorghum Breeder, SAFGRAD, Nairobi, Kenya.

Dr. Robert Schaffert, EMBRAPA, Sete Lagoas, MG, Brazil.

Dr. Dale Hess, Millet Pathology, ICRISAT Sahelian Center, B.P.12404, Niamey, NIGER (via Paris)

Dr. L. M'Ragwa, Ben Kanyengi and Gordon Abayo, Kenya Agriculture Research Institute, Nairobi, KENYA

Drs. Axtell and Housley (Agronomy), Bennetzen (Biology), Donkin (Animal Science), Hamaker (Food Science), all at Purdue University.

Publications and Presentations

Journal Articles

Melake Berhan, A., A. Menkir, G. Ejeta and L.G. Butler. 1996. Grain mold resistance and polyphenol accumulation in sorghum. J. Agric. Food Chem., in press.

Wheeler, R.A., W.R. Chaney, K.D. Johnson, and L.G. Butler. 1996. Leucaena forage analysis for tannin using near infrared reflectance spectroscopy. Animal Feed Science and Technology, in press.

Vogler, R.K., G. Ejeta, and L.G. Butler. 1996. Inheritance of low production of Striga germination stimulant in sorghum. Crop Science, in press.

Book Chapters and Proceedings

Babiker, A.G.T., I.A. Ali, G. Ejeta, L.G. Butler and W.R. Woodson. 1995. Striga asiatica germination requires stimulation of 1-aminocyclopropane-1-carboxylic acid (ACC) synthesis and oxidation. Pp. 23-24. In J.A. Bailey and J.A. Lane (eds.). Proceedings of International Workshop on Parasitic Plants: Biology and Resistance. IACR-Long Ashton Research Station, Bristol, UK. May 30th-June 2nd, 1995

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Presentations

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Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-124

Richard A. Frederiksen
Texas A&M University

Principal Investigator

Dr. R. A. Frederiksen, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843

Collaborating Scientists

Bandyopadhyay, R., Crop Protection, ICRISAT, Patancheru, Andhra Pradesh 502 324, India
Carlos R. Casela, EMBRAPA/CNPMS, Caixa Postal 151, Sete Lagoas 35700, MG, Brazil
Larry Claflin, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506
Jeff Dahlberg, USDA-ARS-TARS, Box 70, Mayaguez, Puerto Rico 00681
R. R. Duncan, Department of Agronomy, Georgia Agricultural Experiment Station, 1109 Experiment St., Griffin, GA 30223-1797
J. Peter Esele, Uganda Agriculture and Forestry Research Organization, Sorghum & Millets Unit, Serere, P.O. Soroti, Uganda
Laura Giorda, INTA, EEA Manfredi, 5988 Manfredi, Cordoba, Argentina
Francisco Gomez, Escuela Agricola Panamericana, P.O. Box 93, Tegucigalpa, Honduras
Issoufou Kollo, INRAN, Niamey, Niger (Currently a Graduate Assistant at Texas A&M University)
John F. Leslie, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506-5502
Jill Lenné, Crop Protection, ICRISAT, Patancheru, Andhra Pradesh 502 324, India
G. Odvody, Texas A&M University Agricultural Research and Extension Center, Highway 44, Route 2, P.O. Box 589, Corpus Christi, TX 78410
El-Hilu Omer, Agricultural Research Corporation, Botany and Plant Pathology Section, Gezira Agric. Res. Station, Wad Medani, Sudan
S. D. Singh, ICRISAT, Patancheru, Andhra Pradesh 502 324, India
G. L. Teetes, Department of Entomology, TAMU, College Station, TX
Ram Thakur, ICRISAT, Patancheru, Andhra Pradesh 502 324, India
Melville D. Thomas, 50 Malamah-Thomas St., Freetown, Sierra Leone

Summary

Emphasis has been placed on the mapping of host resistance in sorghum for use in marker-assisted selection. Populations of recombinant inbreds for mapping resistance genes to anthracnose, downy mildew, head smut, leaf blight, and grain mold are being evaluated. Marker-assisted selection will permit both the breeding of resistance to pathogens not present and the building of more durable resistance. Improved methods for evaluating reaction to head smut and identifying the pathogen mating type in culture will hasten research on both detection of resistance and dynamics of the pathogen population analysis. During the past two years, a major effort to integrate disease management into a broad based crop management model has been designed. Progress in combining agronomic, economic and ecological aspects of crop management is an exciting opportunity for improving crop efficiency and productivity.

Objectives, Production and Utilization Constraints

Objectives

Honduras

Identify the most important disease constraints and design disease control strategies.

Continue studies on variability of *Colletotrichum graminicola* and genetic resistance of sorghum grown in Honduras to anthracnose.

Continue to monitor the major downy mildew screening program run by the Honduran National Program to evaluate disease and host plant resistance.

India/ICRISAT

Continue collaboration with ICRISAT on growing, distributing, and evaluating the Sorghum Anthracnose Virulence Nursery.

Initiated preparations for 1998 or 1999 Sorghum/Millet Crop Protection Conference and an emergency meeting on ergot in the Americas.

Mali

Continue efforts to establish a National Sorghum and Millet Disease Program.

Evaluate the Texas A&M/INTSORMIL nurseries for reaction to the prevalent pathogens in Mali.

Study the interaction of mold and insects on grain deterioration.

Niger

Continue monitoring resistance to long smut performed by the Niger Sorghum Improvement Program, along with evaluation for resistance to head smut, Acremonium wilt, and anthracnose.

Summarize data on the survival of spores from long smut.

Summarize data on a trial on the effect of different fertilization treatments on the incidence of *Striga hermonthica* in pearl millet.

Continue the use and deployment of Apron® Plus as a control for downy mildew of pearl millet.

Domestic

Identify sources of resistance to disease.

Assist in the incorporation of multiple sources of resistance to disease.

Determine inheritance of resistance.

Genetically map disease resistance traits by both conventional and biotechnical methods.

Improve disease screening methods.

Study biology of disease epidemiology of sorghum pathogens as needed.

Organize, maintain, and distribute the international sorghum disease and pathogen identification nurseries in collaboration with ICRISAT, and with TAM-122 and TAM-128.

Detect, identify and catalogue *Colletotrichum graminicola* and *Sporisorium reilianum* isolates worldwide.

Research Approach and Project Output

We use virtually identical approaches to domestic and international work on the control of sorghum and millet diseases. This involves the identification of sorghums with excellent resistance(s) to specific pathogens and collaboration on the incorporation of the resistance(s) into useful cultivars. Most of this work is done cooperatively with plant breeders, biotechnologists, geneticists, and entomologists in the Texas programs, but also occasionally with breeders in other states, nations (NARS), or with an International Crop Research Center, specifically ICRISAT.

Collaborative Research in Niger
(Prepared by Mr. I. Kollo)

This is a report on our work on millet and sorghum pathology during 1995. During this cropping season there was a tremendous deficit of rain. In Konni and Maradi the rains were late and stopped very early. Because of the drought we have not been able to gather data on three *Striga* millet trials, two sorghum *Striga* trials and on the grain mold nursery. In that nursery some of the entries were lines developed and sent to us by Dr. Gebisa Ejeta from Purdue University.

Nematodes on Millet

During the past years we have shown that application of Apron® Plus, a seed dressing fungicide, permits on average a 20% yield increase in pearl millet grain. The application of this product also results in a dramatic increase in seedling vigor and an earlier and better stand establishment, something which is very critical in the unpredictable and harsh sahelian environment where seedlings can be buried by sand storms that are frequent at the beginning of the cropping season. Thus Apron® Plus allows farmers to plant once rather than two or three times. These responses of pearl millet to Apron® Plus can be observed even in the absence of any disease. One possible explanation is the so called tonic effects of pesticides that are carbamic acid derivatives; another explanation may be that Apron® Plus is controlling soil born insects and nematodes. Although there is no direct proof that nematodes constitute a problem on pearl millet in Niger it has been known that pearl millet responds positively to the application of nematicides (Issoufou Kollo, Annual Report 1994). Since Apron® Plus contains some furathiocarb (a systemic insecticide/nematicide) we decided to investigate the presence of nematodes on pearl millet.

One month after planting, soil and root samples were collected from Bengou, Kollo and Tara for nematode isolation. The sampling was carried in Apron® Plus trials where four rates of Apron® Plus were compared on three millet genotypes. The extraction of the nematodes from the soil was done first by sieving and double centrifugation (Jenkins,

1964). Five grams of roots were washed under running tap water, then cut into small pieces in a Waring blender. The root pieces were placed in Baerman funnels for nematode extraction. The remaining roots were surface disinfected in 1% sodium hypochlorite for two minutes and plated in acidified water agar amended with streptomycin sulfate (60 ppm). The plates were placed in a Lab Line incubator at 30°C. After extraction the nematodes were heat killed and preserved in FAA (3%) for counting. The number of nematodes given here is the total number of plant parasitic ones. After counting, samples of the nematodes were sent to Dr. Sarr Etienne, a nematologist working in the school of plant protection of AGRHYMET, for identification. Nematodes densities ranges from 182 to 784/cm^3 in Kollo, 30 to 282/100cm^3 in Bengou and 21 to 331/100 cm^3 in Tara. These numbers greatly underestimate the real population level. Mishandling and poor storage facilities (temperature in the lab was between 30 to 40°C) have caused the death of many nematodes; this is especially true for the samples from Bengou and Tara. The species of nematodes found belong to the following genera, *Helicotylenchus*, *Criconemella* and *Tylenchorynchus*. The relative proportions of the nematodes species were unfortunately not given. Although our results do not prove that nematodes are a serious threat to pearl millet, they nevertheless give some indication of their relative importance. Pearl millet constitutes a good host for many species of plant parasitic nematodes (Johnson and Burton 1977). These species of nematodes were found on sorghum in the Konni area where the level of infestation was much higher and threatening (see part on sorghum). Up to now we were not aware of any report on the importance of nematodes on pearl millet in the Sahel. This lack of research on nematodes on millet and sorghum in the Sahel may be partly explained by the assumption that nematodes cannot survive in an environment which is too dry and hot.

The most predominant fungi associated with pearl millet roots are *Fusarium* spp (mainly *F moniliforme*). *Curvularia* spp and *Helminthosporium* spp have also been isolated, but their frequencies were very low. No test has been conducted to determine the pathogenecity of these fungi on millet. But work done with sorghum showed that these fungi can significantly decrease the vigor of sorghum seedlings (see part of this report on sorghum). Thus, the association between nematodes and fungal pathogens needs to be investigated further.

Striga hermonthica

In 1995 a preliminary trial was conducted to evaluate the effect of adding neem seed to the soil on *Striga* emergence on pearl millet. This technique was reported to us by some farmers who said that soil amended with neem residues controls *Striga*. The trial was carried out in 30 cm diameter pots. Neem seed were ground and applied at the rate of 0.0, 0.5 and 1.0 kg/pot. The seed powder was thoroughly mixed with the soil in the pots. Then 0.3 g of *Striga* seed was added to each pot. Ten days after planting the millet seedlings were thinned to 2/pot. A randomized complete block design with three replications was used. *Striga* emerged only in the control pots. At the rate of 1.0 kg/pot neem was inhibitory not only to the *Striga* but also to the millet. The rate of 0.5 kg slightly retarded the growth of the millet. Neem contains a variety of pesticides and secondary compounds which are allelopathic. Also, the seed is very rich in nitrogen and other mineral elements (see The Neem, a Tree for Solving Global Problems by National Academy of Sciences). In a separate field trial, neem debris was collected from a nearby plantation, and applied at the rates of 0 to 5 T/ha. This application, however, failed to control *Striga*.

In pearl millet no gene for resistance to *S. hermonthica* has been reported. The cultural techniques used to control *Striga* are either expensive or time consuming and sometimes their success is uncertain. Under these conditions chemical control may be very promising, despite the criticism about the use of pesticides. The herbicide Dicamba has been found to be very effective against *S. hermonthica* on pearl millet. In 1994 we observed a more than 80 % reduction in *Striga* emergence, and about a 20 % increase in millet yield when Dicamba was applied at the rate of 0.19 kg ai/ha. When Dicamba is applied late (50 days after sowing) the reduction in *Striga* infestation is not followed by any yield increase; and application at 35 days after planting was better than late application. Therefore we decided to conduct another experiment to determine the most effective rate and time of application. This experiment involved five application rates, (0.0, 0.1, 0.2, 0.3, 0.4 kg ai/ha), and four dates of application (three, four, five and six weeks after planting). The design was a strip plot with 4 replications. The number of emerged *Striga* was counted starting from the first emergence up to the maturity of the millet plants.

The rate of 0.4 kg/ha of Dicamba was not only very effective against *Striga* but also toxic to the host plant. The control of *Striga* was the same when Dicamba was applied at either 0.2 kg or 0.3 kg/ha. Application at three weeks after planting was the least effective. This data indicates that the best time for application is four to five weeks after planting. The level of *Striga* control was lower than the level obtained in 1994. This may be explained by the fact that *Striga* emergence was very low in 1995.

Sorghum

Grain mold is a serious problem on the improved cultivars in the southern part of Niger, particulary during the years of exceptionally good rainfall. But the fungi causing grain mold have not been isolated nor has their respective importance been assessed. Molded and healthy grains from the 1994 cropping season were saved in plastic bags and stored in a refrigerator for study in 1995. For the isolation of the fungi, 400 kernels were used. In the first experiment whole kernels were surface disinfected in 1% solution of chlorine bleach for three to five minutes. They were then plated in petri plates (15 cm of diameter) containing acidified water agar (three drops of 25 lactic acid/100ml). The water agar was amended with streptomycin sulfate (50

ppm). Twenty five grain/plates were used and were placed in a Lab Line incubator at 30° C. They were examined daily for two weeks, starting from the third day after incubation, for fungi identification. The results obtained indicated that three species, *Fusarium* spp, *Curvularia* spp, and *Helminthosporium* spp constitute more than 90% of all fungi isolated. *Fusarium* spp (mainly *F. moniliforme*) were by far the most commonly found fungi, followed by *Curvularia* spp. Although more than 30 % of the grain were covered with pycnidia from *Phoma* spp, no *Phoma* colonies grew on the agar before the end of the second week. It has been deduced that *Phoma* spp was not important in causing grain mold. *Rhizoctonia solani* was isolated twice and *Colletotrhichum graminicola* only once. *Rhizopus* spp and *Aspergillus* spp were considered as common contaminants. The isolation procedure was repeated but modified by using sorghum seed which had been longitudinally split. Both acidified water agar and acidified PDA were used, but the same trend was observed. *Fusarium* spp and *Curvularia* spp were grown on PDA and *Helminthosporium* spp on lactose casein hydrolysat agar. Sorghum heads were then inoculated with each fungus separately and with a mixture of the fungi. The control was sprayed with distilled sterilized water. This experiment failed because of lack of rain.

The same treatments were used to evaluate the effect of the fungi on seed germination and seedling vigor. Since stalk and root rot and lodging are sometimes severe in the Konni area it was thought that this experiment would be a way to develop a quick method for screening for resistance to stalk and root rotting fungi. Non molded grain from two varieties, Mota Maradi and the Hybrid Nad-1, which are highly susceptible to grain mold and stalk rot, were used. Before inoculation the seed were surface disinfected in a 1% sodium hypochlorite solution for three to five minutes. Grain sprayed with distilled sterilized water was used as the control. The seed were planted in styrofoam cups containing sterilized sand. After ten days, the seedlings were removed from the cups by gently washing away the sand under running tap water. The length of the radicle and the epicotyl was measured. A randomized complete block design with three replications was used. Analysis of variance was carried out.

The mixture of the three fungi decreased the germination of the hybrid seed by 28%, whereas germination of Mota Maradi was decreased by 50%. Neither *Fusarium* spp nor *Helminthorium* spp taken alone reduced the seed germination of Mota Maradi. The hybrid seed germination was significantly reduced by *Fusarium* spp and *Curvularia* spp. Radicle and epicotyl elongation of the seedlings of Mota Maradi was suppressed by the mixture of the fungi. The data indicated that there was a synergistic effect of the three fungi. In the case of the hybrid, the radicle length and epicotyl length were significantly reduced by all fungi. The seedlings of Mota Maradi appeared resistant to *Fusarium* spp and susceptible to *Helminthosporium* and *Curvularia*, whereas the hybrid Nad appeared susceptible to all three fungi (Table 1). In another experiment we found that seed treatment either with Apron® Plus or thiram increased at least four fold the number of secondary roots. Therefore data on secondary roots should be included in measurement of seedling vigor.

Nematodes

For at least three years, we have been monitoring the development of Acremonium wilt in the area of Konni. The disease was first observed on the hybrid Nad 1 (ATx 623 x MR732). This hybrid and its parents are highly susceptible to the pathogen. Other introduced sorghum cultivars (IRAT 204, SEPON 82) and maize are also susceptible. Surveys, taken from farmers' fields located around the research station and in the irrigation scheme where wheat is grown after sorghum, showed that sorghum land races were infected but did not wilt. During the cropping season of 1995, the disease was severe on both hybrid Nad 1 and some of the land races. Also, in a demonstration trial 20 km from the research station, Acremonium wilt was particularly devastating. Dr. L.R. House who visited Niger at that time suggested that we should analyze soil and root samples for nematodes, because of the characteristic symptoms.

Soil and root samples were taken from farmers' fields and from the research station. Nematodes were extracted from the soil according to Jenkins (1964). Washed roots were cut into small pieces and placed in Baerman funnels. The nematodes density in the soil ranged from 800 to 2000/225 ml of soil. Very few nematodes were extracted from roots. But subsequent observations of stems under a stereoscopic microscope revealed the presence of nematodes in lower internodes. Nematodes were heat killed and fixed in FAA. They were sent to Dr. Etienne Sarr for identification. Four species

Table 1. Effect of *Fusarium* spp, *Helminthosporium* spp and *Curvularia* spp on the germination and seedling vigor of two sorghum genotypes. Radicule and epicotyl length were measured in mm. Interaction was highly significant for both epicotyl and radicle length ($p<0.001$).

	Mota			Hybrid Nad		
Fungus Genera	% Germination	Radicle Length	Epicotyl Length	% Germination	Radicle Length	Epicotyl Length
Fusarium	93.3	74.2	51.9	48.6	20.6	20.0
Helminth	96.7	21.0	47.8	78.8	45.0	44.9
Curvularia	83.3	23.9	53.7	54.5	21.8	33.3
Mixture	50.0	7.9	19.6	63.6	20.4	37.0
Control	100	78.5	56.7	81.8	58.6	65.0

were identified, *Pratylenchulus* spp, *Criconemella* spp, *Helicotylenchus* spp, and *Tylenchorhynchus* spp.

An experiment was conducted in pots using soil from an infected area. The nematode density was adjusted to 500 nematodes/200ml by adding pasteurized soil. Four treatments were used: control, benomyl in soil treatment (2%), furadan (1g/pot) and furadan plus benomyl. After one month, there was a 2:1 difference in plant height between furadan and control. At the rate used, benomyl was toxic to the sorghum. I was not able to finish the observations because I left for Texas A&M.

This is the first time that nematodes have been shown to infect sorghum in Niger. The association between nematodes and fungi is responsible for the severe lodging which is common in the Konni area. This finding is very important because the Konni area is the sorghum belt of Niger. Arable land is so scarce that in the region most of the people are forced to use all of the land each year.

Our work with the nematodes suffered from the lack of trained personnel in nematology, and the lack of facilities and appropriate equipment. In the lab temperature was as high as high 30 -40°C because the air conditioner was not working. Under such conditions most of the nematodes die during storage.

Domestic Research

Disease evaluation studies are conducted primarily in large research nurseries in South Texas. Several uniform nurseries are grown in locations where sorghum/millet diseases are important. These include the International Sorghum Anthracnose Virulence Nursery (ISAVN), in collaboration with ICRISAT, the Uniform Head Smut Nursery (UHSN), the Sorghum Downy Mildew Virulence Nursery (SDMVN), the International Sorghum Virus Nursery (ISVN), and also a uniform nursery for grain mold (GWT). These nurseries provide quick assessment of disease severity and pathotype differences among locations.

Elite sorghums are also distributed and evaluated for multiple resistances in international nurseries, which also provide a means of distributing elite germplasm from different breeding programs in INTSORMIL. The most widely grown is the International Disease and Insect Nursery (IDIN), a 30-entry test, followed by the All Disease and Insect Nursery (ADIN), a 70-entry test, which is composed in part of unreleased experimental materials that are evaluated in many different disease environments. Both of these collections represent one of the best means of comparing germplasm from region to region. Additionally, we have collected disease information on converted sorghums and, with the assistance of Dr. Rosenow (TAM-122), maintain sets of anthracnose, sorghum downy mildew, and head smut resistant converted lines. These specific nurseries represent valuable sources of disease resistance traits for breeding programs. Dr. Rosenow crossed most of the anthracnose resistant converted lines. F_1 seed was increased and F_2 plants were planted for evaluation in 1996. It is unlikely that there will be sufficient data this year because of the prolonged and severe drought but initial infection was obtained.

Recombinant inbred populations are being developed and maintained for the mapping of selected host resistance genes to anthracnose, head smut, leaf blight, grain mold, and downy mildew. Dr. Jeff Dahlberg and Dr. Clint Magill have assisted in the development of these populations. We are continuing to develop near-isogenic lines of Tx430 and TAM428, each possessing downy mildew resistance from four different sources.

We grew 189 exotic sorghum lines in quarantine grow outs in 1995-96. These were from Botswana (5), China (30), Ethiopia (10), Mali (36), Nigeria (5), South Africa (7 pairs of A&B lines), Zambia (11), Zimbabwe (46) and we germinated and grew 32 miscellaneous items from the National Seed Laboratory for increase at St. Croix.

Sorghum Head Smut

Presently, sorghum resistance to *Sporisorium reilianum*, the causal organism of head smut, is evaluated in field trials following natural infection or artificial injection with inoculum. These trials can be expensive in terms of time and money and are restricted to the growing season. Natural infection requires repeated trials to obtain reliable data since environmental effects may result in disease escape, whereas inoculation with sporidia is labor-intensive and may bypass resistance factors (non-meristematic) that provide satisfactory levels of resistance under field conditions. Mr. Jairo Osorio is working on a research program to address some of these concerns. His objectives are: (1) to develop an infection assay that does not bypass non-meristematic resistance mechanisms and yet is highly efficient in reducing escape from infection, and (2) to identify molecular markers linked to this non-meristematic resistance in sorghum.

Detection of S. reilianum

Teliospores of *S. reilianum* germinate slowly in soil but in the presence of sorghum seedlings some teliospores germinate producing an elongated form of promycelium. Teliospores placed on root protrusion cracks in the mesocotyl area of maize seedlings resulted in infection of at least 15% of the plants. Sporidia of the smut pathogen placed at several parts of seedling tissues failed to infect both sorghum and maize. Inoculations of sorghum under greenhouse conditions were repeated. Infection of susceptible sorghums RTx7078 and B1 were 65% and 82% respectively. These levels of infection using teliospores exceeds that normally obtained under field conditions.

Infection courts and initial infection of sorghum with the head smut fungus have rarely been detected. Consequently, attempts were made to develop a PCR generated probe from the ITS regions of sorghum and the head smut fungus. Using

primers ITS3 an expected 0.9Kb amplification product was observed in extracts from different tissues of inoculated seedlings or tillers from smutted plants, but not from non-inoculated seedlings nor tillers from healthy plants.

Mapping of Head Smut

Identification of sources of resistance to head smut in sorghum has relied on field testing of large numbers of entries for several seasons. This process is slow, expensive and not very accurate; yet, a few resistant lines have been found by this method. The present study seeks the identification of DNA markers to assist selection of resistant lines by their genotype.

The bulked segregant analysis approach has been used with two different populations derived from crosses between resistant and susceptible inbred lines. The first search for linked markers was conducted with DNA preparations from 21 individual F_3 families from the cross between CS3541 (resistant) and RTx7078 (susceptible). Field data of head smut infection were used to choose more likely susceptible and resistant progeny rows to constitute pools for AP-PCR amplifications of their DNA with 10mer oligonucleotide primers. Among a series of polymorphic loci detected, two of them - generated with primers of oph-04 and opaa-11, showed linkage (4.8 and 8 cm) with the susceptible allele of the head smut resistance locus at segregation rates typical for a monogenic trait (1:3, corresponding to the segregation of resistance when the individuals were injected with sporidia of the smut pathogen, 16 S: 5 R). None of the polymorphic RAPDs explained the segregation of resistance for field infection (1R : 2S). These results suggested therefore that, the RAPDs identified a locus in CS3541 which controls resistance by a meristematic mechanism.

A second population was used to expand our search for markers to head smut resistance. The parental lines were BT635 (R) and B1 (S). The two RAPD markers described above were polymorphic between them and segregated in a 1:3 fashion among 200 F_3 families tested. Two additional inoculations on 50 F_3 families are under way to complete the linkage analysis.

To use RAPD markers in selection for smut resistance, we isolated the original oph-04 band (150bp), sequenced it, and expanded it by a PCR-based walking strategy to develop it into a 1.5 Kb band that was used to survey for RFLPs; it is also being used to screen the sorghum BAC library. Fine sequence analysis is performed to exploit single base differences between B1 and BTx635 for marker development.

The resistant parental line BTx635 appears to posses two different resistance mechanisms. One mechanism is meristematic, as detected by needle inoculation of its progeny, while the other one appears to be non meristematic as measured by field infection. If two different, unlinked loci are controlling the same phenotype in this line, results of needle inoculations as well as segregation data for the oph-04 and opaa-11 markers would allow us to create new discrete classes among the 200 F_3 families. The bulked segregant analysis approach was used to identify RAPDs between pools of lines susceptible to needle inoculation and the RAPD marker oph-04 but with different reactions to natural infection.

Head Smut Population Study

Graduate student Heriberto Torres made hierarchical collections of *Sporisorium reilianum* from sorghum and maize in Mexico and Texas. Comparisons will be made between host samples and within and between locations to determine the extent of natural variability in the pathogen causing head smut using neutral RFPL markers. Three sorghum head smut collections were made in northern Mexico near Tamaulipas, and three from the coastal bend and upper coastal regions of Texas. Maize head smut collections came from central Mexico and the Texas high plains. Currently, Mr. Torres has made a genomic library from *S. relianum* and is in the process of screening these probes for use in detecting polymorphisms in field populations of *S. relianum*.

Sorghum Downy Mildew

Sorghum materials continue to be screened in the greenhouse for resistance to sorghum downy mildew using our greenhouse inoculation technique. We also evaluated sorghum for reaction to downy mildew in field nurseries at three locations in Texas (College Station, Corpus Christi, and Edroy).

Sorghum Anthracnose/Sorghum Leaf Blight

Dr. K. Boora completed his work on mapping of anthracnose and leaf blight resistance in January, 1996. Currently, papers on the locations of these genes are being written in collaboration with Dr. Clint Magill. Leaf blight resistance in SC326 is dominant. Primer OPD12 amplified a 329 bp product closely linked with the resistance gene. Ends of cloned products linked with both resistance and susceptibility to leaf blight were sequenced. These traits have not been mapped because the amplified band appeared in all 136 out of the 137 mapping parents. Dr. Boora also attempted to map the recessive resistance to anthracnose in SC326.

Dr. Liane Rosewich completed her research. Her findings, summarized last year, are being prepared for publication. The multilocus hapotypes developed by Dr. Rosewich are being distributed as tools to compare isolates within and between other regions. Dr. Rosewich's probes have been prepared for distribution to ICRISAT in India and EMBRAPA in Brazil.

Sorghum Grain Mold

Dr. Sunitha Kumari is mapping fungal inhibiting proteins in grain sorghum. The objective of her investigation is to develop probes mapping for specific antifungal protein

genes and to use these probes for identifying cultivars more resistant to grain mold. One of the major constraints to the production of sorghum is the susceptibility of sorghum to grain molds. The two major fungal species associated with the deterioration of sorghum grains are *Fusarium moniliforme* and *Curvularia lunata*. Little research has been conducted at the molecular level on sorghum grain mold resistance. Availability of tightly linked markers would make the screening procedures easier and more accurate because with such markers, disease resistance genes could be identified at the seedling stage. The objectives of the present investigation were to develop probes for specific antifungal protein genes and to use these probes in identifying cultivars that are resistant to grain molds. Probes were also developed for three antifungal proteins, for other antifungal genes described in the literature, and also by the use of PCR and PCR-RAPD techniques. Two sorghum lines resistant (Sureno) and susceptible (SC-120) to grain molds were selected for the present study. F_3 progeny consisting of 143 individuals were grown in the greenhouse. The pathogen *F. moniliforme* was isolated from the molded sorghum grains.

The crushing strength of grains of the variety Sureno was higher (18 kg/cm^2) when compared to the susceptible variety SC-120 (8 kg/cm^2). The incidence of *F. moniliforme* was 68% in the susceptible line and 15% in the resistant line. The harder grain was more resistant to grain mold when compared with the softer grain. The PCR-RAPD technique was used to obtain markers linked to grain mold resistance. Four primers (OPA12, OPN05, OPR10 and OPR11) showed fragments segregating with resistance. The size of fragments amplified by OPN05 were 1.6, 1.0 and 0.3 kb. A single fragment was linked to susceptibility, the size of which was found to be 0.5 kb. When used as RFLP probes, polymorphism was detected only with OPN05-1R. The RNA studies revealed that the level of OPN05-1R increases after infection with *F. moniliforme*. Antifungal genes for chitinase, ribosomal inactivating protein, P-23, GRP, pHvPR-1a and zeamatin were successfully placed on the sorghum RFLP map.

Networking Activities

Conferences Attended or Organized

R. Frederiksen traveled with Mr. H. Torres across Mexico collecting smut samples for analysis, August 27-Sept. 1, 1995.

R. Frederiksen evaluated sorghum and millet nurseries in Mali for disease with D. Rosenow, G. Peterson, G. Teetes and J. Leslie, Oct. 8-17, 1995. R. Frederiksen met with ICRISAT Plant Pathologist R. Bandyopadhyay and R. Thakur who were presenting a short course on plant pathology to West African sorghum researchers. Mr. Z. Ngoko, former graduate student in the INTSORMIL program was also present.

R. Frederiksen participated in the Eastern African Regional Sorghum and Millet Workshop Nov. 6-9, 1995. where he presented a paper on "Integrated Disease Management: Opportunities for the Horn of Africa.

During the year, R. Frederiksen served as a member of the Editorial Advisory Board of the African Crop Science Journal. In addition, R. Frederiksen co-edited the Proceedings of the Sorghum Biotechnology Conference which appeared as a special issue of the African Crop Science Journal Vol.3:1995 254pp.

R. Frederiksen traveled to Sete Lagoas, Brazil to discuss with EMBRAPA sorghum workers the status of ergot and the opportunities of establishing collaborate work on ergot. Current plans call for holding a global conference on ergot of sorghum and related grasses in June, 1997.

Research Investigator Exchanges

Dr. El-Hilu Omer from the ARC, Wad Medani, Sudan finished his sabbatical leave.

Other Cooperating Scientists

A. S. Ferreira, EMBRAPA/CNPMS, Caixa Postal 151, Sete Lagoas, M. G., Brazil

Mengistu Hulluka, Agricultural Research Center, P.O. Box 32, Debre Zeit, Ethiopia

John Millet, Dept. of Biochemistry, Texas A&M University, College Station, TX 77843

Jesus Narro, Campo Agricola Experimental Bajio, A.P. 113, Celaya, Guanajuato, Mexico

William Rooney, Dept. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843

Ralph Waniska, Dept. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843

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Insect Pest Management Strategies for Sustainable Sorghum Production

Project TAM-125
George L. Teetes
Texas A&M University

Principal Investigator

Dr. George L. Teetes, Professor/Entomologist, Department of Entomology, Texas A&M University, College Station, TX 77843-2475

Collaborating Scientists

Dr. Yacouba O. Doumbia, Entomologist, IER/SRA/CRRA, Sotuba, B.P. 438, Bamako, Mali
Dr. Gary C. Peterson, Professor/Sorghum Breeder, Texas A&M University Agricultural Research and Extension Center, Route 3, Box 219, Lubbock, TX 79401-9747
Dr. Darrell T. Rosenow, Professor/Sorghum Breeder/Mali Country Coordinator, Texas A&M University Agricultural Research and Extension Center, Route 3, Box 219, Lubbock, TX 79401-9747
Dr. Aboubacar Toure, INTSORMIL Host-Country Coordinator/ Sorghum Breeder, IER, Sotuba, B.P. 438, Bamako, Mali
Dr. Alain Ratnadass, Entomologist, CIRAD-CA, ICRISAT/WASIP, B.P. 320, Bamako, Mali
Dr. Lloyd W. Rooney, Professor/Cereal Chemistry, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843-2474
Dr. Richard A. Frederiksen, Professor/Plant Pathologist, Department of Plant Pathology & Microbiology, Texas A&M University, College Station, TX 77843-2132

Summary

Research for project TAM-125 during this reporting period resulted in major achievements leading to management of sorghum panicle-feeding bugs in Mali, sorghum midge, and greenbug. Based on observations during travel in southern Mali during October 1995, panicle-feeding bug abundance was less in areas where sorghum had not been grown extensively or in farmers' fields than at experiment stations where sorghum is extensively grown and multiple plantings are made. Implication from these observations, coupled with low levels of resistance to bugs in improved sorghums developed by Malian sorghum breeders, is that panicle-feeding bugs may not pose as serious a production threat in farmers' sorghum fields as once expected. Research in Texas confirmed that sorghum midge abundance the subsequent year is reduced when sorghum residue containing overwintering larvae is shredded, disked, and deep plowed after harvest compared to when residue is only shredded or shredded and disked. Sorghum midge resistance in sorghum is caused by morphology of spikelets and asynchrony between time of flowering during the day and the presence of sorghum midges. Gene mapping showed that genes conferring resistance to different greenbug biotypes are slightly different, but probably control the same resistance process. Efforts to assess genetic diversity among populations of greenbug were initiated as companion research to the sorghum plant biotechnology research. Collaboration with project TAM-123 resulted in confirmation of outstanding levels of sorghum midge-resistance in hybrids from new A-lines in combination with released R-lines. Significant progress was made to develop biotype E and I greenbug-resistant lines. Several thousand selections were screened for seedling resistance during 1995-1996.

Objectives, Production and Utilization Constraints

Objectives

Mali

Confirm the most reliable and efficient method to protect sorghum from infestation by panicle-feeding bugs and compare for resistance assessment protected panicles with naturally infested panicles; screen sorghum lines produced in the sorghum breeding program; apply different combinations of insecticides and fungicides to determine the role insects and pathogens play in kernel deterioration; and assess the importance of sorghum panicle-feeding bugs and sorghum midge in farmers' fields.

U.S.

Conduct greenhouse and field experiments to evaluate sorghums resistant to greenbug, sorghum midge, and yellow sugarcane aphid; supervise graduate student research including the research programs of: 1) a Malian Ph.D. student assessing causes of resistance in sorghum to sorghum midge; 2) a Mexican Ph.D. student studying sorghum midge population distribution and survival on resistant sorghums;

3) a U.S. M.S. student assessing factors affecting termination of diapause and overwintering survival of sorghum midge; 4) a U.S. Ph.D. student using RFLP technology to assess genetics of greenbug resistance in sorghum; 5) a U.S. Ph.D. student using RFLP/RAPD technology to assess genetic variability of the greenbug and its biotypes; and 6) a U.S. Ph.D. student assessing the role of sorghum in the population dynamics of Mexican corn rootworm. Participate in Entomological Society of America, Plant Resistance to Insects Workshop, CRSP, and other professional and scientific activities and meetings.

Constraints

Mali

Panicle-feeding bugs can be very abundant and cause serious losses in grain yield and quality of non-landrace sorghum varieties. Bugs are potential constraints to efforts to deploy improved sorghum varieties, especially nonphotoperiod sensitive, compact-panicle sorghums that yield more than currently grown, local varieties. The problem is exacerbated by pathogen infection that significantly increases when kernels are damaged by bugs. Damage by bugs and infection by pathogens greatly reduce grain yield and quality and render the grain unusable for human consumption. The interrelationship of damage by bugs, infection by pathogens, and reduction in grain yield and quality requires an interdisciplinary approach to resolve.

Insect pests in the U.S. constrain sorghum production in a different way than in developing countries. Ready availability of insecticides in the U.S. lessens the yield-reducing impact of insect pests. However, insecticides result in significantly increased production costs, occurrence of secondary insect pests, insect pest resurgence, ecological disruption, and environmental contamination. Sorghums resistant to aphids, sorghum midge, and panicle-infesting bugs and caterpillars would enable sorghum insect pests to be managed in a more ecologically sound way and provide a more economically and environmentally sustainable sorghum production system. Insect-resistant plants provide an important foundational component to an integrated pest management approach. However, development of resistant cultivars requires a holistic approach including identification of insect resistance genes, incorporation of the resistance into agronomically elite hybrids, and deployment into production systems. Much research is needed on the role resistant cultivars play in an integrated pest management program so research progresses and farmers readily accept resistant cultivars as part of an integrated pest management approach.

Research Approach and Project Output

Sorghum panicle-feeding bug research in Mali. In October 1995, the Principal Investigator for project TAM-125 traveled to Mali to review the on-site, collaborative, entomological research of Dr. Yacouba Doumbia. On-site review of research revealed that research on panicle-feeding bugs of sorghum consisted of studies on bug biology and population dynamics and screening of sorghum germplasm in preliminary and advanced trials for resistance to panicle-feeding bugs.

During this visit, the PI traveled south of Bamako to Sikasso and then to Cinzana. At Sikasso and other areas south of Bamako, especially where sorghum had not been grown extensively for many years, bug infestations were low. At Cinzana experiment station, bug infestation was very severe. Bug infestation at Sotuba was low. The lateness of planting at Sotuba could have caused bug infestations to be lower than usual. There was evidence that bug infestation level was increasing, and this was especially true at Samanko (ICRISAT) where bug infestation was beginning to increase to very severe levels.

It was encouraging to see progress being made by Malian sorghum breeders to develop improved sorghums, especially the improvements to Guinea-type sorghums. Also, it is apparent that resistance to panicle-feeding bugs can be transferred to elite varieties. For example, resistance of MaliSor 84-7 can be moved into improved types. The important possibility is that if improved Guinea sorghums have low levels of resistance and bug severity is less in farmers' fields, panicle-feeding bugs may pose little production constraint to sorghum in Mali.

There is urgent need in Mali for two kinds of research on panicle-feeding bugs in addition to the on-going research being conducted. Research is needed on the relationship of panicle configuration to bug infestation and on the severity of bugs in farmer's fields where traditional and improved sorghum cultivars are grown. Research on panicle configuration in relation to bug infestation severity is needed to assist sorghum breeders develop bug-resistant sorghums. Research in farmers' fields is needed to define how severe bugs would be if improved sorghum varieties were made available to farmers. The bug problem may be much greater at experiment stations where there is a wide variety of genotypes of different maturities than in farmers' fields where sorghum would be more determinate in its growth pattern.

For entomological research to contribute to resolving the panicle-feeding bug problem in Mali, more research is needed in farmers' fields. Hopefully, when Niamoye Diarisso completes her Ph.D. degree at Texas A&M University she will be given responsibility to conduct research on panicle-infesting insects and sorghum entomology research in farmers' fields.

Technology Development and Graduate Student Research. Following are summaries of results of technology development efforts supporting international research collaboration, especially with regard to evaluating sorghum midge-and aphid-resistant sorghums; and research projects of graduate students associated with INTSORMIL. The

technology development component of TAM-125 is in collaboration with TAM-123, the project of Dr. Gary C. Peterson, Sorghum Breeder at the Texas A&M University Agricultural Research and Extension Center at Lubbock. During 1995, emphasis was placed on evaluation of sorghum midge-, greenbug-, and yellow sugarcane aphid-resistant sorghums.

Technology Development

Sorghum hybrids were evaluated for resistance to sorghum midge at Corpus Christi, Texas, with high sorghum midge abundance, and at College Station, with moderate sorghum midge abundance (Table 1). Resistant x resistant, resistant x susceptible, and susceptible x susceptible checks were included. Sorghums were rated for damage based on percentage of kernels that failed to develop. Damage rating was higher, indicating more damage by sorghum midges, at Corpus Christi (mean damage rating 4.5) than at College Station (mean damage rating 2.3). Relative differences between hybrids were similar between and over locations. Superior experimental resistant hybrids sustained much less damage than did susceptible or resistant checks. Hybrids with superior resistance (damage rating less than 3.0) at Corpus Christi were less damaged at College Station. At both locations, hybrids reached 50% flowering within an eight-day period. Within and over locations, susceptible hybrids sustained more damage for a specific day of flowering than did resistant hybrids.

Mean grain yield at Corpus Christi and College Station ranged from 396 to 4,980 and 1,740 to 5,488 kg/ha, respectively. Experimental hybrids produced from newly developed A lines yielded 4,322 and 4,873, resistant x resistant checks yielded 4,042 and 4,219, resistant x susceptible checks yielded 3,204 and 5,201, whereas susceptible x susceptible checks yielded 1,293 and 2,990 kg/ha at Corpus Christi and College Station, respectively. Although differences were not consistent, resistant hybrids less damaged usually produced more grain. However, damage was of sufficient magnitude to identify sorghums with superior grain yield potential. Experimental hybrids produced significantly more grain than did susceptible x susceptible checks. Most differences between experimental hybrids and resistant x resistant or resistant x susceptible checks were not significant although experimental hybrids generally produced more grain. Experimental sorghums with female parents A91-6, A92-3, and A93-6 produced superior hybrids during at least two previous years and will be released to the commercial seed industry. Hybrids with female parents designated A94 were evaluated for the first time and will be evaluated further to determine suitability for commercial production.

In collaboration with TAM-123, testing of advanced B-line selections resistant to biotype E greenbug continued in 1995. Lines identified for release, with their experimental designations, are GR107-90M17, GR108-90M23, GR134A-90M50, and GR127-90M41. Each line produces hybrids with excellent grain yield.

Increased emphasis was given in 1995 to development of new germplasm lines resistant to both greenbug biotypes E and I. Two excellent sources of resistance have been identified for biotype I resistance, PI550607 and PI550610. To diversify the germplasm base of greenbug-resistant germplasm, PI550607 is used exclusively in R-lines and PI550610 primarily in B-lines. Approximately 90 different backcross populations were developed to place the greenbug resistance genes in elite agronomic backgrounds. Several populations have three or four crosses to temperate germplasm, and selections for agronomic types were made in the 1996 winter nursery in Puerto Rico. Selections were screened for resistance to both greenbug biotypes and preliminary determination made of suitability for release. The primary goal of early generation release would be to allow the seed industry to select for their specific purpose from a population of material.

Genes for resistance to yellow sugarcane aphid were identified, confirmed, and initially utilized. Progeny derived from PI457709 have been developed that possess acceptable resistance in a combine-height, early maturing sorghum genotype. These lines are currently being evaluated for agronomic type. Progeny in the F_3 generation were grown in 1995 to combine resistance to yellow sugarcane aphid with resistance to greenbug because yellow sugarcane aphid resistance sources are very susceptible to greenbug. Progeny in the F_3 generation derived from PI453951 were grown during 1995. Primary effort with this resistance source is to move the resistance gene into B-line material while the PI457709 resistance gene is used in R-line material. Selection in 1995 was for combine-height, early maturing genotypes with acceptable agronomic traits.

Table 1. Sorghum midge damage to sorghum hybrids at Corpus Christi (C.C.) and College Station (C.S.), Texas, 1995.

Sorghum hybrid classification	Yield (kg/ha)			Damage rating		
	Mean	C.C.	C.S.	Mean	C.C.	C.S.
Experimental hybrid	4,598	4,322	4,873	2.4	3.3	1.6
Resistant check	4,130	4,042	4,219	2.9	3.8	2.1
Resistant x susceptible check	4,203	3,204	5,201	4.0	4.9	3.0
Susceptible check	2,142	1,293	2,990	7.2	8.2	6.2

Damage was rated 1=0-10, 2=11-20, to 9=81-100% kernels destroyed.

Graduate Student Research

The relationship between the presence of ovipositing sorghum midges and times of spikelet flowering was assessed during 1993, 1994, and 1995. By flowering before daylight, resistant sorghum avoided much sorghum midge oviposition and damage. Susceptible sorghum flowered at the time most sorghum midges were ovipositing (0700-1100 hours). After flowering, glumes of resistant spikelets overlapped and enclosed the floral parts or cut the anthers off.

Spikelet morphology of resistant sorghum lines ATx2755 and RTx2767, resistant hybrid ATx2755 x RTx2767, susceptible lines ATx2752 and RTx430, and susceptible hybrid ATx2752 x RTx430 was studied to determine the relationship between spikelet morphology and resistance to sorghum midge. Rachis branches were removed each day from panicles in field plots and taken to a laboratory where differences in spikelet morphology of resistant and susceptible sorghums were studied with the aid of a dissecting microscope. After dissection, floral parts, including anther, stigma, style, and ovary, were measured in millimeters. The General Linear Model (GLM) procedure was used to analyze data. Results are in Table 2.

Within a column, means followed by the same letter are not significantly different ($P < 0.05$, Tukey's Studentized Range Test).

Magnitude of survival of overwintering sorghum midges was assessed in a field near College Station, Texas. Also determined were effects of crop residue destruction treatments on mortality of diapausing sorghum midges. A mean of 1,325 sorghum midges per square meter was estimated to have entered diapause during the 1994 sorghum growing season. This estimate was based on 20.5 panicles per each of 20 one-square meter areas in the field, 36 rachis branches per each of 30 panicles, and 1.8 diapausing sorghum midges per each of 140 rachis branches from 140 field-collected panicles. Only 0.8% of the sorghum midges that entered diapause in 1994 emerged from shredded and disked sorghum residue in 1995. Sorghum midges emerged between 11 April and 19 June, a range of 69 days. A total of 386 sorghum midges was captured in three sets of 16 pyramid traps in areas where sorghum residue had been shredded only; shredded and disked; or shredded, disked, and deep plowed. The mean of 82 sorghum midges (51,244 per hectare) that emerged from shredded, disked, and deep-plowed residue was significantly less ($F = 3.59$, $P = 0.03$) than the 185 sorghum midges (115,614 per hectare) that emerged from shredded and disked residue. One hundred nineteen (74,366 per hectare) sorghum midges emerged from the shredded only sorghum residue. Forty-four and 64% fewer sorghum midges emerged from shredded, disked, and deep-plowed residue as from shredded only and shredded and disked residue, respectively.

RFLP analysis is being used to determine the genetic map location of genes conferring resistance in sorghum to greenbug biotypes C, E, and I. Five sorghum populations have been produced for the purpose of mapping this resistance. Locations of greenbug resistance genes are based on DNA markers selected from a complete sorghum genome RFLP map developed by Dr. Andrew H. Paterson at Texas A&M University.

F_3 families of a cross between greenbug-susceptible Tx430 and biotype E and I resistant PI550607 were individually screened against biotypes E and I. There appears to be one gene segregating for biotype E resistance while resistance to biotype I seems to be more complexly inherited. RFLP analysis revealed one molecular marker cosegregating with resistance to both biotypes E and I. A second marker, on a separate linkage group, is cosegregating with biotype I resistance as well.

Analysis of F_3 families of a cross between biotype E-resistant Tx2783 and susceptible SC283 revealed transgressive segregation, suggesting that cytoplasmic inheritance may be modifying resistance gene action. Plants of reciprocal crosses between Tx430 and Tx2783 are being grown to further investigate this possibility. RFLP analysis of molecular markers suggests resistance conferred to biotype E in Tx2783 is a separate locus from the loci identified in PI550607.

A genomic DNA library was produced and RFLP probes developed to characterize field populations of greenbugs. The probes are being screened against progeny of single greenbugs collected from field populations in north, central, High Plains, Coastal Bend regions of Texas and central Kansas.

Mexican corn rootworm is often controlled through the use of crop rotation or soil insecticides. Soil insecticides protect corn roots from large amounts of damage, but do not reduce the corn rootworm population. In Central Texas, corn usually is rotated with sorghum or wheat. In recent years the corn-sorghum rotation scheme has failed to reduce populations of corn rootworms the first year corn is grown following sorghum. To determine if Mexican corn rootworm larvae survive on sorghum, several sorghum fields planted with corn in 1995 within a 3,000-acre Mexican corn rootworm management area were monitored for corn rootworm

Table 2. Spikelet morphology of sorghum midge-resistant and susceptible sorghums.

Sorghum	Stigma (mm)	Ovary (mm)		Filament length (mm)	Anther (mm)	
		Width	Length		Width	Length
Resistant	1.384c	1.303a	1.424a	1.401b	1.287b	1.673c
Resistant x Susceptible	1.443b	1.268c	1.384c	1.385c	1.285b	1.693b
Susceptible	1.504a	1.290b	1.400b	1.493a	1.312a	1.761a

emergence. Counts were taken in sorghum to monitor adult migration from corn. Roots were rated for damage where corn was grown continuously, rotated from sorghum, or rotated from wheat to evaluate the effectiveness of crop rotation in reducing larval corn rootworm damage. During 1996, 23,232 beetles emerged per acre in sorghum fields, 192,500 per acre emerged from continuous corn fields, and 420,750 per acre emerged from a corn field where sorghum had been grown in 1995. Mexican corn rootworm abundance ranged from 0 to 0.78 beetles per sorghum plant. Treatment thresholds are 1 beetle per corn plant or 0.2 beetles per sorghum plant. The root rating scale ranged from 1 to 6, with 1 least damaged and 6 most damaged. Roots where corn was grown continuously rated 5.4 compared to 3.7 and 1.2 for corn rotated with sorghum and wheat. Sorghum yields will be determined in fields with varying Mexican corn rootworm abundance. Laboratory and greenhouse tests will determine the suitability of different sorghum hybrids as hosts for Mexican corn rootworm larvae.

Networking Activities

Research Investigator Exchanges

Dr. George Teetes visited Dr. Yacouba Doumbia in October 1995 to discuss and plan collaborative research on sorghum panicle-feeding bugs in Mali. Plans also were made for Dr. Doumbia's entomology technician to come to Texas in July 1995 to receive short-term training in methodology to assess sorghum resistance to insects, especially sorghum midge. The technician did not come. Ten other LDC scientists visited the sorghum entomology research program at Texas A&M University. In addition, Dr. Klaus Leuschner, ICRISAT Sorghum Entomologist from Zimbabwe, spent six months with the Sorghum Entomology Research Program during his sabbatical leave.

The PI continues to serve on the TAMU Advisory Board for the Mali SPARC project and participated in several activities with IER/Malian officials during their visits to Texas A&M University. The PI also serves as a member of the Board of Directors of the Consortium for International Crop Protection (CICP). From funding sources other than INTSORMIL, the PI is contributing to the development of a Comprehensive Sorghum Crop Management Manual.

The PI traveled to Australia during February 1996. The trip had two goals - 1)to participate in the Third Australian Sorghum Conference and Post-Conference Grower Tour, 2)interact with research scientists in the Queensland Department of Primary Industries (QDPI) sorghum improvement program. Agricultural production in Australia is based on a 'free market' with no government programs. Producers grow crops which they believe will produce a profit, are aware and attempt to take advantage of marketing opportunities, and have made a significant research investment in the QDPI sorghum program. Agricultural production without government support is similar to the system U.S. producers are moving into.

Tamworth, New South Wales was the site for the Third Australian Sorghum Conference. Tamworth is located adjacent to the Liverpool Plains agricultural production area which is characterized by flat/ slightly rolling plains, several irrigated areas, and diverse agricultural production. The Conference was attended by research scientists and graduate students from Australia, producers, commercial seed industry, U.S. scientists, and ICRISAT scientists. Presentations were on a wide array of topics pertaining to sorghum including breeding, entomology, pathology, physiology, agronomy, biotechnology, and grain quality and processing. Producers are keenly aware of research in the QDPI program and its benefit to production. Many are able to ask direct questions concerning sorghum research and results, as well as give input on future research goals.

Sorghum midge is a major production constraint and its control is the major objective of the QDPI breeding program. Genetic basis for the midge resistance in the breeding program is primarily germplasm developed by TAM-123. Some use is also made of ICRISAT derived germplasm. Germplasm developed by the program is released to industry on a royalty basis. Significant royalties are generated to support some research activity. The breeding program resembles U.S. programs with a range of research objectives, continual introduction of new sources of traits, development of A/B-line pairs and R-lines. Germplasm developed by Texas A&M University scientists has many traits useful to Australian sorghum industry.

The commercial seed industry views sorghum midge as a major constraint and all the breeding programs are actively evaluating resistant hybrid. Industry and the QDPI have devised a program to evaluate hybrids and assign each a rating which all agree on. The ratings are used in marketing activities. There is apparently significant interaction between the public and private sector, with each knowledgeable concerning research that others are doing. As with producers, industry is supportive of the QDPI program and its benefit to the seed industry.

Support generated by producers and industry for the QDPI program was impressive. Producers have made a significant financial commitment to research, apparently much greater than U.S. programs receive. Producers view research as an important tool in maintaining or improving the profitability of their business. Several producers expressed willingness to increase support due to the benefits or potential they feel have accrued to them. Industry support the research program through royalties on germplasm release. Funding from both sources has apparently given the QDPI program a strong, consistent private funding base.

In addition to damage by sorghum midge to sorghum in Australia, infestations in sorghum panicles of corn earworms and corn leaf aphids were common. These latter two insects are of concern. In the U.S. these insects are often induced insect pests as a result of insecticide use for other insect pests. Sorghum hybrids with open panicles would

likely be beneficial. Also, the Texas A&M University Sorghum Breeding/Entomology program has identified sources of resistance to corn leaf aphid. This germplasm has been sent to Australian sorghum breeders and entomologists. Corn leaf aphid infestations in sorghum whorls are common in Texas, but panicle infestations are rare. In Texas, corn leaf aphids play a beneficial role in that they cause no damage and attract many natural enemies that help suppress the abundance of other insect pests in sorghum and adjacent crops such as cotton.

The trip was beneficial from several aspects. Research in the QDPI is complementary with that at Texas A&M Univ. and germplasm/information exchange will benefit producers in both countries. Some research in Australia is not currently done in the U.S., primarily in plant physiology. Interaction between producers and research is greater than what occurs in the U.S., at least in Texas. This interaction has contributed to the strong support, verbal and financial, given to the research program. Lastly, private industry apparently strongly supports the research program and funds from hybrids derived from the QDPI program have a positive impact on future research.

Germplasm and Research Information Exchange

Seeds were requested by seven LDC scientists, and these requests were forwarded to Dr. Gary C. Peterson, the sorghum breeder collaborating with the Principal Investigator. Publication reprints or copies related to sorghum entomology were sent to 34 LDC scientists. Research supplies and equipment were sent to Mali to support on-site research activities. Material for cages, bags to cover panicles, insect-collecting supplies, insect-preservation supplies, computer software, and other research-related supplies were provided.

Important collaborative linkages were maintained with Dr. K. F. Nwanze, Principal Cereals Entomologist, ICRISAT, Patancheru P.O., Andhra Pradesh 502 324, and Dr. Klaus Leuschner, Entomologist, SADC/ICRISAT Southern Africa Sorghum/Millet Improvement Program, P.O. Box 776, Bulawayo, Zimbabwe. Dr. Nwanze visited the sorghum entomology research program at Texas A&M University in September 1995. Discussions were on collaborative research, other networking opportunities, and plans for an international sorghum conference scheduled for September 1996. Dr. Klaus Leuschner did a six-month sabbatical with the PI in 1995-96.

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Biological Control Tactics for Sustainable Production of Sorghum and Millet

Project TAM-125B
Frank E. Gilstrap
Texas A&M University

Principal Investigator

Dr. Frank E. Gilstrap, Professor, Department of Entomology, Texas A&M University, College Station, TX 77843

Collaborating Scientists

Mr. Soualika Boire, Millet Entomologist, Institute Economie Rurale, Mali
Dr. Ouendeba Botorou, INTSORMIL Host Country Coordinator, Cereals Breeder, Institute Nigerien du Researche Agronomic, Niger
Mr. Hamé Kadi Kadi, Millet Entomologist, Institute Nigerien du Researche Agronomic, Niger
Dr. Gerald Michels, Professor, Texas Agricultural Experiment Station, Amarillo TX 79106
Dr. William Plapp, Texas A&M University, College Station TX
Dr. Ousmane Youm, Principal Scientist (Entomology), ICRISAT-Sahelian Center, Niamey Niger

Summary

Project TAM-125B addresses arthropod-insect pests of sorghum/millet. The pests addressed by this project are key pests and constraints to production in the U.S. and West Africa. Detailed ecological understanding of pests and their natural enemies is essential for a sustainable management strategy for an annual crop, especially during times of year when pests occupy noncrop portions of an agroecosystem. Collaborative research in Niger addresses biological control of stalk borers and the millet head miner, and in the U.S. addresses biological control of midges, aphids and spider mites. An important part of the U.S. research is to provide training for graduate students and evolve theory and concepts for implementing biological controls in West Africa, evolve concepts and definitions for functional agroecosystems, develop methods for measuring impacts of natural enemies, and validate results of biological controls when they are implemented.

During 1995-96, two NARS scientists from West Africa were recruited and admitted as graduate students in the Department of Entomology at Texas A&M University. On arrival in January 1996, these students developed an understanding and appreciation for pertinent literature on MHM and biological control; they also developed plans for their research to be conducted in the growing season of 1996. In May 1996, they began their research at ISC. Their research objectives and results will build on findings for MHM biological control reported by this project in Years 15 and 16 (growing seasons of 1993 and 1994).

Graduate student research in the U.S. developed an insecticidal check approach for assessing the impact of natural enemies of greenbugs. Specific objectives were: (1) Develop *enemy removal* as a method to evaluate the impact of natural enemies attacking greenbug in grain sorghum that is treated. (2) Develop *enemy trapping* as a method to evaluate the efficacy of natural enemies of greenbugs in grain sorghum. (3) Determine the effects of insecticide applications on parasite host finding behavior by (a) quantifying parasite behavioral response to host location when sorghum plants are infested with greenbugs, and (b) quantifying the variation in parasite behavioral response to host location (i.e., avoidance, irritation, etc.) when insecticide-treated sorghum plants are infested with greenbugs. The *enemy removal* experiments did not prevent natural enemies from entering exclusion plots and attacking greenbugs. However, one of the *enemy trapping* treatments worked very well and effectively prevented natural enemy activity in the experimental plots. The behavioral experiments resulted in the natural enemy being attracted to the insecticide-treated plants, an unexpected result and an outcome that is contrary to most available literature. Apparently, the insecticide or insecticide additives caused plant damage which was attractive to the parasites.

TAM-125B was an invited INTSORMIL representative to two network activities, and both activities were with the West African Millet Network (ROCAFREMI) . The first activity was a ROCAFREMI meeting in Senegal in August 1995 to review the previous four years, and to begin setting a new agenda for the next 4 years. The second activity was a ROCAFREMI Annual Reunion, the third such meeting which at least one representative from TAM-125B attended. A key activity for the Annual Reunion was preliminary planning to convene a conference on "Integrated Plant Pro-

duction." This conference is tentatively scheduled for October, 1996, and probably will take place in Senegal.

During January through June 1996, TAM-125B hosted Mrs. Aissetou Yaye, a student conducting her Ph.D. research at ICRISAT-SC. Mrs. Yaye took courses at Texas A&M University, and these will be used toward her Ph.D. program at the University of Ghana.

Objectives, Production and Utilization Constraints

Objectives

Sorghum and millet collaborative research objectives. The collaborative research objectives of TAM-125B are to (1) assess natural enemies for biological control of stalk borers and the millet head miner; (2) implement effective biological controls; and (3) provide graduate level training on processes and strategies for biological controls in sorghum and millet, and (4) assess biological control as a component of on farm pest management for sorghum and millet pests in local crop protection practices. The listed objectives are pursued in the United States on grain sorghum and in the Republic of Niger on millet.

Graduate student research. A primary objective of TAM-125B is to train national agricultural research system scientists from collaborating countries so that they can produce quality results for science and local farming clientele, and so they become productive scientists who can contribute leadership toward efficient agriculture in countries with developing agriculture. In this regard, this TAM-125B is training two scientists from West Africa. These scientists' objectives are to (1) improve methodologies for sampling and manipulating populations of millet head miner (MHM), (2) assess the spatial distribution and mortality of all life stages of MHM, (3) conduct experiments to show age-specific mortality in populations of MHM, (4) identify and assess the role of alternate host plants occupied by MHM, (5) determine the optimal survival of MHM in a laboratory environment, and (6) conduct field cage experiments to assess MHM fecundity. One student seeks a Ph.D., and the other an M. S.; both are currently in Niger conducting research in collaboration with Dr. Ousmane Youm of the ICRISAT-Sahelian Center. Other graduate students associated with TAM-125B have finished their research and are writing their research results. Results from one of these students are reported in detail below.

Constraints

Insect pests of sorghum/millet addressed by this project are key pests and constraints to production in the U.S. and West Africa. Detailed ecological understanding of pests and their natural enemies is essential for a sustainable management strategy for an annual crop, especially during times of year when pests occupy noncrop portions of an agroecosystem. Collaborative research in Niger addresses biological control of stalk borers and the millet head miner, and in the U.S. addresses biological control of midges, aphids and spider mites. U.S. research seeks to provide training for graduate students that evolves theory and concepts for implementing biological controls in West Africa, evolves concepts and definitions for functional agroecosystems, develops methods for measuring impacts of natural enemies, and validates results of biological controls when implemented.

Research Approach and Project Output

Millet Head Miner (MHM) Research in Niger. Integrated Pest Management (IPM) traces its beginnings to the mid-1960's. In brief, effective IPM manages pests by conserving effective naturally occurring pest controls (i.e., pest diseases, predators, and parasites), using selective pest behavior modifiers (e.g., baits, pheromones, etc.), and using resistant hosts and crop production practices. In IPM, these crop protection tactics are integrated into a sustainable and mutually complimentary system of crop production. In 1991, National Agricultural Research System (NARS) scientists of West Africa inaugurated the Réseau Ouest et Centre Africain de Recherche sur le Mil (ROCAFREMI). The network, funded by the Swiss Development Cooperation, consists of thirteen member NARSs, and seeks to improve production of Sahelian millet in a manner consistent with effective natural resource management. Network participants are divided into four projects including millet genetic improvement (P1), millet entomology (P2), millet pathology (P3) and millet agronomy (P4). Collectively, these projects seek to integrate the best knowledge for producing millet while conserving the most natural resources and minimizing farmer inputs.

IPM of millet pests is a prominent goal of ROCAFREMI. Thus, early in network activities, crop protection participants identified the key pests of Sahelian millet, i.e., millet head miner (*Heliocheilus albipunctella* (de Joannis)), millet stalk borers (*Coniesta ignefusalis* (Hampson)) and downy mildew disease (*Sclerospora graminicola* (Sacc.) (Schroter)). The millet head miner (MHM) commonly causes significant crop losses of pearl millet in Sahelian West Africa. Infestations sometimes approach 95% with a collective grain loss of 60%. Current management options are mainly cultural practices (e.g., late planting and deep plowing), and these are generally impractical. However, MHM is a good candidate for a control strategy that emphasizes effective natural enemies, i.e., biological control. It supports a relatively large guild of natural enemies (reported in previous TAM-125B annual reports and by others), occupies a predictable habitat in an ecosystem with relatively consistent annual presence, and has one generation per year.

Before advocating a strategy using biological controls, extant natural enemies must be assessed. This is especially important for the low input and fragile Sahelian farming systems. Thus, in 1993 we began a research project on MHM

survival, especially seeking to understand the contributions of MHM natural enemies to total mortality. Specific objectives of our research are to (1) expand aspects of MHM biology; (2) evaluate the impact of MHM enemies; and (3) construct an age-specific life table (k-factor analysis) for MHM.

Research Methods for MHM

Our experiments will be conducted mainly in fields at and near the ICRISAT Sahelian Center (ISC) in Niger. Previous research was conducted in the growing season of 1993, and continued through the growing season of 1994 (reported in INTSORMIL Annual Report, 1995). To date, we have conducted four series of experiments on MHM, but the most important experiments were caged exclusion experiments that measured the contribution of natural enemies to total MHM mortality. These experiments excluded natural enemies from MHM on some experimental plants, and permitted free access of natural enemies to MHM on others.

Research Findings for MHM. During INTSORMIL Year 17, two NARS scientists from West Africa were recruited and admitted as graduate students in the Department of Entomology at Texas A&M University. On arrival at Texas A&M University in January 1996, these students developed an understanding and appreciation for pertinent literature on MHM and biological control. They also developed plans for their research to be conducted in the growing season of 1996. In May 1996, they began their research at ISC. Their research objectives and results will build on findings for MHM biological control reported by this project in Years 15 and 16 (growing seasons of 1993 and 1994). When this research is complete, the key mortality sources, including natural enemies of MHM, will be identified and methods of manipulation will be described for those that can be effectively managed for optimal mortality to MHM populations. We have already shared our methodology and results with participants in ROCAFREMI. Soon, ROCAFREMI projects on plant breeding and agronomy will be asked to participate in our experimentation to help assess the role of crop production practices on tactics to manipulate MHM mortality.

Graduate Student Research. Greenbugs, *Schizaphis graminum* (Rondani), have been a frequent pest in the United States since 1882 on wheat, *Triticum aestivum* L., and since 1969 on grain sorghum, *Sorghum bicolor* (L.) Moench. Several indigenous and exotic natural enemies are associated with greenbugs, and previous experimental evaluations have determined the efficacy of these natural enemies. Some of these enemies are considered important for controlling greenbugs on sorghum and wheat. Evaluations of natural enemies provide a scientific basis for their control performance, for developing management options to improve their control potential, and essential for developing strategies to augment natural enemies.

Research Methods

Natural enemy efficacy can be evaluated using indirect and direct methods. Methods for indirect evaluations typically involve construction and analysis of life tables, and are useful for understanding the ecological role of a natural enemy in a particular ecosystem. Direct evaluation methods provide direct proof of natural enemy impact. They assess pest population growth over time with the only variable being the presence and absence of natural enemies. Direct evaluations explain the impact of natural enemies in terms of the role of natural enemies in slowing pest population growth. Growth rates of pest populations in these two settings are compared, and the difference between them is attributed to the impact of natural enemies.

Several direct methods of evaluating natural enemies have been used in various biological control projects, including caged exclusions, host-exposures, biological exclusions and insecticidal exclusions. Of these, the most useful and least developed method is the insecticidal exclusion method which avoids the limitations of cage effects, small plot effects, and interference with emigration of pests and natural enemies. The insecticidal exclusion method uses selective insecticides to prevent natural enemy activity, and these insecticides are chosen to avoid adverse effects on the treated pest population.

The present research sought to develop a useful insecticidal check approach for assessing the impact of natural enemies of greenbugs. The following specific objectives were addressed. (1) Develop *enemy removal* as a method to evaluate the impact of natural enemies attacking greenbug in grain sorghum that is treated. This research also determined the effects of selected insecticides and application frequencies on parasitism and predation. (2) Develop *enemy trapping* as a method to evaluate the efficacy of natural enemies of greenbugs in grain sorghum. This method required trapping natural enemies in insecticide-treated areas bordering the experimental plots. This methodology also examined three frequencies of insecticide application. (3) Determine the effects of insecticide applications on parasite host finding behavior by (a) quantifying parasite behavioral response to host location when sorghum plants are infested with greenbugs, and (b) quantifying the variation in parasite behavioral response to host location (i.e., avoidance, irritation, etc.) when insecticide-treated sorghum plants are infested with greenbugs.

Research Findings

In *enemy removal* experiments, malathion applied at 0.03 kg AI/ha and chlorpyrifos applied at 0.005 kg AI/ha produced no significant differences (at $P = 0.05$) in the natural enemy or greenbug populations when compared with the untreated (control) plots. Also, three application frequencies of these insecticides (i.e., three, seven and fifteen day intervals) produced no differences in the greenbug or natural

enemy populations. In *enemy trap* experiments, Karate^R (0.02 kg AI/ha) and Bidrin^R (14.88 oz/ha) applications at three day intervals were effective to exclude predators. These natural enemy exclusion agents permitted significantly higher populations of greenbugs and lower populations of predators in the treated plots when compared with the untreated plots (P = 0.05). This failure to prevent natural enemy activity could be due to several reasons. (1) Coverage of the insecticide on plants in the exclusion experiments was insufficient due to the thick canopy of the plants, i.e., the insecticides possibly collected only on the upper part of plants and the natural enemies at the bottom of the plants were unaffected. (2) The insecticides were applied at very low rates, and the preliminary experiments on seedling sorghum plants to determine these rates may have been too artificial to have merit in the experimental field situation. (3) There could have been an adverse effect of insecticides on the greenbug population thus introducing a flaw into data on greenbug population growth in plots that were treated.

In summary, these results showed the *enemy removal* method as used is not useful for evaluating the effects of natural enemies on greenbug. Results showed that malathion applied at 0.030 kg AI/ha and chlorpyrifos applied at 0.005 kg AI/ha caused incomplete exclusion of natural enemies. The frequency of applications of these insecticides showed no significant effects on the natural enemy populations. The relatively greater insecticide tolerance of predators and developing parasites in mummified aphids makes it difficult to find an ideal insecticide or to adjust the application rate to exclude natural enemies without affecting the aphid population.

The *enemy trap* experiment proved to be an effective evaluation tool for greenbug natural enemies, in part because the experimental design avoided plots treated with insecticides. Thus, greenbug populations in the experimental plots were not immediately affected by the insecticidal applications. This research treated only a block of plants bordering the experimental plots thus creating a trap to prevent enemy movement into the experimental plots. Applications of insecticide at three-day intervals caused a significantly adverse effect on natural enemy populations in the *enemy trap* plots. Application frequencies of seven and fifteen days did not prevent natural enemy activity in the experimental plots. Moreover, the significant effects were observed mostly to impact the coccinellid populations and not the parasite populations. This is probably because of the difference in the coccinellid and parasite biologies. All feeding developmental stages of coccinellids are mobile and feed on aphids, and coccinellid larvae walk and search for prey. This walking behavior increases the probability of the predators coming into contact with the insecticide more often. On the other hand, the larval and the pupal stages of parasites are inside the host (mummified aphid) and are not mobile. Only adult parasites are mobile, and they move mostly by flying and thus are not in contact with the insecticide-treated plants. Thus, chances of adult parasites coming in contact with the insecticide treated plants in trap areas is less when compared to the coccinellids. This problem could probably be reduced by increasing the trap area from 3.03 m x 3.03 m to 6.06 m x 6.06 m. Reduction of coccinellids in *enemy trap* plots also may have been due in part to coccinellids feeding directly on insecticide-treated greenbugs. This transfer of insecticide by feeding would be an indirect effect of insecticide on the natural enemy population.

Considerable variability among experimental plots with the same treatment plagued the research in both *enemy removal* and *enemy trap* experiments. The research could have been improved by increasing the number of replications and by selecting plants from random samples with approximately the same numbers of greenbugs (i.e., to have the same initial population of greenbugs in all samples). However, both of these options would significantly increase the amount of labor to conduct this research.

Results of the behavioral studies in this research program showed that the greenbug parasite, *Aphelinus asychis* Walker, is attracted to malathion-treated sorghum leaves infested with greenbugs. Parasite attraction to the treated leaf could be due to the insecticide, or due to associated additives in the insecticide that increases the attractiveness of the insect-plant complex. It is well established that many insecticides do alter the chemistry of plants, though the prevailing thinking has been that this alteration would be repellent and not attraction. The attraction of parasites to insecticides in these experiments helps to explain the presence of parasites in the treated plots of *enemy removal* experiments. Once a parasite reaches an insecticide treated plant and contacts the insecticide, it is killed or ceases movement at the sublethal levels of insecticide application used in the *enemy removal* experiments. The cessation of parasite movement could have caused accumulation of aphid parasites in the treated plots, and thus these experiments showed inadequate exclusion. Further research is needed to reveal whether the females are attracted to the volatiles released by the insecticide-treated plants as a result of plant damage from insecticides, attracted the solvents involved in the formulation, or attracted to the insecticide itself.

Networking Activities

In August 1995, Frank Gilstrap was an invited participant and INTSORMIL representative to a special one-week workshop conducted by ROCAFREMI, the millet network for West Africa. This workshop took place at M'Bour near Dakar, Senegal, and was designed to begin visioning the next level of activities for the network. Discussions included restructuring the network, constraints to network impact on local farming, network scientist training as specialists, and kinds of training needed by network scientists. Themes of Dakar meeting included network scientist publications; the increased partnering among network projects to improve the

scope of research; improving the integration of research among network projects; more focus on IPM and on control of *Striga;* decentralizing the network planning process; more follow up on network decisions; and improved and sustained contact between scientists of different network countries.

In February 1996, Gilstrap was an invited participant and INTSORMIL representative to the Annual Reunion of ROCAFREMI. During this Reunion, the Network scientists began working to implement decisions made at the August workshop held in Senegal. The Reunion reaffirmed a need to begin transferring network research results to farms, and recognized that this transfer will require very close coordination with extension, non-government organizations and private volunteer organizations. The Network leadership wants Network scientists to become more open to cooperation with other organizations, to be more applied and to be more productive. The Reunion decided to try and organize a special workshop on integrated crop production, and to try and conduct this workshop in Senegal in October 1996.

During January through June 1996, the Gilstrap INTSORMIL project hosted Mrs. Aissetou Yaye, a student conducting her Ph.D. research at ICRISAT-SC. Mrs. Yaye took courses at Texas A&M University, and these will be used toward her Ph.D. program at the University of Ghana. She also worked with Gilstrap to improve here dissertation research plan and to capture a broad understanding of biological control as an applied crop protection discipline. Mrs. Yaye visited with many faculty while she was in residence at Texas A&M University.

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Journal Articles

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Development of Plant Disease Protection Systems for Millet and Sorghum in Semi-Arid Southern Africa

Project TAM-128
Gary Odvody
Texas A&M University

Principal Investigator

Dr. Gary Odvody, Texas A&M Research and Extension Center, Route 2, Box 589, Corpus Christi, TX 78406

Collaborating Scientists

M. Chisi, Sorghum Breeder, Golden Valley Research Station, Golden Valley, Zambia
L.E. Claflin/J.F. Leslie, Plant Pathologists, KSU-108, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506
P. Ditsipi, Plant Pathologist, Agricultural Research Station, Private Bag 0033, Gaborone, Botswana
D. Frederickson, Department of Biological Sciences, University of Zimbabwe, Harare, Zimbabwe
R.A. Frederiksen, Plant Pathologist and Principal Investigator, TAM-124, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843
S. G. Jensen, USDA-ARS Plant Pathologist, Department of Plant Pathology, University of Nebraska, Lincoln, NE 68583-0937
G.M. Kaula, Plant Pathologist, Private Bag 7, Mt. Makulu Research Station, Chilanga, Zambia
B. Matilo, Plant Pathologist, Agricultural Research Station, Private Bag 0033, Gaborone, Botswana
C. Manthe, Entomologist, Agricultural Research Station, Private Bag 0033, Gaborone, Botswana
E. Mtisi, Plant Pathologist, Plant Protection Research Institute, RSS Box 8108 Causeway, Harare, Zimbabwe
T. Obilana, Sorghum Breeder, SADC/ICRISAT, Sorghum Millet Improvement Program, P.O. Box 776, Bulawayo, Zimbabwe
B. Rooney, Sorghum Breeder, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
D.T. Rosenow, Sorghum Breeder and Principal Investigator, TAM-122, Texas A&M Agricultural Research and Extension Center, Route 3, Box 219, Lubbock, TX 79401
B.N. Verma, Sorghum and Millet Coordinator/Sorghum Breeder, Mt. Makulu Central Research Station, Private Bag 7, Chilanga, Zambia

Summary

A bacterial disease of pearl millet first observed in Southern Zimbabwe in 1995 has been tentatively identified as *Pseudomonas syringae* by D. Frederickson at the University of Zimbabwe. If confirmed this would be the first report of *P. syringae* on pearl millet outside of the United States. The importance of broad-based foliar disease resistance was apparent in the divergent response of some cultivars to leaf blight at the Henderson Station in Zimbabwe and to sooty stripe at the Panmure station in Zimbabwe. Derivatives of SC326-6 continued to show good adaptation and resistance to anthracnose and other foliar pathogens in Zambia and Zimbabwe but a few did show some vulnerability to sooty stripe. A virus apparently similar to MDMV-A again caused high infection in a late planting of A-lines of released hybrids at one location in Zambia and it (or another virus) was also present in several sorghums in the Pandamatenga and Southern regions of Botswana including a newly released sorghum variety. Live virus samples collected from Zambia and Botswana are being characterized by S. Jensen at the University of Nebraska. Through elimination of inactive isomers a new formulation of metalaxyl (Apron XL) has twice the amount of active ingredient and it showed good control of systemic sorghum downy mildew in sorghum in both greenhouse and field studies when utilized at half of the normal treatment rate.

Objectives, Production and Utilization Constraints

Identify unknown virus occurring in the Pandamatenga area. (Botswana)

Evaluate the ecology and economic importance of *Exserohilum turcicum* and *Ramulispora sorghi*, and evaluate specific versus general leaf disease resistance. (Zambia, Zimbabwe)

Identify sources of late season drought tolerance with adequate charcoal rot and other disease resistance. (Botswana, Zimbabwe)

Characterization of *Macrophomina phaseolina*. (Botswana, Zambia, Zimbabwe, U.S.)

Assist national programs in identification of adapted foliar disease resistant cultivars that have stable disease resistance reactions in strategic multilocational nurseries over several years. (Botswana, Zambia, Zimbabwe).

Develop alternate disease control strategies including biocontrol and chemicals to augment host plant resistance where needed. (Botswana, Zambia, Zimbabwe).

Determine the potential for pre-harvest aflatoxin in sorghum and evaluate influence of pericarp genetics on sorghum's vulnerability to aflatoxin. (U.S.)

Research Approach and Project Output

Foliar Diseases (Anthracnose, Leaf Blight, Sooty Stripe)

In 1995-96, three sorghum disease nurseries were planted at two locations in Zambia and two locations in Zimbabwe to evaluate response to anthracnose, leaf blight, and sooty stripe. Two of these nurseries, called Anthracnose Resistant Germplasm Nurseries (ARGN-1, 39 entries and ARGN-2, 40 entries), consisted primarily of entries that had maintained excellent anthracnose resistance, good adaptation to the region, and good to excellent resistance to either or both leaf blight or sooty stripe in previous SADC testing over one or more years.

During the 1995-96 season in Zimbabwe, there was a low incidence of sooty stripe and high incidence and severity of leaf blight at the Henderson Station and the reverse occurred at the Panmure station. The obviously divergent response to sooty stripe and leaf blight demonstrated by some cultivars between these two locations only about 100 km apart indicate that a broader based foliar disease resistance (or at least reduced susceptibility) would be more valuable than high resistance to either foliar pathogen (Table 1). At Henderson, leaf blight almost completely negated grain development in the most vulnerable cultivars of the ARGN-1 and ARGN-2 nurseries and, conversely, sooty stripe dramatically reduced grain yield in two or more of the most vulnerable cultivars of the ARGN-1 and ARGN-2 nurseries at the Panmure station. Sooty stripe development at the Golden Valley station was moderate but cultivar responses were similar to the Panmure station which is consistent with previous years' observations. The severity of leaf blight at the Henderson station in the susceptible sorghums shown in Table 1 ranged from 4 to 20%, 28 to 95%, and 35 to 99% foliar incidence at 56, 85 and 104 days after planting, respectively.

Some cultivars in the ARGN-1 and ARGN-2 nurseries maintained high resistance to both pathogens at both Zimbabwe nursery locations (Table 2). Many of the sorghums with SC326-6 in their background had good resistance to both sooty stripe and leaf blight (Table 2) but a few showed some vulnerability to sooty stripe in both Zimbabwe (Table 1) and Zambia. Most of the sorghums with SC326-6 also have broad adaptation and good resistance to anthracnose and other foliar diseases in Zambia where two of them (EON 361 and EON362) are being extensively utilized in the sorghum improvement program.

The expected contrasting foliar disease response of cultivars R8602 (S to leaf blight and R to sooty stripe) and R6956 (R to leaf blight and S to sooty stripe) at Henderson and Panmure stations was especially apparent this season (Table 1) as both had good yields where foliar disease was low and little or much reduced yield where disease was severe. These two cultivars and a few others with differential

Table 1. Sorghum entries of the ARGN-1 and ARGN-2 with divergent incidence of leaf blight at the henderson station and sooty stripe at the Panmure Station in Zimbabwe in 1996.[a]

Genotype or Designation	Leaf blight-Avg	Sooty stripe-AVg
R8602	99	0
(EBA7XTx434)-C7-C1 ...-L1	91	1
ATx638*R8602	77	2
SRN39 (*Striga* Resistant)	75	5
89BD1557/SC414*TAM428	60	7
(M35-1*CS3541)-1-1-B1-.....LBK	60	15
93BD2455/)Sureno*87BB396)-BE?-BE5	50	5
ATx378*RTx434	47	6
Sureno	45	3
BTx638 (B8618)	45	17
R8924	42	5
(SC173*SC414)/413	35	0
B9006	35	3
RTx436 (R8505)	15	32
91CC362/R8505*(R5646*SC326-6)	14	35
91CC371/R8505*(R5646*SC326-6)	13	32
R8511	12	35
R6956/SC103*SC326-6	6	80
(((SC120*Tx7000)*Tx7000). . .-1*R6956). . .C1	<1	55
R9109	0	32

[a] Average incidence (average percent leaf area destroyed) of leaf blight (causal agent *Exserohilum turcicum*) at the Henderson station and sooty stripe (causal agent *Ramulispora sorghi*) at the Panmure station from two reps at 104 days after planting. Entries shown are those which had a disease incidence of 30% or higher for the primary pathogen at either location and 20% or less incidence for the primary pathogen at the other location. Entries are listed in order of decreasing incidence of leaf blight. ARGN-1 (39 entries) and ARGN-2 (40 entries) = Anthracnose Resistance Germplasm Nursery. Evaluations were done on April 1- 2, 1996 by Odvody, Mtisi, and Benza.

Table 2. Sorghum entries of the ARGN-1 and ARGN-2 with low incidence (15% or less) of both leaf blight at the Henderson Station and sooty stripe at the Panmure Station in Zimbabwe in 1996.[a]

Genotype or Designation	Leaf blight-Avg	Sooty stripe-Avg
92BD1908/(PL2120*86EO361)-BD8	15	11
((ADN55*Tx430)...-1*80C2241)....-C2	15	5
IS3552C/SC748	11	0
89PR1679/(SC173*SC414)/499	10	2
87BH8341/86EON361sel	8	4
86EON361/R5646*SC326-6	7	1
IS2395C/SC647	6	10
91CC673/R8505*((TX432*CS3541)*SC326-6)	6	10
(TX435*R3338)-C1-C1-T3-BK	5	15
((Tx414*SC108)-15...-2-OP*R6956)-3...-C1	5	8
86EON362/R5646*SC326-6	3	13
82BDM499/ SC173*SC414	3	1
IS12219C/SC991	2	2
87L3570/86EON362sel	2	3
IS2508C/SC414-12e	1	10
IS12637C/SC146	0	5
86EON374/(Tx432*CS3541)*SC326-6	0	2
SC326-6	0	1

[a] Average incidence (average percent leaf area destroyed) of leaf blight (causal agent *Exserohilum turcicum*) at the Henderson station and sooty stripe (causal agent *Ramulispora sorghi*) at the Panmure station from two reps at 104 days after planting. Entries shown are those which had a disease incidence of 15% or less for the primary pathogen at both locations. Entries are listed in order of decreasing incidence of leaf blight. ARGN-1 (39 entries) and ARGN-2 (40 entries) = Anthracnose Resistance Germplasm Nursery. Evaluations were done on April 1- 2, 1996 by Odvody, Mtisi, and Benza.

response to leaf blight and sooty stripe were selected from the ARGN nurseries and crossed in specific combinations in Texas in the summer of 1995 by TAM-122 to initiate development of near-isogenic F3 populations to assess the impact of leaf blight and sooty stripe on yield. F1 seed of at least twelve different crosses were grown in Puerto Rico in the winter of 1996 and the F2 seed is being grown in Lubbock in the summer of 1996.

Virus Identification

Virus reactions were recorded in the International Sorghum Virus Nursery (ISVN) and in some other introduced cultivars grown for the first time at Pandamatenga and at the Sebele research station. Virus mosaic symptoms and red leaf necrosis were again observed in the released variety Mahube (SDS2583) at both the Pandamatenga and Sebele stations. Virus symptoms were again evident in some sorghum cultivars at a few locations in Zambia near Lusaka and, although sporadic in occurrence, high vulnerability to virus in some A-lines of popular, released hybrids may prove problematic in some production areas. Live virus samples were collected from known cultivars in the International Sorghum Virus Nursery (ISVN) and other nurseries at the Pandamatenga and Sebele stations in Botswana and from two or more locations in Zambia, including Mt Makulu and near the Golden Valley Research Station. These collected virus specimens were sent, under a special import permit, to S. Jensen who is identifying and characterizing the viruses. The viruses are also being studied by P. Ditsipi at the Sebele station in Botswana.

Bacterial Disease of Pearl Millet

Dr. D. Frederickson, in collaboration with this project and with L. Claflin of KSU-108, has tentatively identified *Pseudomonas syringae* as the bacterium causing the foliar disease of pearl millet first observed in Southern Zimbabwe in 1995. If confirmed, this would be the first report of *P. syringae* on pearl millet outside of the U.S. and one of the few reports since its initial description in Iowa in 1926. In April, TAM-128 assisted D. Frederickson in rating a leaf spot disease nursery established by E.S. Monyo of SADC/ICRISAT to determine cultivar response of pearl millet to this bacterial pathogen at two locations in Southern Zimbabwe. The disease was present but levels were less than those observed in 1995.

Chemical Control

Both greenhouse and field results with soilborne oospores of *Peronosclerospora sorghi* confirmed that a new formulation of metalaxyl (Apron) from Ciba-Geigy gave equivalent control of sorghum downy mildew when utilized at half the normal rate. Production of the new formulation, called Apron XL, eliminated the non-active isomers of metalaxyl normally present as 50% of the active ingredient in previous metalaxyl formulations.

Cultivar Evaluations

Several sorghum disease nurseries, other nurseries, selected sorghums, and advanced generation breeding germplasm were evaluated at two sites in Botswana (Sebele and Pandamatenga) to identify those with improved drought tolerance, and resistance to sugarcane aphids and disease. In early April 1996 TAM-128 assisted DAR scientists in identifying and selecting cultivars for incorporation into their sorghum improvement program. Several cultivars with reported resistance to sugar cane aphid at other locations demonstrated similar resistance at the Sebele station and some, like CE-151, had excellent adaptation to Botswana; however, they will require evaluation under the more normal, severe drought stress that occurs at the Sebele station

rather than the reduced stress of this past season. The All Disease and Insect Nursery, selections from other nurseries, and additional sorghums requested by B.N. Verma were evaluated at two or more sites in Zambia for adaptation, disease resistance and other factors.

Networking Activities

Sorghum Ergot Activities

TAM-128 has been active in soliciting, gathering and disseminating information about the global threat now posed by the ergot pathogen, *Claviceps africana*. Along with TAM-124, information about ergot has been disseminated to scientists and sorghum workers around the globe, including USDA/APHIS scientists, as we seek to control ergot where present and prevent or slow its spread to new regions. During a three week trip to Southern Africa in March-April 1996 the TAM-128 PI visited sorghum ergot authorities, Dr. D. Frederickson of the University of Zimbabwe and Dr. Neal McLaren of the Grain Crops Research Institute in Potchefstroom, South Africa. The visits were to gain additional information about the disease and to review their research activities with *C. africana*. The TAM-128 PI traveled to Brazil in June 1996 to confer with EMBRAPA scientists about the sorghum ergot problem, their current ergot research activities, and to develop potential collaborative research plans and proposals. Another goal of the trip was to discuss activities related to the global ergot conference scheduled for early June 1997 at EMBRAPA in Brazil.

Germplasm exchange

Over 500 lines & cultivars were evaluated for response to various diseases, adaptation, drought response, and sugarcane aphid resistance in the SADC region in 1995-96 (collaborative with TAM-122, B. Rooney, TAM-123, and TAM-124)

Research Support

Supplies were provided in 1995-96 to D. Frederickson in Zimbabwe to support collaborative research on the bacterial pathogen of pearl millet found in Southern Zimbabwe in 1995.

Sustainable Production Systems

Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries

Project PRF-105
John Sanders
Purdue University

Principal Investigator

Dr. John H. Sanders, Department of Agricultural Economics, Purdue University, 1145 Krannert Building, West Lafayette, IN 47907-1145

Collaborating Scientists

Mamadou Sidibé, Department of Agricultural Economics, Purdue University, 1145 Krannert Building, West Lafayette, IN 47907-1145
Moustapha Kebe, ISRA/PASE, BP 3120, Dakar, Senegal
Bakary Coulibaly, Icofil, IER, BP 258 Bamako, Mali
Demba Kebe, ESPGRN/IER, BP 186, Sikasso, Mali
Jeffrey Vitale, Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907-1145
Nina Lilja, Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907-1145
Pareena G. Lawrence, Department of Economics, University of Minnesota-Morris, Morris, MN 56267
Sunder Ramaswamy, Department of Economics, Middlebury College, Middlebury, VT 753
Miguel López-Pereira, ECOHON Consultants, Tegucigalpa, Honduras

Summary

The econometric results for the determinants of the payments to women for their work on the farm indicated that they did benefit from the introduction of new technologies. Moreover, increased bargaining ability led to substantially increased incomes supporting the conflict-cooperation type of family decision-making. This type of decision-making, which is the same type of negotiation that goes on between management and labor in a firm, has been shown in previous work to result in much greater gains to women from technology and greater economic opportunities in the region than those gains obtainable from the autocratic male dominance with the use of social sanctions. The latter has been frequently argued to be the predominant type of family decision-making in the semiarid West African region, especially in the Women in Development literature. The significance of several of the variables helps support our case for the negotiated types of decision-making. The percentage impact of increased economic alternatives on the income of women was much lower than expected, apparently indicating the returns to better information and other improvements in the functioning of the job market.

Objectives, Production and Utilization Constraints

Objectives

The objectives of our research are to estimate the potential effects of new technology introduction, to identify the constraints to its introduction, and to suggest complementary policy to accelerate that introduction process. There is an increasing emphasis in this project on evaluating the effects of new technologies on the welfare of women and on the sustainability of the natural-resource systems.

Southern Mali

We have been engaged in fieldwork and modeling to evaluate the determinants of the implicit wages paid to women and to estimate the impacts of specific policy changes to increase their incomes.

Semiarid Sub-Saharan Africa

From March 17 to April 14, 1996, there was a review of the impact of ICRISAT in introducing new technologies into the major sorghum and millet zones of Sub-Saharan Africa. Since INTSORMIL was also involved in some of these activities and endeavors to build upon these successes, it is relevant to summarize some of the results from this review. In another contract for the USDA/USAID, we summarized some of our previous fieldwork emphasizing the contribution of technological change to the sustainability of the natural-resource system.

Research Approach and Project Output

Impact of Agricultural Technologies on Women's Income — southern Mali

The fieldwork in southern Mali was designed to estimate the impacts of new agricultural technologies, the type of household decision-making, and opportunity costs of

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Table 1. Average annual total female income from various sources (FCFA).

Village	No. of observations	Communal	Own private plot	Work groups	Other's private plot	Other off-farm income	Total
Koutiala	14	1502	14256	0	0	1482	17240
Sikasso	12	1238	140486	7616	554	583	150477
Fana	9	5070	6022	0	0	5556	16648
Bougouni	8	1937	60872	1688	1219	4125	69840
San	9	2722	978	0	400	11056	15155
Mean	53	2337	46834	2017	384	4043	55616
N = 52							

Lilja et al., 1996.
Exchange rate, 1994: 555 FCFA/US$

Table 2. Regression results, variables affecting daily female wage rate.

Variable	Estimate	t-ratio
Area under cotton	28.734	4.167[a]
Right to refuse	62.869	2.256[b]
Opportunity cost	0.00092	2.361[b]
Area of private plot	-77.302	-3.122[a]
Household size	-2.053	-1.993[b]
Constant	5.3178	0.225
N=52, R^2 = 0.37, [a]significant at 1% level, [b]significant at 5% level		

Lilja et al., 1996

women on the payments received by women for their work on the communal fields. Payments to women included both money and the value of payments in kind, including grain payments. Fifty-two women were interviewed from five different villages.

The principal income source for the women was their private-plot earnings (Table 1) with very high revenues from this activity in two of the sites. The recent devaluation (January 1994 of the FCFA) substantially increased the costs of imported foods; the prices of rice and potatoes were especially high in the region. These high prices were a windfall gain to the women specializing in these crops. Off-farm work was also more important than the income from the communal fields and, as with the private plots, there was substantial variability between the sites. In San, young women benefited from the Minianka of letting women do domestic work in the town. The other ethnic groups were not as flexible with their women. Also in San, women were able to make very little from their private plots. This was not due to the lack of available land, as in Koutiala, but due to cultural factors of the women preferring not to work the land.

The principal research question of this fieldwork was what determines the implicit wage payments (cash, clothing, and additional food) paid to women for their work on the communal land, principally in cotton production. The subsistence grain allocation given to all family members was not included but additional grain payments were. The technology (area in cotton), bargaining, and opportunity cost variables all were associated with higher wage payments for the communal field work (Table 2). The average pay for women was 49 FCFA/day. Another hectare under cotton raised female wages 29 FCFA and the ability to bargain (a dummy variable) by 63 FCFA. A 10% increase in the opportunity cost, or the wages women receive outside the household, would increase their wage only 4.9%. It is surprising that opportunity costs do not have a greater effect on wages; this may reflect the continuing social controls men have over their wives.

Both accelerating the introduction of technological change on the communal fields and increasing the alternatives of women to work off the farm resulted in higher wages for the women. Fifteen percent of the women believed that if they were dissatisfied with the payment, they could refuse to work on the communal field. The perception by women that they could indeed negotiate for higher wage payments and that they had alternatives if the men paid them lower than expected wages after the harvest was associated with higher wages. There was a payoff to bargaining and improving bargaining ability as a variable to raise women's incomes may be a viable public policy.

When the women are allocated a lower area in private plots, they receive higher wages for their work on communal plots. The negative sign of the area in the private plots indicates the need to consider earnings from the private plot as one of the components of women's compensation, and this was done in another regression. Finally, in the larger households lower wages are paid for the communal work. This significant negative coefficient probably indicates the reduction of bargaining power in the larger households. Women would benefit from smaller household sizes and would be expected to press for this type of social change.

The above regression results indicate that the payments to the women in the household responds to the usual economic incentives in any labor market, including technological change and alternative opportunities. There is little support here for one traditional view that the household head is able to dominate the females through social sanctions and exploit them, extracting the gains from technological change and ignoring other alternatives available to them. The ability to bargain or the perception that they could bargain is clearly associated with higher incomes. The significance of this variable supports the conflict and cooperation view of household decision-making (for more details on different bargaining theories in the household see Sanders et al., 1996, pp. 161-163).

Impact of New Sorghum-Millet Technologies in West Africa

In reviewing the effects of new sorghum and millet technologies, we interviewed scientists, input dealers and a brewery representative (Table 3). There are several diffusion studies underway to provide more exact information. S-35 is the only successfully diffused direct sorghum introduction from India. It has already been diffused into farmers' portfolios in northern Cameroon and is presently being promoted in southern Chad with an FAO-sponsored seed-production program.

Other studies (Sanders et al., 1996) have shown that inadequate development of the input or product markets can impede the technology-introduction process. In northern Nigeria, one large national seed company and one of the major breweries were involved in the introduction of a new sorghum variety and a hybrid. With the brewery, there were long-term plans for rapid expansion of production and for contract purchases from farmers. This better integration of the input and product markets is expected to accelerate diffusion.

Advanced contracts and involvement of end-product users take much of the risk out of more intensive cropping practices. This northern Nigeria introduction process is an important model for the Sahelian countries. For example, if the recent (summer 1995) Malian regulation encouraging millers to combine maize with wheat flour for bread could be extended to white sorghum, this would stabilize the sorghum price and accelerate the diffusion of new sorghum technology. Influencing policy makers on specific subjects critical to technology introduction is expected to be a high return activity for both INTSORMIL and ICRISAT.

Of the new materials being introduced, INTSORMIL has been most associated with SEPON 82. As indicated in the notes on the development of these new sorghum cultivars in Table 3, there is a continuous exchange process between the various research organizations.

Finally, there was an emphasis in the report on the importance of increasing soil fertility. Only in northern Nigeria and southern Mali has there been some progress on combining these new sorghum cultivars with increased fertilization. With the general deficiencies of N and P there are unlikely to be significant yield effects that can be sustained over time from new cultivars alone. It would be unfortunate if the new cultivar programs resulted only in the moderate yield gains that result from earliness in adverse rainfall years and from improved seed quality. Sustainable yield gains need to include higher fertilization levels.

Soil Degradation and Technological Change

We prepared a summary document for USDA World Soil Resources (under contract with USAID), reviewing the literature on the costs of soil degradation and policy measures to reduce it. This monograph was then distributed to policy makers in developing countries (see Sanders et al. 1995). Here we summarize some of the recommendations from our previous fieldwork discussed in this review:

In the severely degraded Mossi Plateau of Burkina Faso, farmers have introduced contour dikes, the "zaï" (holes dug

Table 3. Estimated on-farm diffusion of NARS-ICRISAT sorghum and millet cultivars

Cultivar[1]	Country	Area of adoption	Source/ICRISAT study[2]
S-35(S)	Chad Cameroon Northern Nigeria	Firm data not currently available	Yes Yes
Framida (S)	Ghana Togo Côte d'Ivoire Burkina Faso	Firm data not currently available	Breeders' estimate
GB8735(M)	Chad	30,000 ha	Breeders' estimate
ITMV 8001	Chad	10,000 to 20,000 ha	Breeders' estimate
IBMV 8001 IBMV 8004 (M)	Senegal	10,000 to 30,000 ha	Breeders' estimate
ICSV 400(S)	Nigeria	4,800 ha	For Guinness brewery
ICSV 400(S)	Mali	20 to 30% adoption	ICRISAT field study in the region surveyed
ICSV 1049 ICSV 1002(S)	Burkina Faso	Firm data not currently available	N/A
ICSH 89002 NG	Nigeria	10 tons of seed sold (1992-1995)	Estimate obtained from Premier Seed Co. (hybrid sorghum)
SEPON 82(S)	Niger	Firm data not currently available	Diffusion study in progress
Toroniou C-1(M)	Mali	Diffused near the Cinzana Station	N/A

[1] For ICRISAT releases, the code for sorghum or millet is the third letter. For others, sorghum(S) and millet(M) are identified in parentheses.

[2] Source: Estimates of economists and breeders in ICRISAT-WCA are based on their field data or interviews with national scientists. Estimates for cultivars 6 and 9 were obtained from the companies listed.

Notes: S-35 was identified by Rao and is the only sorghum success in western Africa of materials brought in directly from India; Framida is a selection (red) from Botswana selected by Ramaiah for its tolerance to *Striga*; GB 8735 is a cross from Anand Kumar's breeding program. Besides the success in Chad, this variety has been released and seed is being multiplied for farm-level distribution presently in Mauritania; ICSV 1049 and ICSV 1002 were E-35 (selected by Patanayak of the original ICRISAT Burkina Faso program) crossed with Framida by Dr. Ramaiah; IBV 8001 and 8004 were crosses of Dr. Gupta in his work with ISRA in the early '80s; ICSH is Murty's hybrid; SEPON 82 has E-35 and other ICRISAT material and SRN 39, also released, has Framida; Toroniou C-1 was developed by Niangado from local populations with some ICRISAT material in the population.

for water capture), and manure. Yields have increased and further increases are possible with other combined measures for simultaneously increasing water retention and soil fertility, such as tied ridges and inorganic fertilizers.

On the slopes in southern Honduras, the construction of stone terraces and other soil-conservation techniques make profitable the use of inorganic fertilizer and new cultivars by preventing farms from washing down into the valleys. This combination of new technologies can increase farmers' incomes by 50% (Sanders et al., 1995).

In both Burkina Faso and Honduras, these combined measures for improving water control and increasing soil fertility require very large labor inputs, but we show them to be both profitable and to increase the sustainability of the agricultural systems.

Most of the rural poor are concentrated in marginal agricultural regions, such as much of the semi-arid regions and hillsides (Sanders et al., 1995). In the long run there are undoubtedly more efficient solutions for the alleviation of rural poverty than the introduction of new technologies. Nevertheless, in many developing countries, including most of Sub-Saharan Africa, there is high population growth and slow nonagricultural employment growth. Hence, raising the incomes of this sector will continue to involve specific measures to increase agricultural productivity. Fortunately, there are labor intensive measures for both regions that have demonstrated success both in raising farmers' incomes and in increasing the sustainability of the agricultural system.

The most common soil degradation problem appears to be nutrient depletion. As countries remove the various price distortions that reduce the profitability of agriculture, increasing the use of inorganic fertilizers and the introduction of new cultivars will become more profitable. We demonstrated the potential to substantially increase sorghum yields with moderate levels of nitrogen on the rainfed Vertisols of the Sudan, the principal sorghum production zone of this country. Both the evolution of the input markets and the expansion of alternative uses for the basic food staples to reduce the between-season price variability are important components of higher purchased input utilization for the large farmers in this region.

Networking

Research Investigator Exchange

Sanders participated in two multidisciplinary teams to evaluate ICRISAT's programs in West-Central and in East-Southern Africa in March-April 1996. Each mission took two weeks and produced a report for the Board of Directors of ICRISAT.

Sanders and two natural-resource specialists collaborated to produce a bulletin for USAID (see Publications) on technological change and soil degradation. The audience was principally developing-country policy makers.

Mamadou Sidibé spent six weeks in Senegal, working with ISRA in finishing three bulletins on impact analysis; these have been submitted to ISRA for internal publication. He also worked on a diffusion study of millet and revised an earlier bulletin on the impact of new millet cultivars.

Demba Kebe came to Purdue from ESPGRN/IER, Sikasso, Mali, for two months (Jan.-Mar., 1996). He worked with Jeff Vitale on adapting and updating the farm models of Ousmane Coulibaly to his region. Then Vitale went to Mali for three months (May-Aug. 1996) to work with IER personnel in southern Mali. He will be giving a short course on GAMS, updating these models, and preparing papers for a journal article and two conferences.

Issiaka Dembélé came to Purdue in June for two months. He is working with Nina Lilja on the impact of new technologies and other factors on the welfare of women. Previously, he worked in southern Mali with Nina as the technical person responsible for the activities of CMDT to benefit women in the Sikasso zone.

Publications

Journal Articles

M. Ahmed, Mohamed, William A. Masters, and John H. Sanders, 1995. Returns From Research in Economies With Policy Distortions: Hybrid Sorghum in Sudan, Agricultural Economics 12(2):183-192.

Books

Sanders, John H., Barry I. Shapiro, and Sunder Ramaswamy. 1996. The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa. Johns Hopkins University Press, Baltimore, MD, 303 pp.

Proceedings

Bezuneh, Taye, and John H. Sanders. 1995. Research orientation towards the needs of cereal-based agro-industries, Pp. 229-235. In J.M. Menyonga, Taye Bezuneh, C.C. Nwasike, P.M. Sedego, and A. Tenkouano (eds.). Processing and Industrial Utilization of Sorghum and Related Cereals in Africa, OAU/STRC-SAFGRAD Regional Symposium on Processing and Utilization of Sorghum and Related Cereals in Africa, Ouagadougou, Burkina Faso, Nov. 22-26, 1993. The Coordination Office, OAU/STRC-SAFGRAD, Semi-Arid Food Grain Research and Development, Ouagadougou, Burkina Faso.

Lilja, Nina, John H. Sanders, Catherine A. Durham, Hugo De Groote, and Issiaka Dembélé. 1996. "Factors Influencing the Payments to Women in Malian Agriculture," principal paper presented at AAEA annual meeting, San Antonio, TX, July 28-31. Forthcoming in American Journal of Agricultural Economics Dec. 1996.

Miscellaneous Publications

Sanders, John H., Douglas D. Southgate, and John G. Lee. 1995. The Economics of Soil Degradation: Technological Change and Policy Alternatives. SMSS Technical Monograph No. 22, USDA/Natural Resources Conservation Service, World Soil Resources, Washington, DC, 82 pp.

Cropping Systems to Optimize Yield, Water and Nutrient Use Efficiency of Pearl Millet

Project UNL-113B
Stephen C. Mason
University of Nebraska

Principal Investigators

Dr. Stephen C. Mason, Professor, University of Nebraska, Department of Agronomy, Lincoln, NE 68583
Mr. Minamba Bagayoko, IER, Mali
Mr. Samba Traore, IER, Mali
Mr. Nouri Maman, INRAN, Niger

Collaborating Scientists

Prof. David Andrews, University of Nebraska, Lincoln, Nebraska
Dr. Ouendeba Botorou, INRAN, Niamey, Niger
Dr. Max Clegg, University of Nebraska, Lincoln, Nebraska
Mr. Adama Coulibaly, IER, Cinzana, Mali
Mr. Sidi Bekaye Coulibaly, IER, Cinzana, Mali
Prof. Robert Klein, University of Nebraska, North Platte, Nebraska
Mr. Zoumana Kouyate, IER, Cinzana, Mali (TROPSOIL Coordinator and Head of Cowpea Program)
Dr. Jerry Maranville, University of Nebraska, Lincoln, Nebraska
Dr. Alex Martin, University of Nebraska, Lincoln, Nebraska
Dr. S.V.R. Shetty, ICRISAT Sahelian Center, Niamey, Niger
Mr. Seyni Sirifi, INRAN, Kollo, Niger
Prof. William Stegmeier, Kansas State University, Hays, Kansas
Mr. Abdoul Wahab Toure, IER, Bamako, Mali
Mr. Antime Sagara and Oumar Coulibaly, IER, Cinzana, Mali.
(On-farm agronomists working with the Extension Service and PVOs in the Segou area)

Summary

Cropping system research has been conducted in INTSORMIL UNL-113B to address water and nutrient constraints in grain sorghum and pearl millet production. Efforts address factors that improve the production environment to allow improved cultivars to express their higher grain yield potential, and to improve yield, water and nutrient use efficiency through use of improved production practices. The project strengthened research efforts with pearl millet by developing cooperative studies with breeders in Mali, Niger, and the U.S., and participation in the ROCAFREMI Network. Principal Investigators Samba Traore started a Ph.D. program and Nouri Maman a M.S. program at the University of Nebraska. Minamba Bagayoko and Nouri Maman completed short-term training at University of Nebraska, and Minamba Bagayoko was accepted into a Ph.D. program at the University of Hohenheim, Germany with thesis research conducted in West Africa through the ROTOPHOS project centered at the ICRISAT Sahelian Center, Niamey, Niger.

Rotation with cowpea in Mali increased pearl millet grain yield by 19, 17, 31, 27 and 30% in 1991, 1992 1993, 1994 and 1995, respectively, while application of 40 kg/ha N fertilizer increased grain yield 8, 20, 16, 35 and 6%. All cropping systems plots had lower pH, N, K and Mg levels than the fallow after four years, suggesting that all continuous, rotational and intercrop systems studied were mining the soil of nutrients. In both Mali and Niger, increasing the production level (manure, fertilizer, higher plant population) increased grain yield of all pearl millet cultivars, suggesting that differential production practices are not required. However, in both locations cultivar grain yield differences were large indicating the importance of cultivar selection.

Research in Nebraska indicated the importance of using narrow rows to maximize yield of dwarf pearl millet hybrids, although some variation in response by hybrids was found, Early planting was necessary to maximize grain yield in the low rainfall, sandy soil Ogallala site in western Nebraska. Much more production research is needed in different eco-physiological sites to determine recommended production practices for pearl millet in the Great Plains.

Objectives, Production and Utilization Constraints

Objectives

Conduct long-term studies to determine pearl millet/cowpea cropping systems (monoculture, rotation, intercropping) by nitrogen fertilizer rate interaction effects on grain and stover yields, and nitrogen use efficiency were continued at two locations in Mali.

Conduct long-term studies to determine the influence of crop residue removal, incorporation and leaving on the surface on grain and stover yield of pearl millet were continued at one location in Mali.

Initiate studies to develop production practices for new pearl millet cultivars to be released by national programs in Mali and Niger.

Initiate studies in Mali and Nebraska to determine dry matter production and nutrient uptake of pearl millet cultivars with different growth habits.

Study the "rotational effect" in pearl millet-soybean rotation by evaluating: 1) grain and stover yields, 2) nitrogen uptake and use efficiency, and 3) soil water relationships.

Determine the influence of planting date and row spacing on grain yield of dwarf pearl millet hybrids in Nebraska.

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher grain and stover yields. This involves systems which increases nutrient and water availability to growing crops, and produces desired uniform stands. Present efforts emphasize crop rotation, intercropping, fertilizer utilization, and residue management interactions with traditional and improved cultivars. These cropping systems research efforts require long-term investments of well-trained, interested scientists and stable funding. Training of additional scientists in crop production and continued support of their work after return to their home countries is needed to improve productivity of cropping systems and to maintain the soil/land natural resource.

Research Approach and Project Output

Grain sorghum and pearl millet are usually grown in stressful environments with high temperatures, lack of a predictable water supply, and often on fragile soils with low nutrient status. Generally, lack of water is considered to be the most critical environmental factor controlling plant growth and yield in most environments, but a source of nitrogen and/or phosphorus often is more critical. The importance of these elements is becoming recognized as more intensive cropping systems using improved cultivars are adopted. The unavailability of "new" land for cultivation due to population growth and land degradation has heighten awareness of this constraint. Rotational or intercropping legumes become a viable alternative for providing some nitrogen and yield enhancement when fertilizer availability are limited or the cost is excessively high. Increased nutrient availability also improved water use efficiency of grain crops, indicating the major increases in grain sorghum and pearl millet yields requires improved cultivars combined with production practices that provide adequate water and nutrients. The complex interaction of water, N, P and pearl millet cultivars is the focus of Project UNL-113B's research efforts.

International

Mali

Research Methods

Long-term cropping system and residue management studies were continued at Cinzana and Koporo. In 1995, more intensive study of N uptake and partitioning of pearl millet and cowpea is underway in these long-term studies.

A study was initiated to develop recommended production practices for soon to be released new pearl millet cultivars. A sequential designed experiment was implemented starting with traditional conditions and stepwise increasing management practices/inputs from the traditional system to an intensive set of production practices (plowed soil, high fertility, high plant population).

Research Results

Rotation with cowpea at Cinzana increased pearl millet grain yield by 19, 17, 31, 27 and 30% in 1991, 1992, 1993, 1994 and 1995, respectively, while rotation with a pearl millet/cowpea intercrop increased pearl millet yields by 0-8%. In this study, soil levels of phosphorus were high due to Telemsi rock phosphate application, and cropping system by nitrogen rate application interactions were not found. Application of 40 kg/ha N increased pearl millet grain yield by 8, 20, 16, 35 and 6% in 1991, 1992, 1993, 1994 and 1995, respectively. Similar results were found at low rainfall Koporo site, but grain yield levels were lower.

Soil nutrients levels were similar at the start of the study in 1990. In 1994, after two cycles of rotation treatments, all cropping systems had lower pH, K and Mg levels than the fallow plots (Table 1). Total N declined in all cropping systems including fallow, while the cation exchange capacity remained constant. Continuous pearl millet and pearl millet-cowpea plots had similar soil nutrient levels. However, continuous pearl millet, pearl millet-cowpea rotation and intercrops had lower soil pH, K, Ca, Mg and cation exchange capacity than the fallow treatments, suggesting that all the cropping systems studies were mining the soil of nutrients.

Table 1. The influence of pearl millet-cowpea cropping systems on soil properties in 1994 as compared to the initial conditions in 1990.

	pH (Water)		pH (KCL)		P (Bray 2)		Total N		K		Ca		Mg		CEC	
Cropping System	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994
					----- ppm -----				---------- C mol $_c$/kg ----------							
Pearl Millet-Cowpea Rotation†	5.0	5.2	4.3	4.4	10	36	2.3	0.8	0.22	0.11	0.53	0.53	0.24	0.16	2.3	1.7
Pearl Millet-Intercrop Rotation†	5.0	5.2	4.3	4.3	10	24	2.0	0.8	0.20	0.10	0.64	0.60	0.25	0.15	2.2	1.9
Continuous Pearl Millet	5.2	5.2	4.5	4.2	11	34	2.8	0.6	0.25	0.12	0.52	0.55	0.24	0.15	2.1	1.9
Continuous Intercrop	5.1	5.2	4.4	4.3	9	23	3.4	0.8	0.21	0.10	0.53	0.62	0.62	0.18	2.1	1.8
Continuous Cowpea	5.0	5.4	4.3	4.4	12	39	3.4	0.8	0.21	0.14	0.43	0.54	0.54	0.17	2.0	1.9
Fallow	5.1	5.5	4.3	4.7	9	34	1.9	1.0	0.20	0.30	0.65	0.83	0.83	0.28	1.9	2.1
P > F	0.98		0.97	0.02	0.15	0.02	0.74	0.31	0.77	<0.01	0.94	0.42	0.42	<0.01	0.61	0.11
C.V. (%)	3	5	10	6	100	35	100	56	14	47	97	61	44	32	35	14

† Average of two phases of the rotation.

Crop residue management research with residues removed, left on the surface, and incorporated had no effect on pearl millet or cowpea grain or stover yield. Similar results have been recently reported by the ROTOPHOS project, University of Hohenheim, Germany, on Nigerien sites that were not degradated and that had medium to higher soil P levels.

New research on production practices for improved pearl millet genotypes was initiated. Advanced, recently released, and improved local cultivars were produced at different fertilizer levels (manure and N) and plant populations. No cultivar by production practice interaction was found, suggesting that the cultivars respond similarly to these practices. The advanced cultivars "Benkadinio" and "Sanioba 03" yielded 100-300 kg/ha better than the other cultivars. Increasing the fertilizer rate to the highest level (15 t/ha manure plus 100 kg/ha N) increased grain yield from 1246 to 2475 kg/ha and stover yield from 3178 to 5067 kg/ha. Increasing plant population slightly decreased grain yield.

Niger

Research Methods

Studies were initiated to study the dry matter accumulation and the nutrient uptake of pearl millet cultivars with different growth habits. The cultivars were grown under low yield (zero fertilizer; 30,000 plants/ha) and high yield (5 t/ha manure; 18 kg/ha P_2O_5; 46 kg/ha N; 60,000 plants/ha) conditions. Plots were sampled bi-weekly, plant parts separated, dried and weighed, and nutrient levels determined.

Research Results

Analysis of variance for grain yield indicated no cultivar x production level interaction effects for grain yield, with the local cultivar producing higher yield at both Production Levels, and the "High Production Level" produced yields 350 to 850 kg/ha higher than the "Low Production Level" for all cultivars (Table 2). Interaction effects were found for stover yield with the "High Production Level" producing 3400 kg/ha more stover for the local cultivar, but only 850 to 1900 kg/ha for the improved cultivars. Growth analysis and nutrient uptake are being analyzed, and are to be included in the 1996 Annual Report.

Table 2. Grain and stover yield of pearl millet cultivars with different growth habits as influenced by production level, 1995.

	Grain yield†		Stover yield‡	
Cultivar	Low	High	Low	High
	---------- kg/ha ----------			
Local	971	1836	3016	6422
Zatib	854	1286	2661	4591
3/4 HK	738	1093	1730	2593

† Significant contrasts was Local vs Zatib + 3/4 HK (p = 0.005).

‡ Significant contrasts was (Local vs Zatib + 3/4 HK) * (Production Level).

Nebraska

Research Methods

A two-year study on competitive ability of pearl millet and grain sorghum as measured by yield and canopy temperature was completed at Mead, NE. Planting date by row spacing studies were conducted with two dwarf pearl millet and one grain sorghum hybrid on a sandy site near Ogallala, NE and on a silty clay loam site at Mead, NE.

Research Results

In 1994, pearl millet was more competitive with weeds than grain sorghum, but in the low rainfall year of 1995, grain sorghum and pearl millet had similar competitiveness. The number of kernels produced per head was the most sensitive yield component to weed competition. Narrowing rows from increased average grain yield by 1.4 Mg/ha in 1994 and 0.8 Mg/ha in 1995, and effective weed control greatly increased yield of both crops.

Narrow rows increased yield more for grain sorghum than pearl millet, and more at Mead than at Ogallala (Table 3). Pearl millet hybrids did not respond to narrowing rows at Ogallala, while at Mead the hybrid 68A x 89-0083 produced greater yield in narrower rows. Early planting date increased yield of both crops at Ogallala, with no significant

Table 3. Row spacing and planting date influence on pearl millet and grain sorghum grain yield in 1995.

Crop	Hybrid	Row spacing (cm)				Planting date			
		Ogallala		Mead		Ogallala		Mead	
		50	76	38	76	June 12	June 27	June 15	June 27
		Mg/ha							
Pearl Millet	68A x 89-0083	1.4	1.6	2.2	1.6	1.7	1.4	2.0	1.7
Pearl Millet	68A x 086R	1.9	1.8	1.8	1.8	2.0	1.7	1.9	1.6
Grain Sorghum	DK28	1.7	1.2	3.4	2.3	1.9	0.9	2.8	2.8
L.S.D. (0.05)		0.24		0.32		0.28		0.40	

differences at Mead. However, there was a trend for early planting to increase pearl millet yield. Much more pearl millet production research is needed to help make it a viable alternate crop for the Great Plains.

Networking Activities

Workshops

American Society of Agronomy Meetings, 29 Oct - 3 Nov 1995, St. Louis, MO.

Regional Workshop on Technology Development and Transfer to Improve Natural Resource Management in West Africa, 18-22 Sept 1995, Niamey, Niger.

Research Investigator Exchange

Facilitated Ph.D. program in Weed Science for Malian collaborator Samba Traore at the University of Nebraska.

Hosted Minamba Bagayoko (29 Oct - 30 Nov, 1995), Mali, and Nouri Maman (8 Jan - 8 May 1996), Niger for short-term training. Nouri Maman has entered a M.S. degree program at the University of Nebraska.

Visited collaborators and IER scientists in Cinzana and Bamako, Mali, 28 April - 6 May 1996.

Explored collaborative research with ROTOPHOS Project of the University of Hohenheim (Germany) and ICRISAT Sahelian Center colleagues, 6 - 8 May 1996.

Research Information Exchange

Two mailings of photocopies of pearl millet research articles to ROCAFREMI P-4 (Agronomy) Netwok participants in 6 West African countries.

Computer purchased for IER, Mali to facilitate research.

Plant sample collection paper bags and plastic bags for storage/shipment of plant samples sent to INRAN, Niger

Laboratory analysis of plant samples from Mali and Niger conducted in Nebraska (228 samples from Mali for nitrogen, 96 samples from Niger for multi-elements)

Publications and Presentations

Abstracts

Limon Ortega, A., S.C. Mason, and A.R. Martin. 1995. Competitive ability of pearl millet and sorghum to weeds measured by canopy temperature and yield. Agron. Absts., p. 119.

Mason S.C., T.D. Galusha, R.W. Klein and A. Limon-Ortega. 1996. Pearl millet row spacing and planting date in the Great Plains. Agron Absts. (In Press).

Journal Articles

Mason, S.C., J.M. Lasa and K.M. Eskridge. 1995. Number of samples, replication and measurements for a screening technique of sorghum emergence potential in crusted soils. Invest. Agrar. Prod. Prot. Veg. 10(1):61-69.

Book Chapter/Proceeding

Mason, S.C., and J.W. Maranville. 1995. Crop production strategies: An INTSORMIL perspective, p. 51-63. IN Gebrekidan, B. (ed). Natural Resource Management and Inter CRSP in West Africa. Proc. Regional Workshop: Technology Development and Transfer to Improve Natural Resource Management in West Africa, 18-22 Sept. 1995, Niamey, Niger.

Thesis

Limon-Ortega, A. 1995. Competitive ability of pearl millet and grain sorghum to weeds measured by canopy temperature and yield. M.S. Thesis, University of Nebraska, Lincoln, NE. 95 pp.

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-114
Jerry W. Maranville
University of Nebraska

Principal Investigator

Dr. Jerry W. Maranville, Department of Agronomy, University of Nebraska, Lincoln, NE 68583-0817

Collaborating Scientists

Professor David Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE 68583-0915
Dr. Stephen Mason, Department of Agronomy, University of Nebraska, Lincoln, NE 68583-0915
Dr. Max D. Clegg, Department of Agronomy, University of Nebraska, Lincoln, NE 68583-0817
Dr. Darrell Rosenow, Texas A&M Agricultural Experiment Station, Rt. 3 Box 219, Lubbock, TX 79401-9757
Dr. Paula Bramel-Cox, Department of Agronomy, Kansas State University, Manhattan, KS 66506
Mr. Abdoulaye Traore, Ph.D. Student, University of Nebraska (Mali)
Dr. Oumar Niangado, Director General, IER, B.P. 258, Bamako, Mali
Mr. Abdoul Toure, Sorghum Agronomist, IER, B.P. 258, Bamako, Mali
Dr. Aboubacar Toure - IER Sorghum Breeder, B.P. 258, Bamako, Mali
Mr. Minamba Bagakoyo - IER Cropping Systems, B.P. 258, Mopti, Mali
Mr. Sogodogo Diakalidia - IER Cropping Systems, B.P. 258, Bamako, Mali
Mr. Sidi Bekaye Coulibaly - IER Physiologist, B.P. 258, Cinzana, Mali
Dr. Alhousseini Bretoudeau, Professor, IER, BP06, Katibougou, Mali
Mr. Seyni Sirifi, Agronomy Division, INRAN, B.P. 60, Kollo, Niger

Summary

Sorghum varieties having known N use efficiency (NUE) characteristics were studied to determine the physiological basis for superior NUE. Carbon isotope discrimination methodology which can distinguish CO_2 assimilation efficiency among crops and varieties within crops was used and compared to methods which estimate carboxylation enzyme activity. The study clearly demonstrated the superiority of two sorghum lines from China for CO_2 assimilation capacity when leaves were experiencing N stress (deficiency). The discrimination values indicated that the enzyme of particular interest is most likely phosphoenol pyruvate carboxylase, the first catalytic enzyme in the CO_2 capture process in cells. Lines derived in the U.S. were generally less efficient for CO_2 assimilation, but not exclusively so ('Martin' for example). The discrimination method did not appear to be as precise in distinguishing varietal differences as gas exchange methods.

A study to assess nitrate uptake and metabolism differences among sorghum genotypes indicated that soil N levels did not affect photosynthesis rate at any developmental growth stage although it influenced dry matter production and plant N content. Photosynthesis rate was greater at flowering than at other growth stages. NUE was superior in lines 'VG146' and 'S34' (Malian line) compared to a 'CK60' control. Lines differed in nitrate reductase activity at the early vegetative and flowering stages. Total N and its partitioning may be genetically controlled and environmentally regulated.

Experiments in Mali to assess mutant sorghum lines derived by seed irradiation indicated that some mutants were markedly superior to their parents for grain yield at different soil N levels. The average grain yield for two locations at two soil N levels was 1056 kg ha^{-1} for parents compared to 1313 kg ha^{-1} for mutants. Added N generally produced a 27% grain yield response over all genotypes tested. Several mutants have shown promise as important sorghum types for Mali, but more information is needed regarding their overall adaptability.

Nitrogen fertility and hill spacing experiments in Niger indicated that grain yield response to added N is quadratic and that 100 kg urea ha^{-1} produced maximum yields in 1995. It was evident that poor seed quality resulting in poor plant stands is a factor needing immediate attention. The best hill spacing to maximize yields was 0.8m x 0.2m followed closely by 0.8m x 0.4m in 1995. Variety NAD1 was superior for grain yield among the five genotypes tested at two locations.

Objectives, Production and Utilization Constraints

Objectives

Identify sorghum and pearl millet genotypes which are superior in nutrient use efficiency (primarily nitrogen).

Determine the physiological and morphological mechanisms which allow genotypes to be nutrient use efficient.

Quantify the effects of environment on genetic response at different soil fertilities (primarily nitrogen).

Determine optimum nitrogen and phosphorus management practices for arid and semi-arid environments.

Provide long and short term training experiences for students and scientists of collaborating institutions, as well as certain technical expertise for collaborative efforts related to overall INTSORMIL objectives.

Constraints

Soil nutrient deficiency stresses.

Lack of adequate nutrient use efficiency in current sorghum and pearl millet cultivars.

Inadequate knowledge of proper management practices to help cope with nutrient stresses.

Lack of technically trained personnel who can devise and carry out sound research programs.

Research Approach and Project Output

Domestic Research and Research Related to Student Training

Studies of the Mechanism of N Use Efficiency.

Previous research indicated that N use efficiency may be related to the ability of the photosynthetic enzymes to maintain catalytic activity when plants are undergoing leaf N stress (Ann. Rep., 1995). Additional studies were conducted using eight genotypes grown in both field and greenhouse environments to measure carbon isotope discrimination values which can give an indication of the efficiency of CO_2 uptake. Atmospheric CO_2 contains about 1.1% of the non-radioactive carbon isotope ^{13}C and 98.9% of ^{12}C. During photosynthesis, plants discriminate against ^{13}C because of small differences in chemical and physical properties imparted by the differences in mass. This isotope fractionation reflects limitations on photosynthetic efficiency imposed by various diffusional and chemical components of CO_2 uptake. The isotope discrimination values were compared to the CO_2 assimilation efficiency (AEI) which estimates activity of the carboxylation enzyme system and are obtained using a LiCOR photosynthesis system. The genotypes in the study were China 17 and San Chi San (high N use efficiency), VG146, DR50, IR204, and Martin (potential for good N use efficiency) and CK60 and TX623 (poor N use efficiency).

The results (Table 1) indicated that the ability to take up CO_2 and assimilate it were markedly greater with the high N treatment. The isotope discrimination method did not appear to be as precise in distinguishing varietal differences for N use efficiency as compared to the AEI method which estimates carboxylation activity. The AEI values confirmed the superiority of China 17 and San Chi San for CO_2 assimilation ability. Lines CK60 and TX623 were generally less in this trait and are also less for N use efficiency. Martin appeared to have good CO_2 assimilation ability but had lesser isotope discrimination values. Although isotope discrimination did not always reflect varietal differences for N use efficiency, the magnitude of values i.e. -12 to -14 indicated that phosphoenol pyruvate carboxylase enzyme is a primary enzyme of interest. Had the values been lower i.e. -20 to -24, then the carboxylation enzyme RUBISCO would be prominent. Further studies will be conducted to measure total variability and growth stage differences.

Investigation of Nitrate Uptake and Metabolism.
Abdoulaye Traore - Mali.

Two field experiments were conducted to assess genotype differences in sorghum N metabolism. Nitrogen uptake, partitioning, nitrate reductase activity (NRA) and nitrogen use efficiency (NUE_1 and NUE_2) were measured. The soil N level did not affect the photosynthesis rate at any developmental stage, although, it altered the total dry matter production and the total N in plant tissue. There was evidence of differences among genotypes for photosynthesis rate, total dry matter production and NE_1 calculated as biomass per amount plant N (Fig. 1). The photosynthesis rate was greater at flowering than at the vegetative stage. At

Table 1. Isotope discrimination (‰) and assimilation efficiency (AEI) values for eight greenhouse grown sorghum genotypes having diverse N use efficiency in terms of biomass or grain per unit of plant nitrogen.

	N level					
	High		Medium		Low	
Genotype	‰	AEI	‰	AEI	‰	AEI
China 17	-13.83	.833	-13.59	.259	-.13.44	.187
San Chi San	-13.47	.572	-13.08	.398	-13.16	.160
VG146	-13.74	.289	-13.32	.308	-13.35	.276
DR50	-13.63	.284	-13.14	.143	-13.23	.046
IR204	-13.90	.240	-13.21	.151	-13.33	.159
Martin	-13.30	.504	-13.25	.249	-12.86	.131
CK60	-13.34	.389	-13.34	.153	-13.35	.070
TX623	14.12	.329	-13.66	.138	-13.45	.089
Mean	-13.66	.430	-13.32	.225	-13.27	.140

physiological maturity, it was 50% less than at the vegetative stage, and the pattern was consistent for all genotypes but not M35-1 and CK60. During flowering, HH640 and VG146 had greater photosynthesis followed by P720, CK60 and S34. Total dry matter production was significantly increased at the high soil N level; and there was evidence of genotypic differences. At flowering and physiological maturity stages, M35-1 had greater biomass production followed by VG146 and S34.

Nitrogen use efficiency calculated at physiological maturity (Fig. 1) indicated that the greatest values were found in VG146 and S34 followed by Malisor 7, HH640, CK60 and M35-1. P720 had the least value. Nitrate reductase activity (Fig. 2) was significantly different for the N level and the genotypes at vegetative and flowering time. At physiological maturity, the differences were not significant. Genotypes had similar N uptake patterns, but the total N and its partitioning may be genetically controlled and environmentally regulated.

International Research

Assessing Mutant Sorghums for Nitrogen Uptake Efficiency In Mali. Abdoul Toure - Mali

Several sorghums were developed by mutation through irradiation of seed. Some of these have shown drought tolerance and are agronomically acceptable, but have not been fully evaluated for nutrient response. Three parents (P) and six mutant (M) sorghum lines were tested at two locations (Kolombada and Katibougou) at zero N or 90 kg ha^{-1} urea to better understand nutrient response of the mutant sorghums as compared to parents from which they were derived. The sorghum lines were as follows (mutants listed after parent): CSM388 (P1), MIK-SOR-86-25-11 (M1), MIK-SOR-86-25-20 (M2), MIK-SOR-86-30-42 (M3), CSM228 (P2), MID-SOR-88-10-10 (M4), IPS0001 (P3), MIP-SOR-90-30-23 (M5), MIG-SOR-86-30-03 (M6).

There was a significant difference between locations for grain yield (Table 2) with the average yield at Katibougou exceeding that of Kolombada by about 40%. There was no response to N and no fertility by genotype interaction at Katibougou and the data were combined. At Kolombada, differences were found among genotypes and fertility levels (Table 2). Added N produced a grain yield increase of 27%

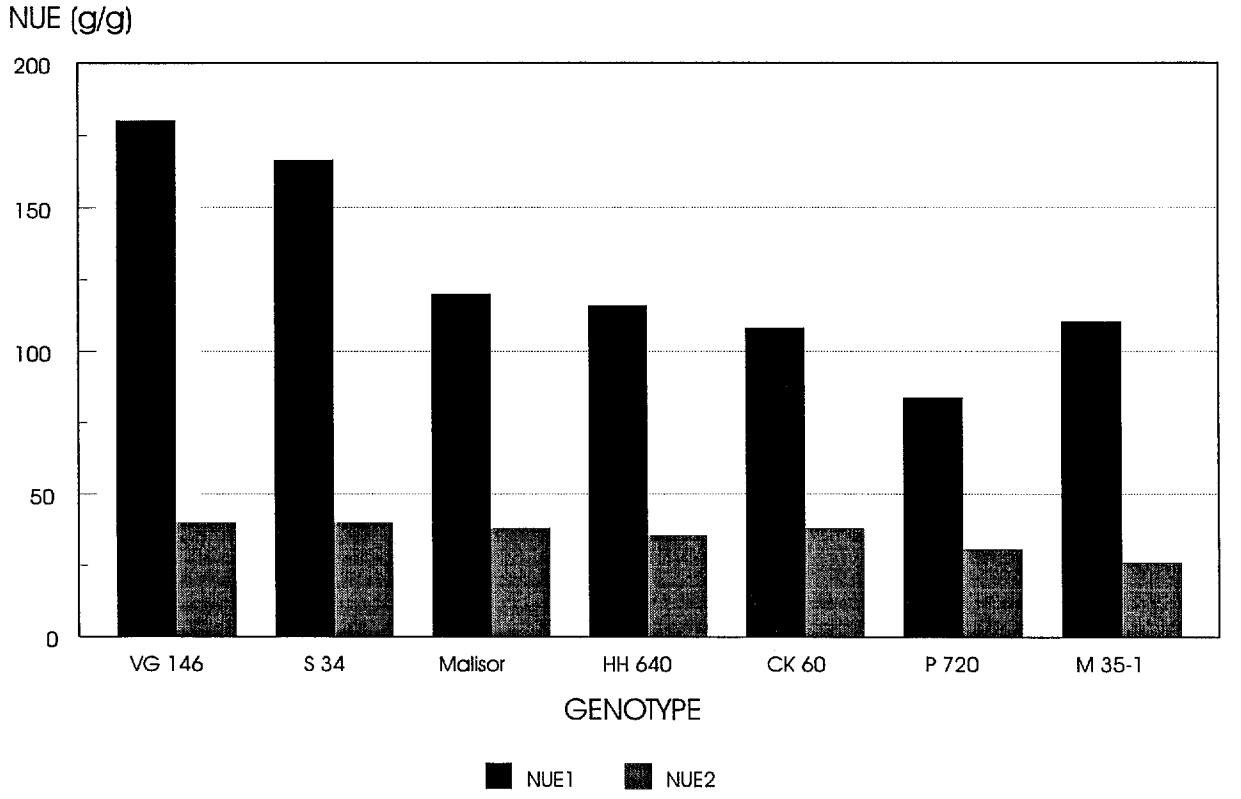

Figure 1. Nitrogen Use Efficiency (NUE1, NUE2), Mead, NE 1994

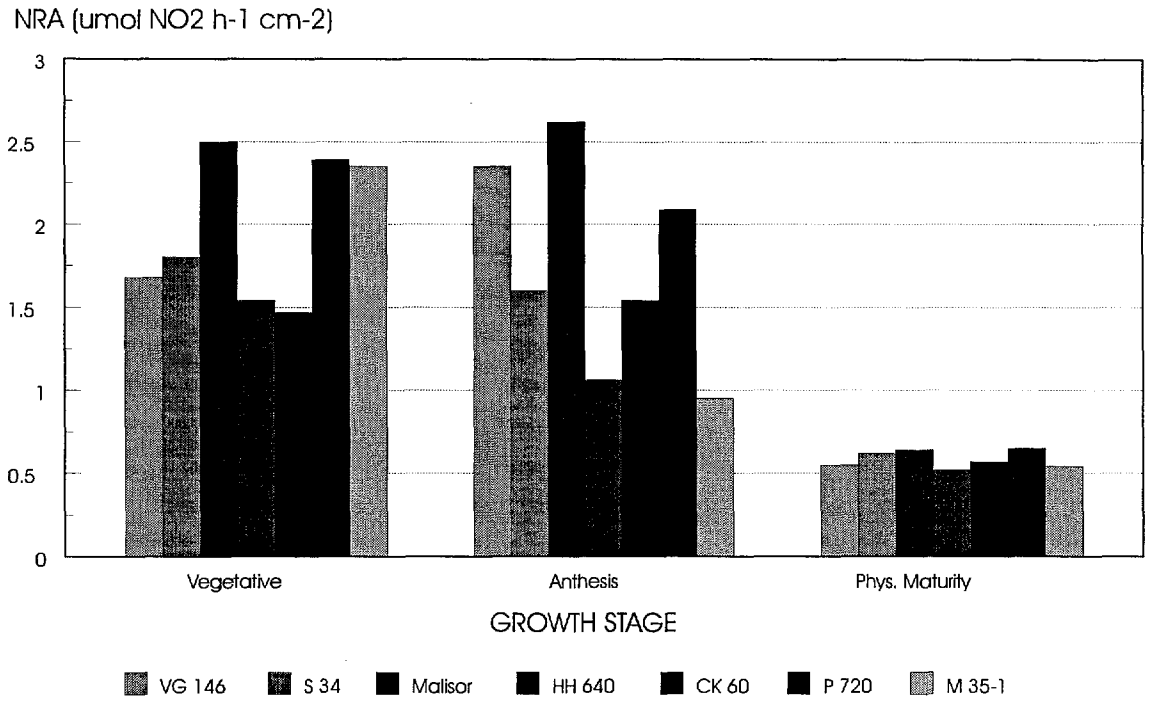

Figure 2. Nitrate reductase activity, Mead, NE 1994.

Table 2. Grain yield (kg ha^{-1}) of three parent and six mutant sorghum lines at Kolombada and Katibougou during the 1995 growing season.

	Kolombada		Katibougou
Sorghum line	Zero N	High N	Ave. N
P1	1028 d	1417 c	1758 a
M1	306 e	222 d	1932 a
M2	1722 ab	2361 a	2096 a
M3	1806 a	2056 ab	1693 a
P2	639 de	361 d	1246 b
M4	1417 bc	1389 c	1560 a
P3	1000 de	1889 b	1932 a
M5	1194 cd	2111 ab	1630 a
M6	639 de	528 d	1652 a
Mean	1083	1370	1722

on the average, and a significant interaction between genotype and fertility level occurred.

Two mutants derived from CSM388 (P1) were superior but a third (M1) was markedly inferior. The mutant derived from CSM 228 (P2) was superior for grain yield as was one mutant (M5) derived from IPS0001 (P3). Mutant M6, however, was markedly inferior. The average of parents across fertility levels was 1056 kg ha^{-1} compared to 1313 kg ha^{-1} for the mutants.

Greater grain yields with more N fertility was in part due to greater number of panicles indicating greater tillering (data not shown). The low yields of some genotypes was due to a lack of adaptability to that location i.e. Kolombada in particular. Several mutants have shown promise as important sorghum types for Mali, but more information is needed concerning their overall adaptability and acceptability for farmers.

Agronomic Assessments of Sorghum Response to Nitrogen In Niger. Seyni Sirifi - Niger.

The best agronomic practices for sorghum production in Niger has received limited attention and improved varieties will need agronomic recommendations before maximum yield potentials can be achieved. Five varieties were grown at five N fertility levels and five hill spacings in a four replication experiment at two locations (Bengou and Tillakaina). Both locations were replanted due to stand problems, and even then, stands were poor due to poor seed quality. Varieties used were SRN3S1, NAD1, IRAT204, SEPON 82 and Local. N rates were 0, 50, 100, 150 and 200 kg ha^{-1} and hill spacings were .8m x .8m, 8m x .6m, .8m x .4m, .8m x .3m, and .8m x .2m. N fertilizer was applied in a split application (1st and 2nd weeding).

Three variables were statistically analyzed: head weight, grain yield and 100 kernel weight for the fertility and spacing study.

Bengou. There were significant difference among varieties for all the three variables observed (Table 3). There were

Table 3. Average yield of head weight, grain yield and 100 kernel weight of the N fertility experiment. Bengou and Tillakaina locations in 1995.

Varieties	Bengou			Tillakaina		
	Panicles	Yield	100 kernel wt	Panicles	Yield	100 Kernel wt
SRN39	364.9 d	146.1 d	1.90 ab	412.2 bc	358.7 b	2.45 b
NAD1	4380.8 a	2788.9 a	1.70 c	1272.8 a	875.7 a	2.06 a
IRAT 204	824.1 cd	455.6 cd	1.81 bc	259.3 b	259.3 b	2.41 b
SEPON 82	1003.7 c	532.4 c	1.41 d	731.8 b	530.6 b	1.88 c
Locale	2724.1 b	966.3 d	2.28 a	1386.1 a	1015.6 a	2.82 a
LSD	530.45		0.17		293.87	0.22

Letters following values are Duncan Test results.

a positive response to increased N level only for head weight; grain yield and 100 kernel weight did not change significantly with N level. The variety NAD1 was more productive for total head weight (4380.8 kg/ha), followed by the variety (2724.1 kg/ha).

SRN39 was the least productive primarily due to its bad stand. For grain yield, NAD1 and the local variety were best followed by the others which were not different from each other. For 100 kernel weight, the local variety and SRN 39 were superior (2.28 g and 1.90 g, respectively) .

The maximum grain yield (2331.75 kg/ha) was obtained with 100 kg/ha urea followed by 200 kg/ha N at 1809.2 kg/ha giving a quadratic response to N. This result is confirmed by contrast analysis which indicated a significant quadratic effect of N on grain yield ($P \leq .058$).

Tillakaina. There were differences among varieties for the three variables observed (Table 3). Nitrogen effect was not significant for any variable. In general, grain yield and head weight were low for all varieties due to less rainfall, late planting date and poor seed quality. As at Bengou, NAD1 and the local variety were best for head weight, 100 kernel weight and grain yield (Table 3). There was no interaction between varieties and N levels for any variable measured at either location.

At the two locations for the spacing study there were significant differences among varieties for the three variables analyzed. Plant population had a significant effect on the measured variables at Bengou, but at Tillakaina, no significant difference was detected. There were no interactions between varieties and plant population for any of the three variables measured and the CV's were high except for 100 kernel weight.

The head weight varied from 3083 kg/ha with NAD1 to 273 kg/ha for SRN39 at Bengou, and from 1700 kg/ha for NAD1 to 273 kg/ha for SRN39 at Tillakaina. Similar results were observed for grain yield at the two locations. For 100 kernel weight, NAD1, IRAT 204 and the local variety were best at the two locations.

The different plant populations had significant effects on total head weight at Bengou, but didn't affect the other variables at Tillakaina. At Bengou, the plant population .80m x .20m and .80m x .40m produced the maximum total head weight and grain yield. Total head weight ranged from 2026 kg/ha to 1146 kg/ha. For grain yield, the 0.8m x 0.2m plant density was best producing 1079 kg/ha grain.

The total head weight and grain yield at Tillakaina didn't vary with the different densities, and the yields were less than at the Bengou location. There were differences in 100 kernel weight at Bengou and Tillakaina due to the effects of plant population.

The following conclusions were made:

For the increasing N rate study on different sorghum varieties:

100 kg/ha gave the best results compared to the other N levels.

Sorghum grain yield response to increasing N was quadratic at Tillakaina.

Low total grain and head weight production for most of the varieties at the two locations was due to poor seed quality; only NAD1 and the local variety had acceptable stands.

NAD1 was the best productive variety for both locations.

For the plant population study on sorghum varieties:

There were no interactions between density and variety for the different variable measured at the two locations.

NAD1 and the local variety had the best yields.

The densities had significant effects on total head weight and total grain yield at Bengou where .80m x .20m and .80m x .40m were the best spacings.

At Tillakaina, there were no plant population effects on grain yield and total head weight production.

Networking Activities

Supplied $7000 to Mali for collaborative research in nutrient agronomy and physiology.

Supplied $3000 to Niger for collaborative research in nutrient agronomy and physiology.

Shipped soil moisture access tubes to Mali in collaboration with UNL-113B.

Purchased a new computer and accessories for Seyni Sirifi in Niger at a cost of $3200 to be delivered in fall of 1996.

Traveled to Mali and Niger exclusively on UNL-114 funds to plan new research and review collaboration.

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Germplasm Enhancement and Conservation

Breeding Sorghum for Increased Nutritional Value

Project PRF-103A
John D. Axtell
Purdue University

Principal Investigator

John D. Axtell, Agronomy Department, 1150 Lilly Hall of Life Sciences, Purdue University, West Lafayette, IN 47907-1150

Collaborating Scientists

Mr. David Andrews, Agronomy, University of Nebraska, Lincoln, NE 68583
Dr. Jeff Bennetzen, Biological Sciences, Purdue University, W Lafayette, IN
Dr. Larry Butler, Biochemistry, Purdue University, W Lafayette, IN 47907
Dr. Moussa Adamou, INRAN, B.P. 429 Niamey, Niger
Dr. Ouendeba Botorou, INRAN, B.P. 429, Niamey, Niger
Mr. Issoufou Kapran, INRAN, B.P. 429, Niamey, Niger
Dr. Gebisa Ejeta, Agronomy, Purdue University, W Lafayette, IN 47907
Dr. Bob Joly, Horticulture, Purdue University, W Lafayette, IN 47907
Dr. David Rhodes, Horticulture, Purdue University, W. Lafayette, IN
Dr. Bruce Hamaker, Food Science, Purdue University, W Lafayette, IN 47907
Dr. Sam Mukuru, Sorghum Breeder, ICRISAT, Nairobi, Kenya

Summary

The major focus of this project is to develop high yielding sorghum varieties with acceptable food quality and good nutritional value for utilization in developing countries. A great deal of progress has been made in two areas.

We now understand many of the factors necessary for improving the nutritional value of sorghum through local village processing. Sorghum flour is less digestible than most cereal flours unless it is processed using local village procedures that have evolved over hundreds of years. We now understand the scientific reasons why processing is important. This knowledge will help us modify and improve the traditional processing methods and develop improved processing methods for utilization in other countries in the world where sorghum is used as a feed or food grain.

This report notes for the first time that a genetic solution may be possible for the digestibility problem. Bruce Hamaker in the Food Science Department (PRF-112) has been collaborating on studies of new genetic lines with protein digestibility equivalent to corn. Studies are in progress to determine the inheritance of this important trait in sorghum.

The following press release, dateline January 1995, illustrates a breakthrough in sorghum digestibility research done in collaboration with Dr. Bruce Hamaker.

Digestible Protein May Make Sorghum a Better Food Source

West Lafayette, IN - "Irregularly shaped protein bodies discovered in sorghum kernels under the electron microscope at Purdue University may signal improved human nutrition in some developing countries and higher-quality livestock feed worldwide.

Bruce Hamaker, associate professor of food sciences, is conducting sorghum protein digestibility research at Purdue. In tests on 25 experimental genetic lines of sorghum, he found two in which protein digestion was significantly faster. Electron microscope photographs revealed the protein bodies of the more digestible sorghum are irregularly shaped. Typically sorghum protein bodies are spherical.

"Increased digestibility in sorghum could be a major step in providing a higher-quality livestock feed in the United States and other developed countries," says Phillip Warren, senior agronomist in the Agriculture and Food Security Office of the U.S. Agency for International Development (USAID) in Washington, D.C. "But also it could have an immense impact on the protein content in diets of people in less developed countries, especially in parts of Africa."

The two more digestible genetic lines of sorghum tested by Hamaker have about 87 percent digestibility; normal sorghum can be as low as 66 percent. Protein bodies in cereal grains, such as wheat, corn, rice and sorghum, have varying degrees of digestibility. This makes some cereal grains more nutritious than others.

"We were surprised and pleased by these findings," Hamaker says. "These two genetic lines of more highly digestible sorghum fall right between corn and wheat in digestibility. That makes them very competitive with other cereal grains as a source of dietary protein for both humans and livestock. Typically sorghum is at the bottom of the list."

After identifying the digestibility differences, Hamaker and his research team turned to the electron microscope to explore basic structural differences between the protein bodies. Under 2,500 times magnification they found spherical-shaped protein bodies actually indenting the larger starch particles of the normally digestible sorghum. However, in the kernels from the more digestible sorghum, they found dramatically different, irregularly shaped protein bodies tucked in among the starch particles.

Hamaker's tests indicate that digestive enzymes of the intestine begin the basic process of digestion much faster on these irregularly shaped protein bodies.

"Sixty-five percent of the stored protein in sorghum is found inside these bodies," Hamaker says. "It appears there is an enzyme-resistant coating around the spherical protein bodies of normal sorghum, so it takes longer for digestive enzymes to break through to the stored protein inside. But in the irregularly shaped protein bodies, digestion appears to begin almost immediately. We don't know, but we assume the more digestible protein bodies lack this enzyme-resistant coating."

Hamaker compared the proteins using two different digestion tests. He found the irregularly shaped protein bodies began to break down in less than 60 seconds, and had reached a significant level of digestion in less than five minutes. Normal sorghum requires 60 minutes.

"This is important," Hamaker says, "because transit time - the time it takes food to move through a digestive system - is relatively fixed for some livestock animals. So, the sooner protein is available in the digestive process, the more will be absorbed for nutritional purposes before excretion."

Also, Hamaker found the more digestible lines maintained 80 percent digestibility, even after cooking. Most sorghum varieties lose digestibility in cooking; some drop to as low as 46 percent.

According to Hamaker, this could improve human nutrition in some semiarid developing countries where up to 70 percent of the dietary protein may come from cooked cereal grain. In the southern part of India and in countries such as Ethiopia and Mali, in the area of Africa below the Sahara desert, sorghum is a food staple for humans.

In more developed countries, sorghum is used as an animal feed, primarily for cattle, poultry and some hogs. John Axtell, Lynn Distinguished Professor of Agronomy at Purdue and the source of the experimental sorghum lines used in Hamaker's research, says Texas, Kansas and Nebraska are the primary areas of sorghum production in the United States, while the mid-south region, including Arkansas, Missouri, southern Illinois, Kentucky and Tennessee, is an expanding production area.

Digestibility affects the value of sorghum as an animal feed. The market price of sorghum is usually about 90 percent of the price of corn, because it typically requires additional processing to increase digestibility of protein and starch. Hamaker's research could change that.

In addition, the trait for higher digestibility appears to be genetically inherited and not a result of the environment of a particular growing location. Hamaker conduced tests on sorghum kernels grown both in Indiana and Mexico, and the results were similar.

Hamaker and his research team, including food science graduate students Charlotte Weaver (Nappanee, Ind.) and Maria Oria (San Sebastian, Spain), working in collaboration with Axtell's plant breeding research team, still have a full research agenda.

"At this point the irregularly shaped protein bodies seem to be an indicator sign on the road map to more digestible sorghum protein," Hamaker says. "We have come this far in laboratory tests, what we call *in vitro* tests. We need to continue the tests in the field with animals."

Hamaker's research results were presented at the American Association of Cereal Chemists meeting in Nashville, Tenn., in October. This research is part of the Sorghum/Millet Collaborative Research Support Program funded by the Bureau of Science and Technology, USAID.

Drought Tolerant Hybrid Sorghum for Niger
(Issoufou Kapran, John Axtell & Gebisa Ejeta)

Sorghum is the second most important food crop in Niger, with an estimated acreage on the rise from 768,070 hectares in 1980 to more than two million hectares in 1994 (Anonymous,1995). Productivity has however taken the reverse direction, and the average grain yield is less than 300 kg/ha for the same period. This trend was in fact observed from the late 1960s with average yield dropping from 589 kg/ha in 1969-71 to 390 kg/ha in 1974-76 (Dogget, 1988). This is very alarming because Niger has one of the highest population growth rates (3% per year) being observed for the developing world. The population in Niger has increased from 2.4 million in 1950 to an estimated 9.151 million in 1995 (Center for International Health information, 1995). In a country where more than 90% of the people are involved in farming, there is undeniably a lot of pressure on land use for cropping as well as herding, especially since the rainfall patterns have become more erratic in recent decades, reducing the total available area for agriculture. The consequences on genetic resources and their use are very dramatic as can be observed for sorghum. In the absence of a reassuring

alternative, most sorghum growers have the tendency to replace their old later-maturing varieties with new early-maturing types, which are more likely to escape drought periods, often at the expense of higher productivity.

These early selections are taken from any source, even from grain obtained through food aid programs as seems to be the case for a three-dwarf local variety known as Tera; but the most common are in the 'MOTA' group (meaning car in the Hausa language, thus fast moving); selected by farmers from their own landraces probably on the basis of earliness, the Motas are more likely to escape the very frequent drought periods.

Concurrently, landrace varieties like Janjaré, which was considered so well adapted that the French IRAT used it in the early 60s in developing the improved L30, and L30 itself, are becoming practically extinct, and are probably more visible at INRAN research stations than in farmers' fields. Local landraces are certainly the best source for crop improvement in the long term, because they have accumulated many adaptation traits that modern breeders can make use of in scientific approaches for increasing agricultural productivity. However, in the present situation of worsening environmental conditions and population pressure, alternatives are needed that can safeguard local germplasm while improving productivity. With the help of the INTSORMIL project, a new dynamism has integrated the INRAN sorghum breeding program since the early 1980s. While new landraces are continuously brought in for evaluation, especially the early 'dune' sorghums specific to Niger, some of the best adapted have been incorporated in random-mating populations, providing a low maintenance broad base source of local germplasm that we can select from or improve at any time. At the same time, we conduct variety development through the pedigree method, intercrossing germplasm that we select in Niger and that provided by our collaborators on the basis of its geographical origin similar to that of Niger (e.g., Sudan), and/or because it has been improved for the same objectives as those of INRAN (high yield, early maturity, drought tolerance, *Striga*, mold).

The best success of our collaborations is however the demonstration that sorghum hybrids are an agricultural technology viable even for harsh environments, as is the case in Niger. This is essential, because it is recognized that in the context of today's population growth in developing countries, yield increases offer the best answer to meeting new food demands (Pinstrup-Andersen and Pandya-Lorch, 1995). Adoption of hybrids would also be beneficial to the environment since high and stable productivity may restrain the desperate use of marginal soils. Although introduced sorghum hybrids were tested during the IRAT program of the 1960s, they were not seen as a good alternative for Niger because of grain quality problems (Chantereau and Adamou, 1977), and the perception that they were too much input-dependent.

It was not until two INTSORMIL supervised-M.S.. research projects were conducted in 1986 by Kapran and Tyler, respectively, that a systematic study of the value of heterosis was conducted in Niger. Kapran (1988) reports the comparison of a group of 90 hybrids to their parents in presence of local adapted checks, at several environments in Niger. Whereas parental lines were comparable to local varieties only under irrigation, hybrids were consistently better yielding than both: they surpassed the locals by 61% with irrigation and 49% under rainfed conditions; yield advantage of hybrids over parents (heterosis) was 45% higher under irrigated conditions, and even higher in the rainfed experiments (66%). Tyler (1988) tested 40 hybrids under the same rainfed environments as Kapran, with male parental lines grouped as exotic, intermediate, or local. He also found that hybrids were higher yielding than parents or checks; grain yield heterosis over male parents was 127% for exotics, 83% for intermediate, and 66% for locals. Following these clear expressions of heterosis in Niger, the best hybrids from both studies were re-synthesized and evaluated regularly. Over the years, the cross between TX623A and MR732 (later named NAD-1) was consistently high-yielding in comparison with other hybrids or varieties, including the best adapted landraces of Niger. Starting in 1989, it was entered in the regional sorghum trials covering at least six West and Central African countries, and was good yielding under most conditions. Specifically in 1989, it ranked third of twenty entries including a local check and other ICRISAT hybrids or varieties, tested at nine locations in Ivory-Coast, Mali, Burkina-Faso, Cameroon, Nigeria, and Niger (ICRISAT/WASIP, 1989).

Also starting in 1989, an experimental seed production was started at Maradi (Niger), and demonstrated at the level of a national breeding program in West Africa, the feasibility of a large scale hybrid seed production. The same year we also gave the first sample of hybrid seed to a few farmers in the village of Bazaga near the INRAN/Konni station, and the feedback was extremely positive. Incidentally, this is where for the first time, a farmer who heard us explain the system of seed production using A and R lines, compared the hybrid to a mule (Alfadari in Hausa, the 'A' in NAD-1). This was the beginning of our on-going farm-level demonstration plots, which have increasingly attracted more farmer interest, to the point where today it is difficult to satisfy all requests for hybrid seed.

At this point, again with the help of INTSORMIL, additional seed has been continuously produced since 1993 in the U.S. and shipped to Niger for the demonstration plots. Overall, the average yield of NAD-1 between 1986 and 1994 is of 2758 kg/ha on-station, ten times the average yield of the farmer in Niger (273 kg/ha; Anonymous, 1995). Starting in 1993, we have quantified NAD-1's productivity on some of the farm-level plots. For 1993, the average farmer yield for the Konni and Jirataoua region was 2365 kg/ha for NAD-1. In 1994, NAD-1 yielded an estimated 1725 kg/ha (Say), 3500 kg/ha (Jirataoua), 3800kg/ha (Cerasa), and 4600

kg/ha (Konni), for an overall average farmer yield of more than 3000 kg/ha.

Taking into account the food quality problems of an earlier INRAN release, Kapran (1988) and Tyler (1988) conducted preliminary food (tuwo) quality tests of some of their test-hybrids at the village level, and concluded on generally an acceptability similar to that of local varieties. This was taken a step further in 1990, in a collaborative INRAN/INTSORMIL wide scale food quality test. Three of the improved genotypes (NAD-1, SEPON-82, SRN-39) were evaluated together with a local variety across four regions, to obtain farmer feedback and compare the ratings with physico-chemical traits in laboratory analyses. NAD-1 was always rated as a good tuwo-making entry. As can be seen, some ten years later after it was selected, NAD-1, is still a high-yielding medium-maturing hybrid, with good drought tolerance and acceptable food quality, both on-station and on-farm. Its consistency of production was also compared to that of other improved and local genotypes, and NAD-1 hybrid was the most stable. The subject of yield stability was recently addressed by another INTSORMIL thesis project (Ibrahim, 1995). A total of 126 genotypes including 90 hybrids, their parents and other checks were evaluated across 15 different environments in Niger, the U.S., South America, and Sudan. Hybrids not only were better yielders in all environments, they in fact showed a greater yield stability under stress than non-stress environments. Ibrahim (1995) concludes that for stress environments in semi-arid tropics, hybrids are more reliable genotypes.

Despite the lack of a modern seed industry in Niger, the program of new hybrid production and testing, continues. Hundreds of new combinations are made and tested each year, and our preliminary observations indicate that a number of them have a yield potential similar to that of NAD-1. It is striking for example that some of them were obtained using as male parents, lines that we selected in Niger, from early generation germplasm provided by our INTSORMIL collaborators (90SN- series). Also, new A-lines like ABON34 appear to have similar good combining ability as TX623A, the female parent of NAD-1. Based on elements including the continuously encouraging results obtained on-station since 1986, and farmer enthusiasm since 1989, it is realistic to suggest that hybrids may be the best route for increased sorghum productivity in Niger. The crucial problem to be solved is that of a viable seed production mechanism, and the history of its elaboration in countries like India, Zambia, and Sudan, is an encouraging signal.

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Introduction, Objectives, and Constraints Addressed

Nutritional value of sorghum has long been known to be different from other cereals. This includes the tannin problem, the protein quality problem, the protein digestibility problem, and the local processing methods involved in eliminating these problems in the diets of sorghum consuming people. We have made significant progress in cooperation with Dr. Larry Butler on the tannin problem, and Sam Mukuru has now proven in studies conducted in our laboratory that high tannin sorghums traditionally grown at high elevations in Eastern Africa are very satisfactory sources of digestible nutrients if the grain is processed adequately by traditional means. Protein quality improvement will be a major breeding objective during the next five years. We have identified good sources of modified quality protein sorghums which are comparable in yield potential and grain quality to quality protein maize as developed by CIMMYT. The basic high lysine gene, P-721 opaque has been combined with sources of vitreous endosperm to give the QPS (Quality Protein Sorghum). The high yield potential has been demonstrated by Emmanuel Monyo and the modified vitreous endosperm characteristics have been recently documented.

A major unresolved problem is the environmental stability of these modified endosperm sorghums. A recent breakthrough on OPM in maize by Brian Larkins and Mr. Mauricio Lopez has shown a strong relationship between the gamma-zein fraction and modified vitreous endosperm characteristics. An Elisa technique is being developed which will make selection for vitreous endosperm opaque-2 much more reliable and faster. The same technique will be adapted to sorghum P-721 modified lines in improvement programs. Trials will be conducted at several locations during 1995 to confirm the stability of the vitreous endosperm trait in these QPS lines across temperate and tropical environments. It is interesting to note that the digestibility of P-721 high lysine sorghum is about 10% greater than that of most normal sorghum varieties which should be an additional benefit if it can be confirmed in the QPS lines. The digestibility problem can also be approached at this time by a better understanding of traditional processing technologies. We believe the identification of a low fraction III (cross-linked kafirin fraction) sorghum variety in the World Collection has the potential to provide a genetic and breeding solution to the digestibility problem in sorghum which would be a significant achievement in utilization of sorghum as a food grain and also as a feed grain.

A major priority will be the development of a vitreous endosperm high lysine sorghum variety using germplasm developed from crosses with P-721 opaque. This will be a combined effort with Bruce Hamaker, Gebisa Ejeta, and Larry Butler. The modified endosperm high lysine sorghum parental materials will be tested in Niger, Sudan, and West

Lafayette to verify environmental stability of the vitreous endosperm and the lysine content. An extensive second cycle breeding program will be initiated to further improve the protein quality, vitreous endosperm, and protein digestibility of the new lines.

Objectives

Identify, develop and evaluate sorghum lines or mutants with improved nutritional quality and superior food grain quality using both chemical and biological methods.

Develop agronomically elite sorghum lines for Niger, Sudan, and Ethiopia with good adaptability, good grain quality, good drought and *Striga* tolerance, and improved yield potential.

Use new tools from molecular biology, genetics and plant physiology to study the mechanisms of drought tolerance in sorghum.

Investigate the potential for developing varieties of sorghum with high nutritional value and good food properties for potential use as nutritional foods for young children, pregnant women and nursing mothers.

Train LDC personnel in plant breeding and genetics.

Research Approach and Project Output

Research Methods

Much of the breeding activities will be conducted in Niger, Sudan, and also with the ICRISAT Southern Africa and East Africa regional centers. Collaboration with Sudan and Niger will continue on *Striga* tolerance and drought tolerance. Considerable time and effort will be spent working with Sudanese and Nigerien scientists on grain quality using pedigree breeding as well as population and hybrid development. A major effort will be made to develop A&B lines with good grain quality, *Striga* tolerance, drought tolerance which are adapted to Sudan and Niger.

Breeding for good grain quality and high digestibility in elite sorghum cultivars which also have African adaptability, good yield and other needed agronomic traits will be continued. Characteristics such as kernel hardness have now been identified which will facilitate breeding for grain quality. This program also will be carried out jointly with Niger and Sudan. Much of the breeding work will be done in Niger with backup using laboratory facilities at Purdue. Screening and trials will be conducted at three locations in Niger as well as in Sudan.

Training M.S. and Ph.D. LDC students will continue as in the past.

Research Findings

Genetics and Drought Reaction of Epicuticular Wax Mutants in Sorghum bicolor

Epicuticular wax has long been associated with drought tolerance in sorghum. Chemical mutagenesis of two drought resistant sorghum cultivars was used to develop sets of isogenic epicuticular wax lines. These include bloomless mutants with no visible wax, sparse-bloom mutants with reduced visible wax, and sib-derived normal isolines with abundant visible wax. The primary objectives were to determine the number of epicuticular wax production loci and to determine the relationship of epicuticular wax to drought tolerance. Allelism tests distinguished twenty epicuticular wax loci. These loci correspond to mutant groups with specific epicuticular wax biochemistry and ultrastructure. Linkage analysis shows that the bm_2 epicuticular wax locus is linked to the wx waxy endosperm locus with a recombination value of $16.2 \pm 3.0\%$, while loci bm_3 and h_5 are not linked to wx. Yield trials of the epicuticular wax isolines were conducted in a variety of drought environments. Drought is the primary component of effects that significantly reduced yield. Normal isolines produced significantly greater yields than mutants in all environments. Significant differences in yield of normals indicate background mutations of non-epicuticular wax genes. Regression analyses show a strong highly significant correlation of increased yield with increased wax load. In addition, mutation specific effects of epicuticular wax on yield are associated with differences in epicuticular wax biochemistry. Hopefully, in the future an epicuticular wax gene and the associated drought tolerance will be transferred to other crops such as maize.

Transposon Tagging in Sorghum Using the Putative Candystripe Transposable Element

Identification of agronomically important genes will be a major challenge for crop scientists during the next decade. Techniques for transferring genetic information between species is moving very fast and we need to increase our efforts at identifying and tagging genes which can be transferred for the benefit of agronomic species. Transposable elements provide one of the best systems for tagging genes for important agronomic traits for which we have little knowledge of the physiology or biochemistry of the trait.

The candystripe phenotype in sorghum shows a high frequency of somatic and germinal instability for pericarp pigmentation resulting in a characteristic variegated phenotype. This type of instability is associated with the presence of a putative transposable element. Pigmentation in the pericarp is a easily scorable phenotype. Pigmentation in plants is accounted for by anthocyanins and phlobaphenes. The *R* locus in maize controls the production of anthocyanins and other flavonoids hydroxylated at the 3-position and the *P* locus controls the production of C-glycosylflavones and their precursors, the 3-deoxyanthocyanins, the major

pigment in sorghum. Molecular and mapping data demonstrates that the *Y* gene of sorghum responsible for the candystripe phenotype is not homeologous to any of the several pigmentation genes from maize and other species. Analysis of candystripe and red seeded sorghum revertants has demonstrated that the level of flavon-4-ol is much reduced in candystripe sorghum as compared to the red counterpart which accumulates normal levels of flavon-4-ols. The report of the role of *P* gene for 3-deoxyanthocyanin biosynthesis would also support this data (Styles and Ceska, 1977).

Sorghum is a good choice of grasses for transposon tagging due to its small genome size-approximately 3.5 times smaller than maize- (c=0.7 pg; 1 cM=about 400 kb, Aru and Earle, 1991), diploid genetics (2n=2X=20), detailed molecular genetic map (Chittendale et al., 1994) and unique ability to tolerate abiotic stresses particularly water stress and having homology to other grass genomes which will allow one to use information derived in sorghum and apply it to other grasses. Since sorghum is a self pollinated crop with both female and male florets derived from the same somatic tissue, it should be possible to tag agronomically important traits in the immediate progeny of whole red head events selected from the candystripe head rows. Mutant phenotypes can be scored in rows of progeny planted from these independently occurring excision events. This circumvents the necessity of self pollinating plants bearing excision events in maize before transposon tagged phenotypes can be identified because of the different somatic origin of florets in male and female tissue. This should be specially important for tagging unknown genes of agronomic importance for which the biochemistry of the phenotype is unknown such as drought susceptibility. It is rather simple and straight forward to generate large numbers of independently occurring excision events from candystripe lines that can then be used immediately for screening in progeny of these red heads in the first generation. This should be especially valuable for identification of genes for important agronomic traits on a very large scale.

Preliminary studies with the candystripe material has generated further information to substantiate the claim that the phenotype of variegated pericarp in candystripe is a result of activity of a mobile element. These studies include collection of red revertants each representing an independent event, identification of mutant phenotypes at the frequency of approx. 2 mutations in a 1,000 red heads which is much higher than expected for normal sorghum. We have also demonstrated the ability of the putative transposon to reinsert at the *Y* locus as scored by presence of candystripe seed sectors (1 to 75 seed) on an otherwise red revertant head. This data is similar to that observed in maize with *Ac* element transpositions. Two of the putative transposon induced mutants also exhibit somatic instability. All these provide further evidence that a transposonable element is involved with the pericarp color gene in sorghum.

Recent molecular advances with the candystripe sorghum include the discovery in Drs. S. Chopra and T. Peterson's program at Iowa State University demonstrating polymorphism between the candystripe and the red revertant DNA with a *P* locus probe from maize. We have begun preliminary work with this *P* locus probe to classify the mutants identified in the red revertant population for association or lack there of, of the transposon. Although we do not have the transposon isolated at this point, we have generated over 10,000 independent excision events (red heads) which have resulted in many mutants and the discovery of the P locus probe showing polymorphisms has put us in a better position to tag, identify and isolate genes responsible for agronomic traits. Identification of genes specifically fertility genes in sorghum will have a great impact on hybrid production in sorghum since transformation techniques for gene transfer are already in place for sorghum, which would allow one to engineer these fertility genes to ones advantage followed by transformation to get a product.

Objectives

Identification of Male Fertility Genes in Sorghum

In the summer of 1995, we screened 2,820 red head rows (each representing independent excision event) for male sterile phenotypes. These putative male steriles are presumed to be transposon induced and our effort will focus on establishing the association of the transposable element with this phenotype with the use of a specific p gene probe, from Tom Peterson's lab at Iowa State University. DNA polymorphism with this probe would indicate the excision of the transposon from the P locus and then we will use this information for identification of the male fertility genes in sorghum.

Confirmation of Involvement of Transposon

With the use of the p gene probe, we will establish the nature of mutants identified in the candystripe population to be transposon induced or not based on DNA polymorphism associated at the P locus.

Efforts are already underway in Tom Peterson's lab at Iowa State for isolation of the candystripe transposon and preliminary results are promising. The availability of this transposon by the coming year is realistic and we will use the same to pursue our long term goal of studying genes that have been transposon tagged.

Alternate Strategy for Trapping the Transposon

Our efforts on trapping the candystripe transposon in transgenic sorghum carrying the bar gene will also continue.

Research Description

Identification of male fertility genes in sorghum: Our approach to identification of male fertility in sorghum has been via identification of male steriles in the red head row, each row representing one independent excision event. In-

dividual red heads (over 10,000) are grown in field rows and evaluated for male fertility. In 1995, 2,820 red head rows were screened for male fertility. Each row representing independent excision event. Forty putative male steriles were identified and seed from the fertile heads was harvested and grown at our winter nursery in Mexico. Seventeen of these 40 mutants showed the male sterile phenotype in Mexico as segregating for fertile and sterile plants. The seeds from these were collected and are currently being evaluated at Lafayette. These male steriles will be classified and heritability of the trait determined.

Molecular analysis of the male sterile mutants will be conducted including the screening with the P locus probe to determine the movement of the transposon. Preliminary southern blot analysis indicates polymorphism between the parent candystripe and the mutant red revertants indicating transposition of the element. Further information will be obtained to confirm that the male sterile phenotype are as a result of transposon inactivating the gene.

Confirmation of Transposon induced mutants: In addition to male sterile mutants we have 17 morphological putative transposon tagged mutants including dwarf growth habit, chlorophyll deficiency, virescent seedling, brown midrib phenotype, wilty seedling and lack of epicuticular wax (bloomless), that we will screen with the P gene probe, using southern blot analysis, to establish the excision of the transposon from the P locus.

We have been genetically characterizing these mutants for 2-3 generations and with one chlorophyll mutant and the brown midrib color mutant we can show somatic instability. Molecular data indicating that the candystripe transposon has excised from the Y locus and moved to a new location would indicate that these are putatively tagged mutants. Final confirmation can only be obtained when we can demonstrate cosegregation with the transposon probe between mutant and normal plants.

We will further generate and evaluate the red heads for other mutants specifically for drought susceptible phenotype. Sorghum is a naturally drought tolerant crop and identifying drought susceptible mutants will help us identify and isolate genes involved in drought tolerance.

Our collaborative efforts in mutant identification and transposon isolation with Tom Peterson's laboratory will permit us to make faster progress and ultimately isolate some of these genes.

Trapping the candystripe transposon in the bar *gene*: We have initiated crosses between the transgenic sorghum and candystripe sorghum and identified F1 by screening for herbicide resistance. The resistant F2 plants were selected to verify homozygosity and selected F3 progeny will be used for screening. We are in the process now of screening the homozygous *bar*, candystripe phenotype derived F3 plants for herbicide resistance and any susceptible phenotype would be molecularly characterized for the movement of candystripe transposon to the *bar* gene.

Anticipated Results

We expect to classify transposon induced mutants from non-transposon induced mutants with the use of the P gene probe. We will identify new mutants in the candystripe population, including new genetic male steriles. We will establish the basic network for use of candystripe transposon for gene tagging in sorghum.

Proposal for the Production and Marketing of Seed of Hybrid Sorghum in Niger

A sorghum hybrid named NAD-1 was released in 1992 by the National Agricultural Research Institute of Niger (Institut National de Recherches Agronomiques du Niger, INRAN). NAD-1 is the result of a long-term collaboration effort between INRAN, the McKnight Foundation and INTSORMIL (International Sorghum and Millet). The parents of this hybrid are Tx623A and MR732. Since its release, the hybrid has been grown by numerous farmers where it has received an enthusiastic response. This has raised concern for the farmer availability of seed. Being a hybrid it can be used to facilitate the initiation of a seed industry in the private sector. Hybridization is important in increasing farmers yields, particularly in stressed situations. Establishing a seed industry will make it possible for farmers to benefit from hybrids.

The four agencies, INRAN, the McKnight Foundation, INTSORMIL, and the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) at its Sahelian Center are jointly making an effort to initiate a seed production activity in Niger.

About 10 years ago, the INRAN sorghum breeder with support from the McKnight Foundation and in collaboration with breeders of INTSORMIL, introduced breeding stock from outside of the country. This cultivar has exhibited exceptional ability under drought conditions based on extensive research at Purdue and Niger with support from the McKnight Foundation. Varietal improvement was begun and sorghum hybrids were made and evaluated. In 1986, a systematic study of drought resistant hybrids was initiated and results of testing of 90 cultivars involving hybrids, their parents and adapted local checks was undertaken at several locations in the country. Hybrids averaged 61% increase over locals with irrigation and 49% when rainfed. The advantage of hybrids over parents was 45% with irrigation and 66% when rainfed. Additional testing continued to confirm the yield advantage of hybrids across locations and under both rainfed and irrigated conditions. The hybrid NAD-1, in 1989, was entered in regional sorghum trials. It ranked third of twenty entries including local checks at nine locations in Ivory Coast, Mali, Burkina Faso, Cameroon, Nigeria and Niger. Also, starting in 1989, experimental seed production was begun at Maradi, Niger. Modest seed pro-

duction has continued primarily at Lossa, Konni and Maradi so the produceability of the hybrid has been demonstrated. Average yield realized from on farm demonstrations in 1993 in the Konni and Jirataoua region was 2365 kg/ha, and in 1994 NAD-1 produced 1225 kg/ha at Say, 3500 kg/ha at Jirataoua, 3800 kg/ha at Cerasa, and 4600 kg/ha at Konni. The national average for sorghum production is 273 kg/ha. It is not surprising that farmer demand for seed has been steadily increasing.

To initiate a seed industry there are several basic requirements. It is important that a cultivar be identified that has significant yield, good grain quality and is not more susceptible to pests than the locals; NAD-1 satisfies these requirements. The area in the country should be large enough to support a seed industry and this exists in Niger (area sown is in excess of one million hectares). The cultivar involved should be a hybrid to permit the establishment of a suitable market and the hybrid should be readily produceable. NAD-1 satisfies all of these basic requirements.

INRAN Involvement in Seed Production

INRAN, since the release of NAD-1 has undertaken small scale (experimental) production of seed at Lossa, Konni, and Maradi. Some farmers have also been involved with the production of seeds of this hybrid. The breeder responsible for the development of this hybrid, Issoufou Kapran, has been at Purdue University studying for his Ph.D. degree. At Purdue he has undertaken modest production and the seeds shipped to Niger. There has been adequate experience and success in the production of the hybrid to establish its produceability.

Preliminary Activity

Plans were made for 10 hectares of seed production during the 1995-96 winter season. This production involves both public and private agencies. Approximately 9 hectares of seed production of NAD-1 and one hectare of A-line (Tx623A x Tx623B) is growing at Lossa. A half hectare of A-line production has been sown at a school near the Kollo station. There is a private seed producer (onion seeds) who is undertaking a modest production of NAD-1. In the neighborhood of Birni-N'-Konni four farmers are involved with modest production plots (0.4 hectares or less). There is also a half hectare of production of seeds of NAD-1 on the station at Maradi. This winter seed production program is the first of a three-season plan to identify interested private seed producers, get them involved in seed production and to begin a gradual phasing of seed production into private organizations.

Objective of the Project

There is now confidence in the performance of the hybrid, farmer interest, and demonstrated produceability of the seed to proceed in the direction of private sector seed production and marketing. The first steps to begin this seed production have been initiated (see previous paragraph). It is expected from this initial activity that individuals, organizations with interest in seed production would be identified and that they would have some experience with the production of seed. This is an important step in gaining stability in the production and marketing of seeds. It is encouraging that this effort is going well.

The establishment of a seed industry has several components involving production and processing of breeder, foundation and commercial seed, quality control including a seed law, seed certification including field and laboratory evaluation, marketing and extension, availability of credit, training. The processing of seeds involves equipment, design of seed processing units and seed storage. Yields of NAD-1 have been substantially more than of the local variety and raise the concern for grain utilization to avoid over production, drop in price, and loss of interest. To support the growing capability to produce seed, these activities should be planned for.

The success of NAD-1 provides the opportunity to initiate a seed industry. This initial thrust with sorghum provides a base for the production and marketing of quality seeds of other crops. Importance should be given to pearl millet by providing quality seed of existing varieties, production of chance hybrids and possibly multi lines. Heberosis in pearl millet has been clearly demonstrated and the opportunity for farmers to capitalize on it via a seed industry would contribute and strengthen the seed industry. The contribution of the seed industry is not restricted to cereals but can in due course include legumes, oil seeds, vegetables and more. Experience in India indicates a significant increase in production, to self sufficiency and export, because quality seeds of a range of crops were timely available from their seed industry.

The sorghum hybrid, NAD-1, has come from collaborative INRAN/INTSORMIL research. The research component is not only important for the development of new cultivars but also to respond to changes in crop management, particularly pest control. As the seed industry expands it makes it increasingly important that the research program makes significant contribution to cropping opportunities.

Traditionally, seed has been produced by governmental agencies and marketed as a function of extension. The production and marketing of hybrid seed with quality control is a very different activity requiring a unique experience; there is a learning component. To facilitate this learning experience it is recommended that there is a shared experience between individuals and organizations with experience gained in countries with an established seed industry. The interaction involving three staff members, consultancies, and study tours were part of the contribution of the Indian Agricultural Program, of The Rockefeller Foundation and took place over a ten-year period. A similar activity for Niger is suggested.

The Role of Specific Endosperm Proteins in Low Protein Digestibility of Sorghum

The overall goal of this project was to obtain a better understanding of the basis for the low protein digestibility of sorghum grain. In the first study sorghum P721N was harvested at selected days after half-bloom and the relationship between protein digestibility and α-, ß-, and γ-kafirin contents and unextractable disulfide bonded complexes was analyzed. Kafirin synthesis was complete by 40 DAHB. After this, disulfide crosslinking occurred in ß- and γ-kafirin, concomitantly with a large drop in protein digestibility. Digestibility of cooked flour dropped markedly beginning at 35 DAHB. The second study showed the susceptibility of each kafirin to pepsin digestibility. α-Kafirin was the least digestible among kafirins. Cooking the flour reduced the digestibility particularly of ß- and γ-kafirins. When uncooked and cooked flour was treated with a reducing agent, kafirins were much more digestible. In the third study a highly digestible mutant showed a unique protein body microstructure with invaginations that reached the center. γ-Kafirin was localized in discrete dark staining regions at the base of the folds, in contrast with the peripheral location of this kafirin in normal sorghum. A last study was conducted to characterize a high molecular weight protein that is believed to be related to low protein digestibility. Its solubility, amino acid composition, lack of cross reactivity with kafirins antisera, pI, and N-terminal sequence classified it as a non-kafirin. It was located in a dark staining peripheral ring of the protein body, where γ-kafirin is also found. In conclusion, the maturation of the grain leads to disulfide bonded complexes, particularly in the ß- and γ-kafirins. These complexes would exist in the peripheral regions of protein bodies that are resistant to pepsin digestion especially after cooking. A non-kafirin HMW protein located in the outer regions of the protein body may also be associated with the low protein digestibility, although this needs further studies. This resistant periphery retards the digestion of α-kafirin in the interior. However, in the case of the highly digestible mutant genotype the large invaginations and the location of γ-kafirin in discrete regions rather that at the periphery may facilitate enzymatic breakdown.

Networking Activities

Workshop

Organized West African Inter-CRSP Workshop (September 1995)

Research Investigator Exchanges

INRAN Staff, ICRISAT Staff and INTSORMIL Staff are regularly involved in exchange visits at Purdue, as well as Pioneer and DeKalb seed company scientists. A partial list follows.

Dr. Sam Mukuru, ICRISAT Sorghum Breeder, Kenya

Dr. Osman Ibrahim, ARC/Gezira Research Station, Wad Medani, Sudan

Dr. D.S. Murty, Plant Breeder, ICRISAT, Bamako, Mali

Dr. Lee House, Sorghum Seed Consultant, North Carolina

Dr. Darrel Rosenow, Texas A&M University Agricultural Experiment Station, Lubbock, TX 79401

Dr. Lloyd Rooney, Soil and Crop Sciences, Texas A&M University, College Station, TX 77843

Dr. Bruce Maunder, DeKalb-Pfizer Genetics, Rt 2, Lubbock, TX 79415

Dr. Kay Porter, Pioneer Seed Co., P.O. Box 1506, Plainview, TX 79072

Germplasm and Research Information Exchange

Extensive germplasm has been provided to INRAN/Niger, ARC in Sudan, ICRISAT/SADC Zimbabwe, plus numerous seed lots in response to specific requests by both private and public sector institutions. Several Purdue varieties are being increased for release in Kenya. Seed of NAD-1 has been produced for Niger.

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Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, *Striga*, and Grain Mold

Project PRF-107
Gebisa Ejeta
Purdue University

Principal Investigator

Dr. Gebisa Ejeta, Department of Agronomy, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Dr. Osman Ibrahim El Obeid, Sorghum Breeder, ARC, Sudan
Dr. Abdelgabar T. Babiker, *Striga* Specialist, ARC, Sudan
Dr. Mohamed El Hilu Omer, Sorghum Pathologist, ARC, Sudan
Dr. Omar Fadil, NSA, Sudan
Dr. Aboubacar Toure, Sorghum Breeder, IER, Bamako, Mali
Dr. D. Dembele, *Striga* Specialist, IER, Bamako, Mali
Mr. Issoufou Kapran, Sorghum Breeder, INRAN, Niamey, Niger
Dr. Ouendeba Botorou, Millet Breeder, INRAN, Niamey, Niger
Dr. Sam Mukuru, Sorghum Breeder, ICRISAT, Kenya
Dr. John Axtell, Agronomy Department, Purdue University, West Lafayette, IN
Dr. Larry Butler, Biochemistry Department, Purdue University, West Lafayette, IN
Dr. Bruce Hamaker, Food Science Department, Purdue University, West Lafayette, IN
Dr. Darrell Rosenow, Texas A&M Univ. Agricultural Res. Center, Route 3, Lubbock, TX
Dr. Jerry Eastin, Department of Agronomy, University of Nebraska, Lincoln, NE
Mr. David Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE
Dr. Bruce Maunder, DeKalb-Pfizer Genetics, Route 2, Box 56, Lubbock, TX
Dr. Kay Porter, Pioneer HiBred International, Plainview, TX

Summary

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limited production, knowledge of germplasm and appropriate physical environment for evaluation and testing. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Research and germplasm development activities in PRF-107 attempt to address these essential requirements.

PRF-107 addresses three major constraints, namely drought, *Striga*, and grain mold that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in each of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity and stress tolerance have been identified, and gene sources have been placed in improved germplasm background, many of which have already been widely distributed.

In Year 17 we reported on the results of a Ph.D. study by Mitchell Tuinstra on identification of QTL markers associated with pre-flowering drought tolerance in sorghum. The study involved genotypic and pheotypic characterization of traits associated with pre-flowering drought tolerance using a population of recombinant inbred lines developed from parents with contrasting drought reactions. We developed a linkage map using 150 RAPD and 20 RFLP markers scored in the above population to facilitate our analysis of drought tolerance. We identified six QTL to be specifically associated with pre-flowering drought tolerance. We also found eight additional QTL associated with yield and yield component under fully irrigated conditions. Marker contributions associated with phenotypic variability associated with pre-flowering drought tolerance ranged 14-43%.

We also reported on progress made in the distribution of eight *Striga* resistant sorghum lines that were released in December 1994 for use in *Striga* endemic areas of Africa. Eight metric tons (1 ton each) of the eight varieties was produced at Purdue University to provide a nucleus of good quality seed to farm communities. Through a collaborative relationship developed with World Vision International through funding by the USAID - OFDA, bulk quantities of these varieties was shipped and distributed in ten African

countries. In many of these countries seed arrived late during the 1995 cropping season and logistic difficulties did not allow full-scale testing as originally proposed by the joint initiative. In spite of the delays and associated problems, encouraging results were obtained from Mali, Ghana, Southern Sudan, and Rwanda. Plans are currently underway to further advance the testing and distribution in many of these countries.

Objectives, Production and Utilization Constraints

Objectives

Research

To study the inheritance of traits associated with resistance to drought, *Striga*, pests, and diseases of sorghum and/or millets.

To elucidate mechanisms of resistance to *Striga*, drought and diseases of sorghum and/or millets.

To evaluate and adapt new biotechnological (techniques and) approaches in addressing sorghum and millet constraints for which conventional approaches have not been successful.

Germplasm Development, Conservation, and Diversity

To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.

To develop and enhance sorghum germplasm with increased levels of resistance to drought, *Striga*, diseases, and improved quality characteristics.

To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U.S. and LDC scientists and institutions.

To assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity or for discerning genetic diversity of sorghum and millet germplasm pools.

Training, Networking, and Institutional Development

To provide graduate and non-graduate education of U.S. and LDC scientists in the area of plant breeding and genetics.

To develop liaison and facilitate effective collaboration between LDC and U.S. sorghum and millet scientists.

To encourage and facilitate positive institutional changes in research, extension and seed programs of collaborating countries involved in sorghum and millet research and development.

Program Approaches

The research efforts of PRF-107 are entirely interdisciplinary. Much of the on-campus research at Purdue is in close collaboration with Dr. Larry Butler (PRF-104B). Our programs are fully integrated particularly in the areas of pest, disease, and *Striga* resistance, where a concerted effort is underway in elucidating the biochemical and genetic mechanism of resistance to these constraints. Field and laboratory evaluations of sorghum and millet germplasm are coordinated, the results from one often complimenting the other. In addition, there have been collaborative research efforts with colleagues in Africa primarily with Dr. A.G.T. Babiker in Sudan where an integrated approach to *Striga* control has been under investigation.

Our germplasm development and enhancement program utilizes the wealth of sorghum and millet germplasm we have accumulated in the program. Intercrosses are made in specific combinations and populations generated via conventional hybridization techniques, through mutagenesis, or through tissue culture *in vitro*. Conventional progenies derived from these populations are evaluated both in the laboratory and in the field at West Lafayette, Indiana for an array of traits, including high yield potential, grain quality, as well as certain chemical constituents that we have found to correlate well with field resistance to *Striga* or panicle and leaf diseases. We also evaluate our germplasm for tropical adaptation and disease resistance during the off-season at the USDA Tropical Agricultural Research Center at Isabella, Puerto Rico. Selected progenies from relevant populations are then sampled for evaluation of specific adaptation and usefulness to collaborative programs in Sudan, Niger, and more recently Mali. Evaluation of the drought tolerance of our breeding materials have been conducted at Lubbock, Texas in collaboration with Dr. Darrell Rosenow and in a winter nursery at Puerto Vallarta, Mexico. Assistance in field evaluation of nurseries has also been provided by industry colleagues particularly at Pioneer Hi-Bred and DeKalb Genetics.

The training, networking and institutional development efforts of PRF-107 have been provided through graduate education, organization of special workshops and symposia as well as direct and closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali and some in Southern Africa through SADC/ICRISAT.

Project Output

Research Findings

Drought Tolerance: Identification of Quantitative Trait Loci Associated with Pre-Flowering Drought Tolerance in Sorghum

Drought tolerance is an important agronomic trait but the genetic and physiological mechanisms that condition its expression are poorly understood. The difficulties of quantifying drought tolerance have led physiologists and plant breeders to search for specific mechanisms that condition tolerance or susceptibility. It has been argued that if components of drought tolerance can be identified and selected for independent of yield, then progress toward high yielding, well-adapted genotypes could be more rapid. The problem with this approach is that many traits have been proposed as indicators of drought tolerance, but there has been little evidence supporting their agronomic merit.

The development of molecular marker technologies and the use of these markers in quantitative trait loci (QTL) analysis has become a powerful approach for studying the genetic and phenotypic basis of complex traits. If individual genetic components associated with a complex trait can be identified, then research can focus on the function of each locus independently without the confounding effects of other segregating loci. The purpose of this study was to use molecular markers to identify genetic loci associated with the expression of pre-flowering drought tolerance in sorghum.

Two genotypes with contrasting drought reactions, TX7078 (pre-flowering tolerant, post-flowering susceptible) and B35, pre-flowering susceptible, post-flowering tolerant), were selected as parents for a sample of recombinant inbred (RI) lines. Ninety light RI lines were evaluated in two different years under conditions of pre-flowering drought and full irrigation. This information was used to quantify the drought tolerance of each line. Drought tolerance was estimated by four criteria: (i) grain yield per se measured in the pre-flowering drought trial (ii) yield "stability" quantified as grain yield in the pre-flowering drought trial divided by yield measures in the fully irrigated trial, (iii) seed set "stability" quantified as percent seed set in the pre-flowering drought trial divided by percent seed set in fully irrigated trial, and (iv) height "stability" quantified as plant height in the pre-flowering drought trial divided by plant height in the fully irrigated trial.

A linkage map (Fig. 1) of the 150 RAPD and the 20 RFLP markers scored in the population was developed to facilitate QTL analysis for drought tolerance. Six QTL were shown to be specifically associated with pre-flowering drought tolerance. Eight additional QTL were identified for traits generally associated with yield and yield components under fully irrigated conditions. Segregating markers accounted for between 43 and 14% of the phenotypic variation for traits associated with pre-flowering drought tolerance (Table 1). A large degree of the phenotypic variability associated with traits measured under fully irrigated conditions was also accounted for by markers linked to those traits. The identification of QTL accounting for this substantial fraction of the phenotypic variability in drought tolerance is a significant first step towards a more detailed genetic characterization of this important trait.

Table 1. Percentage of the phenotypic variation explained by markers linked to QTL. Estimates were obtained by stepwise regression using markers significantly associated with each trait.

Pre-flowering drought	R^2 (%)
Yield per se	42.1
Yield stability	38.7
Seed set stability	14.2
Height stability	43.0
Fully irrigated	
Yield per se	32.1
Seed set	14.6
Maturity	30.7
Height	27.5

Striga : Biotechnological Approaches for Understanding Mechanisms of Resistance to *Striga*

Genetic resistance to *Striga* requires an interruption in the essential biological interactions between *Striga* and its host. To fully understand and exploit host plant resistance as a means of *Striga* control, we need to develop a good understanding of the basic biology underlying these interactions. It is now known that successful parasitism depends upon a series of host root-derived signals which serve to coordinate the life cycle of the parasite with that of its host. We have also observed that host cultivars vary greatly in their production of these signals, and the host resistance is often correlated with host capacity to produce and exchange these signals with the potential parasite. Host resistance involves both physiological and physical mechanisms. Our goal is to unravel host-resistance by reducing it to components based on the signals exchanged at each stage of the *Striga* life cycle. To develop control strategies primarily based on host-plant resistance, we integrated techniques in biochemistry, tissue culture, genetics, molecular biology, and plant breeding. This effort is a joint undertaking with Dr. Larry Butler in collaboration with our LDC partners, primarily Dr. A.G.T. Babiker in Sudan.

Current effort underway in our laboratory is focused on mapping and identification of QTL associated with field resistance to *Striga*. This work is closely integrated with activities focused on development of laboratory assays that would allow identification of host variants that are resistant to *Striga* because they interrupt interaction with *Striga* at stages beyond germination of *Striga* seeds. One such project emphasizes the hyper sensitive reaction expressed at infection site where *Striga* penetrates a resistant genotype. Host

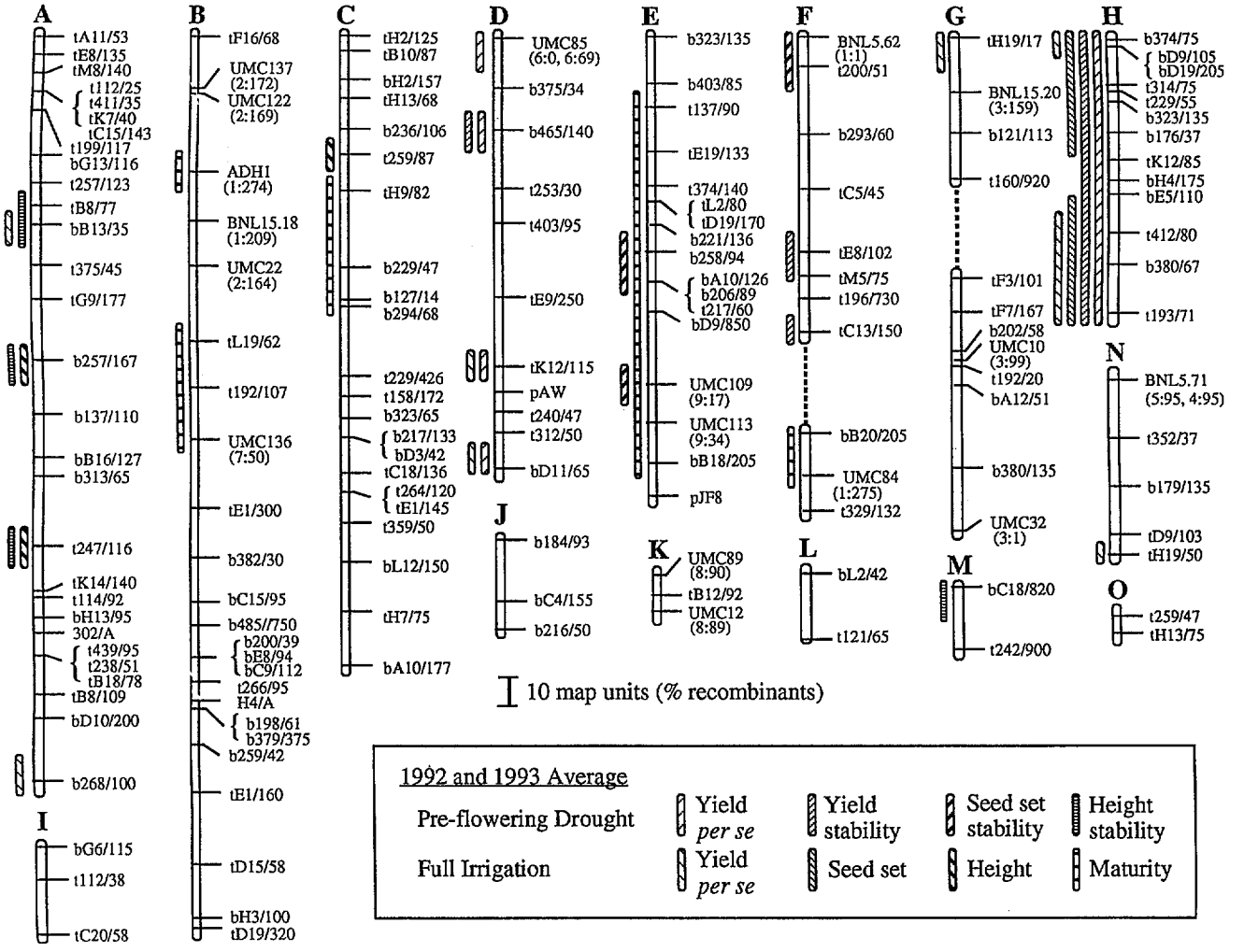

Figure 1. Sorghum genetic linkage map and QTL identified for pre-flowering drought tolerance, yield, and other phenologic traits. The linkage map was developed using *MapMaker* (LOD> 6.0). A dashed line between linkage groups indicates linkage inferred from the linkage of RFLPs mapped in other sorghum populations. QTL were identified by single factor analysis and were declared significant at P<0.01. The positions of QTL are indicated by bars on the linkage map. A significant association between a marker and a trait is indicated when a bar covers that marker. The map positions for RFLPs mapped in maize are indicated (chromosome:position).

resistance to *Striga* and other parasitic weeds are often associated with necrosis of the host-cells surrounding such an infection site. It has been suggested that this necroris may be associated with synthesis of phytoalexins as a post-infection defense mechanism similar to what has been demonstrated in resistance against fungi in higher plants. Our goal, therefore, is to develop an assay for such a hyper sensitive type resistance and identify QTL associated with this mechanism. We have generated genetic populations that would permit screening for this trait and the eventual identification of the genetic factors controlling it. We hope to gradually piece together the factors responsible for a more durable resistance to *Striga* through such an approach of identifying and characterizing each mechanism of resistance independently.

Grain Mold: Selection for Grain Mold Resistance

Grain mold has become a significant constraint to sorghum improvement and production in many parts of the world. It is of particular concern in areas where the period between anthesis and harvest coincides with high humidity and warm temperature. This disease is caused by a number of fungal species belonging to different genera. Most of the fungi isolated from molded grain are facultative parasites,

and the predominant species vary with locations and years. As numerous fungal species occur naturally, the development of grain mold on sorghum depends heavily on the climatic pattern at flowering and grain filling stages of the crop. Fungal damages to kernels could be limited to the discoloration of the pericarp or may involve extensive internal invasion. Grain mold reduces yield, seed viability, kernel weight, nutritional quality, and market value. Molded grain may also contain mycotoxins and, therefore, present health hazards to animals and humans.

Genetic resistance is considered to be the only feasible means to mitigate damage by grain mold in many areas where the crop is grown in a climate conducive to fungal invasion. Visual appraisal of the extent of kernel deterioration has been commonly used to screen germplasm for resistance to grain mold in sorghum breeding nurseries. However, visual rating per se may not adequately reflect the degree of damage caused by fungal invasion of the kernels. Measuring incidence of the different fungi on sorghum seeds may readily differentiate genotypes with otherwise similar kernel appearance. It is also useful to recognize fungal species which are more important in grain molding in a particular environment. The objectives of these experiments were to (i) assess relative incidence of various fungal species and their effect on kernel discoloration and percent germination, and (ii) evaluate extent of variation for grain mold resistance at different stages of maturity in a large and diverse sorghum accession.

We evaluated a diverse array of 231 photoperiod-insensitive sorghum accessions representing different cultivared races of sorghum for grain mold resistance at different stages of grain maturity. Fungal species infecting sorghum kernels at each stage of sampling were isolated and counted. Each sample was also characterized for several physical and chemical properties including kernel color, hardness, weight, texture, and concentration of phenolic compounds. Significant and large differences in levels of kernel infection by fungal species and resistance to grain mold were observed among accessions at all stages of kernel development. Accessions with high levels of grain mold resistance originating from diverse geographical areas and belonging to different botanical races were identified. We found that resistance to grain mold in these sorghums was strongly associated with high concentration of phenolic compounds, kernel hardness, and pericarp color. Each of these kernel properties contributed to grain mold resistance differently in white, red, and brown pericarp sorghum accessions. We also developed a numerical index that integrated the more important kernel attributes, and this index differentiated resistant and susceptible sorghum genotypes effectively.

The predominant fungal species isolated from sorghum kernels collected from field grown panicles did not change across the different sampling dates and years of evaluation. Although visual rating identified highly susceptible accessions as early as 40 days after flowering, rating a few weeks after physiological maturity was more reliable to identify genotypes with higher levels of resistance to kernel damage. A multiple regression model involving all the fungal species accounted for 64% of the variation in the final visual grain mold damage rating. Gibberella zeal and Fusarium moniliforme each accounted for 46 and 16% respectively, of the variation in the final visual grain mold damage rating. Sorghum accessions free from colonization by one or more fungal species across three sampling dates were identified. This observation is significant in that it provides evidence for the fact that, while genotypes immune to infection by all organisms may not be found, sources of resistance to one or more fungi could be identified in sorghum germplasm collections. These results demonstrate that a potential exists for establishing differentials for each fungus or fungi group to facilitate pyramiding of genes for resistance to the grain mold complex into one genotype.

Germplasm Release and Distribution

Eight *Striga* resistant sorghum cultivars released by INTSORMIL, in late 1994 use in *Striga* endemic areas of Africa, were distributed for on-farm testing in Senegal, Mali, Niger, Ghana, Sudan, Eritrea, Somalia, Rwanda, and Mozambique by World Vision Relief and Development, Inc. Distribution of a large quantity of these varieties in Ethiopia was curtailed because of bureaucratic irregularities. Seed shipment intended for Eritrea was also held in the Ethiopian capital for the same reason. As a result, on-farm testing in the two countries was not undertaken as planned for the 1995 crop season. We have since shipped smaller quantity of seed to Eritrea which was multiplied under irrigation during the off-season in cooperation with World Vision and the Ministry of Agriculture in Eritrea. Seed from this local production is expected for distribution and testing during the current 1996 crop season. Support for the project by both World Vision and the Eritrean Ministry officials has been very good. In Ethiopia and Kenya, though no large scale testing was done, results from experimental testing by research scientists have confirmed the high level of *Striga* resistance expressed by these varieties. Specific entries were selected for further testing, presumably some, on-farm. Encouraging results were also obtained from the Bahr-eh-Gazahl province of Southern Sudan where interest by farmers has generated additional on-farm trials for the 1996 crop season. Seed shipments to West Africa in 1995 were delayed and the trials were late planted with mixed results. There was general crop failure in Niger due to delayed planting and shortage of rain. In Ghana the introduced *Striga* resistant varieties showed good adaptation producing good yield and overall plant growth and expression. However, there was little or no *Striga* emergence in fields in which the test materials were planted including the local check varieties. While the INTSORMIL varieties appear to possess acceptable agronomic characteristics, their reaction to local *Striga* strains needs to be retested. Plans for 1996 include 55 on farm trials, one on-station test, and large scale multiplication of four varieties for an even wider distribution in Ghana for the 1997 crop season. On the other hand, the *Striga* reaction of these varieties in Mali was reported as

excellent with some of the entries also producing higher yield than local varieties. However cooperators would like to further test acceptability of the grain and tolerance to grain mold and head by damage before extensive distribution. Potential for use in lower rainfall areas of Mali appear to be good. No report was received about performance of the trial in Senegal, Sudan, Somalia, and Mozambique. The most promising report from results of testing and distribution of these cultivars was received from evaluation in Rwanda in the crop season that just ended in June 1996. World Vision agronomists in Rwanda distributed four of the eight varieties to 50 farmers in three agro-ecological zones. Farmers planted the INTSORMIL varieties alongside their local varieties. World Vision agronomist observed that few or no *Striga* plants emerged in plots planted to the resistant introductions, whereas heavy infestation was observed in the farmers' traditional varieties. In addition, the farmers' varieties did not head or flower well and the leaves were dried and sparse. The *Striga* resistant introductions flowered without difficulty and had luxurious vegetation. The four INTSORMIL varieties has a high level of resistance to *Striga* in farmers fields. The difference was so obvious that there was no need to promote the new varieties. The farmers are asking for more seed.

Networking Activities

Workshops and Program Reviews

Organized, jointly with ICRISAT and ASARECA, a workshop on sorghum and millet research in Eastern and Central Africa, 6-9 November, 1995. Kampala, Uganda.

Participated in "Parasitic Plants: Biological Resistance" Workshop in Bristol, England. Bristol, UK, June 1995.

Served as Visiting Faculty, University of Wisconsin, Summer Institute for Agricultural Research. July 1996.

Participate in African Dissertation Internships Awards Selection, Rockefeller Foundation, November 1995 and March 1996.

Attend American Society of Agronomy national meetings, St. Louis, Missouri, November 1995.

Presented joint papers (with Larry Butler) at the Sixth International Parasitic Weeds Symposium at Cordoba, Spain, April 1996.

Research Investigator Exchange

Interactions with public, private, and international sorghum research scientists continues to be an important function of PRF-107. The following individuals visited our program or worked in our laboratory during the project year:

Dr. Sam Mukuru, ICRISAT-Kenya, August 1995, December, 1995.

Dr. Paula Bramel-Cox, Sorghum Breeder, Kansas State University, September 1995.

Dr. Kay Porter, Pioneer Hi-Bred Int., October 1995.

Dr. Yilma Kebede, Pioneer Hi-Bred Int., October 1995.

Dr. Jeff Pederson, Sorghum Breeder, University of Nebraska, October 1995.

Dr. Ken Vogel, Agronomist, University of Nebraska, October 1995.

Publications

Ouendeba, B., G. Ejeta, W.W. Hanna, and A. Kumar. 1995. Diversity among African pearl millet landraces. Crop Sci. 35:919-924.

Vogler, R.K., G. Ejeta, and L.G. Butler. 1995. Integrating biotechnological approaches for the control of *Striga*. African Crop Sci. Journal. 3:217-222.

Sankara, E., J. Dickey, L. Butler, and G. Ejeta. 1995. Performance of sorghum lines under *Striga hermonthica* infestation in Burkina Faso. In: J. Lowenberg-Deboer (ed), pp. 131-145. Purdue University - INERA Report to USAID.

Babiker, A.G.T. I.A. Ali, G. Ejeta, L.G. Butler and W.R. Woodson. 1995. *Striga asiatica* germination requires stimulation of 1-aminocyclopropane-1-carboxylic acid (ACC) synthesis and oxidation. pp. 23-24. In J.A. Bailey and J.A. Lane (eds.). Proceedings of International Workshop on Parasitic Plants: Biology and Resistance. IACR - Long Ashton Research Station, Bristol, U.K. May 30th-June 2nd, 1995.

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Babiker, A.G.T., N.E. Ahmed, G. Ejeta, L.G. Butler, A. Mohamed, M.G. El Mana, S.M. El Taye, and B.E. Abdel Rhamman. 1996. Chemical control of *Striga hermonthica* on sorghum. pp. 769-776. In M.T. Moreno, J.I. Cubero, D. Berner, D. Joel, and L.J. Musselman (eds). Advances in Parasitic Plant Research: Proceedings of the Sixth International Parasitic Weeds Symposium. Direccion General De Investigcion Agraria. April 16-18, 1996. Cordoba, Spain.

Butler, L.G. and G. Ejeta. 1996. INTSORMIL-Supported research on *Striga* control in sorghum and millet. In J. Lenne' (ed.). Proceedings of ICRISAT's Sector Review of *Striga* Control in Sorghum and Millet. May 27th-May 28th, 1996. Bamako, Mali. ICRISAT, Patancheru, A.P. India. In press.

Invited Presentations

Ejeta, G. 1995. Research collaboration between NARS and INTSORMIL. Eastern Africa Regional Sorghum and Millet Workshop. 6-9 November, 1995, Kampala, Uganda.

Ejeta, G. 1995. Development and release of *Striga* resistant sorghum varieties. International Workshop for Parasitic plants: biology and resistance. 30 May - 2 June 1995.

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-122
Darrell T. Rosenow, Texas A&M University

Principal Investigator

Darrell T. Rosenow, Sorghum Breeder, Texas A&M Agricultural Experiment Station, Route 3, Box 291, Lubbock, TX

Collaborating Scientists

Dr. Aboubacar Touré, Sorghum Breeder and INTSORMIL Host Country Coordinator, (thru December, 1995) IER, Sotuba, Bamako, Mali
Mr. Sidi Bekaye Coulibaly, Agronomy/Physiology, INTSORMIL Host Country Coordinator (from January, 1996) IER, Sotuba, Bamako, Mali
Dr. Francisco Gomez, Sorghum Breeder and Head, Sorghum Investigations, EAP/SRN, Zamarano, Honduras
Dr. Osman El Obeid Ibrahim, Sorghum Breeder, ARC, Wad Medani, Sudan
Dr. L. E. Clark, Sorghum Breeder, TAM-122 (Cooperating Investigator), Texas A&M University, Vernon, TX
Dr. R.A. Frederiksen, Plant Pathologist, TAM-124, Texas A&M University, College Station, TX
Dr. G. C. Peterson, Sorghum Breeder, TAM-123, Texas A&M University, Lubbock, TX
Dr. L.W. Rooney, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
Dr. R. D. Waniska, Cereal Chemist, TAM-126, Texas A&M University, College Station, TX
Dr. G. N. Odvody, Plant Pathologist, TAM-128, Texas A&M University, Corpus Christi, TX
Dr. G. L. Teetes, Entomologist, TAM-125, Texas A&M University, College Station, TX
Dr. Gebisa Ejeta, Sorghum Breeder, PRF-107, Purdue University, West Lafayette, IN
Dr. W.L. Rooney, Sorghum Breeder, Texas A&M University, College Station, TX

Summary

The principal objectives of TAM-122 are to identify and develop disease resistant and drought resistant sorghum germplasm in genetically diverse backgrounds for use by host county and U.S. scientists, and to collaborate with host country scientists, especially those in Mali, Honduras, and Sudan, in all aspects of their crop improvement programs.

The disease and drought resistance breeding program continued to develop excellent germplasm for use in the U.S. and host countries. New cultivars were introduced into the U.S. and evaluated for useful traits. New breeding germplasm was developed from new crosses. This new segregating material plus other sorghum lines, germplasm, and hybrids was used in the U.S. and distributed to LDC collaborators.

Forty fully converted exotic lines and 50 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released. The male sterile (A-lines) of 5 new female parental lines, A1, A2-2(B), A35, A803, and A807 were distributed to private seed companies thru a pre-release materials transfer agreement. These possess drought and/or lodging resistance.

A marker-assisted selection study was initiated using RFLP molecular markers (QTL's) identified for the stay green drought resistance trait.

A white-seeded, tan-plant, tan glume guinea type breeding cultivar named N'Tenimissa looked very good for yield and adaptation in trials and in on-farm trials in Mali. It should be very useful in Mali and West Africa as an improved guineense type sorghum with grain that has improved quality for use in value-added commercial food products.

Objectives, Production and Utilization Constraints

Objectives

Enhance the germplasm of LDCs by developing and distributing early generation breeding materials involving genetically improved disease and drought resistance and other desirable traits for use and selection in host countries with emphasis on Honduras, Sudan, Mali, Niger, and Southern Africa.

Develop high yielding cultivars for LDCs and the U.S. with genetically enhanced resistance to internationally important diseases with emphasis on downy mildew, charcoal rot, grain mold/weathering, anthracnose, head smut, head blight, and foliage diseases.

Develop through breeding and selection, high yielding, agronomically desirable types with superior combination of

pre- and post-flowering drought tolerance and lodging resistance for use in the U.S. and host countries.

Identify, in basic sorghum germplasm lines, new sources of drought tolerance and resistance to diseases of importance in the U.S. and LDCs.

Collect and preserve new sorghum germplasm and evaluate for traits needed in the U.S. and developing countries, and introgress these traits into improved useful lines or germplasm.

Constraints

Drought is the major constraint to sorghum and millet production around the world. Sorghum cultivars differ widely in their response to drought. West Texas has a semiarid environment and high temperatures and is ideal for large scale field screening and breeding for improved resistance to drought. Sorghums with identified high levels of specific types of drought resistance in Texas, specifically pre- or post-flowering, have a similar response under drought in other countries of the world, including Sudan, Mali, Niger, and Honduras. Other adaptation traits such as grain quality, disease resistance, and grain yield must be combined with drought resistance to make a new cultivar useful.

Diseases are important worldwide and are often region or site specific, and on-site evaluation is necessary to determine severity and possible race differences. Most internationally important diseases are present and are serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. Many other diseases such as anthracnose, leaf blight, rust, zonate, and gray leaf spot are also present in Texas. The Texas environment, particularly South Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

Poor grain quality is a major problem in Mali and much of West Africa where guinea type sorghums are almost exclusively grown. This broad band extends from eastern Burkina Faso across all of Mali, except the extreme north, into Senegal and Guinea, and the northern areas of countries bordering on the south. This quality problem is primarily due to the head bug/grain mold complex. Guinea sorghums have quite good resistance to this complex, but their yield is not high and they do not respond well to improved production practices. Also, they are extremely difficult to handle in a breeding program, and efforts to improve them in yield have failed. Also, their unique grain quality adaptation essentially disappears in crosses to non-guinea types. Head bugs are the major constraint to the use of improved high yielding nonguineense type sorghums in much of West Africa. Head bug damage is often compounded by grain mold resulting in a soft and discolored endosperm, rendering it unfit for decortication and traditional food products. The early maturity of introduced types compounds the grain deterioration problem. Therefore, head bug resistance, grain mold/weathering resistance, and proper maturity are essential. In southern Mali, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season. In the drier northern areas of Mali and in Niger where drought stress is severe, earlier, less photosensitive material can be used, and drought tolerant Durra and Feterita sorghums generally perform well.

Mali and Niger are both drought prone areas. Both pre- and post-flowering drought tolerance are extremely important. Foliage diseases such as anthracnose and sooty stripe are important in the central and southern parts of Mali. Long smut is important in Niger and in the drier northern portion of Mali.

In Sudan, the major constraint is drought, and related production problems. Moisture-stress related charcoal rot and subsequent lodging are serious problems. Many U.S. sorghums perform quite well in Sudan, but improved drought resistance, local adaptation, and kisra food quality are needed.

Striga is a major constraint in Mali, Niger, and Sudan, and soil toxicity problems are important in Mali and Niger. Genetic sources of resistance to *Striga* and soil toxicity are used whenever possible in crosses involving disease and drought resistance to develop breeding progeny for selection in host countries.

In Honduras, diseases are a major constraint, including downy mildew, foliar diseases, acremonium wilt, and the grain mold/weathering, food quality complex. Drought is also important in Honduras and the Central American Region. Improvement in the photoperiod sensitive, food-type maicillos criollos grown in association with maize on small, hillside farms in southern Honduras (as well as in southeast Guatemala, El Salvador, and northwest Nicaragua) is a unique challenge. Breeding and selection must be done under the specific daylengths and environment in the host region. Improvement in the nonphotoperiod sensitive combine-type sorghum hybrids and varieties used over portions of Central America can result directly from introduction of Texas adapted cultivars or hybrids.

There is a constant need in both host countries and the U.S. for conserving genetic diversity and for new diverse germplasm sources with resistance to pests, diseases, and environmental stress. New collections can provide new sources of desirable traits. Many developing countries are an important source of diverse germplasm in sorghum and millet. The collection, preservation and utilization of genetic diversity in sorghum is tremendously important to long-term, sustainable sorghum improvement programs. Use of genetic diversity is critical to produce sufficient food for increasing populations in the future.

Research Approach and Project Output

Research Methods

Introductions from various countries with drought or disease resistance, or specific desirable grain or plant traits, are crossed in Texas to appropriate elite U.S. lines or elite breeding materials. Seed of the early generations are sent to host countries for selection of appropriate traits and adaptation. Technical assistance is provided, as time and travel permits, in the selection and evaluation and use of such breeding material in the host country.

New disease resistant breeding material is generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance. Advance generations of breeding lines also are selected each year. Initial screening is in large disease screening nurseries utilizing natural infection in South Texas, supplemented by artificial inoculation in the field and laboratory screening. Selected advanced materials are sent to host countries as appropriate for evaluation and are also incorporated into various standard replicated trials for extensive evaluation at several locations in Texas and host countries.

New breeding crosses are made among various sources of pre- and post-flowering drought resistance and elite, high yielding lines. Progeny are selected under field conditions for pre- and post flowering drought resistance, yield, and adaptation at several locations in West Texas. The locations vary in their degree and time of moisture and heat stress. Selected advanced materials are incorporated into standard replicated trials for extensive evaluation at several location in Texas and sent to host countries for evaluation and use.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials are screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm is collected from several countries, introduced into the U.S. through the quarantine greenhouse or the USDA Plant Quarantine Station in St. Croix, and evaluated in Puerto Rico and Texas for useful traits. Selected photoperiod sensitive cultivars are entered into the cooperative TAES-USDA Sorghum Conversion Program. Cultivars that are not photoperiod sensitive and with known merit are incorporated directly into the breeding program. We also work with NARS to assure their country's indigenous sorghum cultivars are preserved in long term permanent storage, as well as evaluated and used in germplasm enhancement programs. Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs.

Research Findings

Breeding, selection, and screening for drought resistance continued, using major field drought screening nurseries at Lubbock, Halfway, and Chillicothe. Late summer rains precluded post-flowering stress at all locations. Extremely dry early season allowed good pre-flowering stress on dryland plots at Lubbock. The "stay-green" line B35, is an excellent source of post-flowering drought resistance and lodging resistance in breeding progeny. Breeding derivatives of the parental line, B1, a derivative of B35, showed some good stay-green, and many had outstanding lodging resistance especially (B1*(B7904*(SC748*SC630))) and (B1*BTx635). Sterilization of the above mentioned B lines continued or was initiated. Progeny from drought tolerant breeding lines were backcrossed and intercrossed with agronomically elite lines.

New disease resistant breeding materials were developed, screened, and selected along with advanced generation breeding materials for improved agronomic types with high levels of disease or multiple disease resistance. Major diseases involved were charcoal rot, grain mold/weathering, downy mildew, head smut, anthracnose, and foliage diseases such as rust, zonate, and leaf blight. Derivatives involving the white-seeded, tan-plant B-line, BTx635, showed outstanding resistance to head smut in South Texas. This line appears to be an excellent source of resistance to head smut in B-lines.

Forty fully converted exotic lines and 50 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program was submitted for release in April, 1996. The male sterile (A-line) of five new female parental lines, (A1, A2-2(B), A35, A803, A807) were distributed to private companies thru a pre-release materials transfer agreement. Several additional A-B pairs and R lines were selected for release as germplasm stocks. These lines contain various desirable traits, including resistance to downy mildew, head smut, grain mold/weathering, anthracnose, charcoal rot, both pre- and post-flowering drought resistance, food type grain quality, and lodging resistance.

Molecular analysis using RFLP markers, along with drought evaluation was continued on 100 F_8 recombinant inbred lines (RILs) each of (B35*Tx430) and (B35*Tx7000). Three QTLs were identified for the stay green trait in the cross (B35*Tx7000) with one appearing to be the most important. In the cross (B35*Tx430), the same three QTLs were identified for stay green along with two others, and five QTLs were identified for yield. Two populations, B35*Tx7000, and SC56*Tx7000, were developed to attempt marker assisted selection for the stay green trait using the identified QTLs. New crosses were made for possible molecular analysis involving other sources of drought resistance, grain mold resistance, and anthracnose resistance, and progenies will be advanced for future use.

Several F_3 and F_5 progeny from crosses generated primarily for use in Host Countries looked very good. Important traits include head bug resistance, *Striga* resistance, grain mold/weathering resistance, lodging resistance, sugarcane aphid resistance, as well as drought and disease resistance. Lines giving especially good progeny were Malisor 84-7, ICSV1089BF, Sureno, Dorado, SRN-39, Macia, WSV387, SV1, 86EON361, 86EON362, 87EON366, 90EON328, CE151, BTx635, VG153(M62676), Tx2891, all of which are white-seeded, tan-plant types, as well as non-tan lines TAM 428, 82BDM499, PL2120, MB108B, and one red seeded, tan plant line, 90EO343.

Guinea type white-seeded, tan-plant, tan-glume F_7 breeding progeny named "N'Tenimissa" from the cross (Bimbiri Soumale (a late maturing southern Mali Guinea)*87CZ-Zerazera) looked outstanding in yield trials and also good in on-farm trials in Mali. These were given the highest priority in the breeding program for extensive evaluation on-farm as well as grain increase for evaluation for value-enhanced food products.

In limited on-farm trials in 1995 (Table 1 and Table 2) N'Tenimissa produced higher yields than the local guinea check, and was well accepted by farmers due to its phenotypic similarity to local cultivars. In one on-farm trial at Yirimadio (Table 2), three other new experimental non-guinea sorghum cultivars from the Malian IER breeding program performed well for grain yield. However, they were not well accepted due to their short height, non-guinea head type, and poor grain quality, apparently due to head bug and/or grain mold damage. Two new medium maturity lines and five new early maturity lines were selected for on-farm trials in 1996.

Table 1. Results of on-farm tests at Kati, Mali (mean of eight farmers), 1995.

Varieties	Days to 50% flowering	Grain yield T/ha
N'Tenimissa	76 a	0.94 a
CSM 388	69 b	0.98 a
Malisor 84-7	59 c	0.54 b
Local check	71 b	0.61 b
CV (%)	6.77	20.21
Significance	**	**
$LSD_{(0.05)}$	3	0.07

Table 2. Results of on-farm test at Yirimadio, 1995

Varieties	Grain yield, T/ha
Dusu Suma (89-SK-F4-53-1PL)	2.94
N'Tenimissa	2.67
89-SK-F4-192-2PL	4.67
NDarila (89-SK-F4-184-2PL)	4.11
Local check	2.33

Forty fully converted exotic sorghums from the cooperative TAES-TAMU/USDA-ARS Sorghum Conversion Program were released (Table 3). They include sources of drought resistance, seven elite Malian guinea cultivars, and diversity in classification group and origin.

Networking Activities

Workshops/Conferences

Served as Chair of the Organizing Committee for the September 1996 INTSORMIL/ICRISAT International Conference on Genetic Improvement of Sorghum and Pearl Millet and worked directly with many ICRISAT and U.S. scientists.

Presented talk on INTSORMIL activities and potential collaboration at the Steering Committee Meeting of the WCARN (West Central Africa Sorghum Network), May 8, 1996, ICRISAT Center, Samanko, Mali.

Participated and presented poster paper at the Annual American Society of Agronomy Meetings, Oct. 29-Nov. 2, 1995, St. Louis, MO.

Participated in and presented invited paper on drought and lodging resistance at the ASTA (American Seed Trade Assn.) Research Conference, Dec. 6-7, 1995, at Chicago, IL.

Co-organized and presented talk at the Sorghum Conversion and Biotechnology Field Tour and Workshop, Sept. 20-21, 1995, TAES, Lubbock, TX.

Research Investigator Exchanges

Traveled to Mali Oct. 8-20, 1995 to evaluate the INTSORMIL/IER collaborative research program, and plan future collaborative research with the IER National Program.

Traveled to Australia, Feb. 15-March 5, 1996 to participate in the Third Australia Sorghum Conference.

Traveled to Mali (with Dr. A. Toure, Mali sorghum breeder) May 6-13, 1996 to collaboratively plan 1996 IER sorghum research including test entries and nurseries for 1996.

Participated in Sorghum Crop Germplasm Committee (CGC) as Ad Hoc Member at ASA Meeting, Oct. 1995.

Participated in INTSORMIL TC Meeting, July, 1995, Kansas City, MO.

Participated in Sorghum Biotech Partnership meeting (Cargill, NK, NC+, Crosbyton), April 25, 1996. TAES Center, Lubbock, TX.

Met with Dr. James Ryan (Director General) and Dr. Don Byth (Research Director) of ICRISAT to review TAMU Biotech Program, and plan Genetic Improvement Conference.

Table 3. Forty sorghum converted line releases (1996) and information on original exotic cultivars.

Desig.[1]	SC No.[2]	PI or other no.	Local name, no. or description[3]	Origin[4] City/Province	Origin[4] Country	Classification[5] R	Classification[5] WG	Reason for conversion[6]	Fert. Rx[7]
IS1117C	196	248313	Satsemari		India	D	41:Durra	Div/EliteJCS(TS)	B
IS2680C	808	267366	J-16		Uganda	CD	40:Caud-Dur	Mod Nur (M2)	R
IS2871C	855	267524 FAO 8469	Giza 123 S 100	Giza, Orman	Egypt	D	41:Durra	Mod Nur (M2)	R
IS3106C	606	213900	A-2789, S. Nervosum	Thru USA	Prob. China	GB	17:Doc-Rox	Mod Nur (M1)	RP
IS3404C	629	NSL51443	Segaolane 16		Botswana	K	22:Caffrorum	Mod Nur (M)	R&B
IS4832C	1088	NSL55458	Sundhia kana	Broarh, Gujarat	India	D	41:Durra	Midge Res	R
IS5168C	1108	NSL52327	Tella Jonna, Kagatha	Visakapatnam, A.P.	India	G	1:Roxburghii	Dis Res	R
IS5763C	449	591377	Karkatia Salimpur	Monghyr, Bihar	India	D	42:Durra-Rox	Mod Nur (M)	R
IS6733C	532	NSL50503	132 AB Farako-Ba		W. Volta	G	3:Conspicuum	Mod Nur (M2)	B
IS6960C	738	570752	Nagad White, Tozi 249	Tozi	Sudan	C	33:Caudatum	Mod Nur (A)	R
IS7436C	406	NSL54231	KA 4, Basharanba	Kafinsoli	Nigeria	G	35:Caud-Guin	Mod Nur (M)	R
IS7714C	537	NSL50716	NG151		Nigeria	G	3:Conspicuum	Mod Nur (M2)	R
IS8898C	1237	NSL56134	E 563 Esila	Tororo Dist.	Uganda	CK	38:Caud-Kaf	Midge Res	
IS11885C	1031	330165	Col. No. P-31	N. of Debre Sina (Shoa)	Ethiopia	DB	45:Dur-Doc	High Altitude	R
IS11930C	1158	330212	Col. No. P-104	Asmara, Eritrea Province	Ethiopia	D	45:Durra-Doc	Dis Res	R
IS12675C	184	277542	Suki PS295	Pretoria	South Africa	CK	27:Caf-Fet	Div/Elite/JCS	BP
IS17204C	1065		CE 63-18		Senegal	C	33:Caudatum	W.Africa Elite/OJW	B
IS17215C	1076		Line SK-MDW		Nigeria	CB	36:Caud-Bic	W.Africa Elite/OJW	B
IS17216C	1077		Sorgho 137-62		Nigeria	C	39(1):Zerazera	W.Africa Elite/OJW	R
IS23492C	1302	PAB3		Gambella Market	Ethiopia	C	39(1):Zerazera	Elite Zerazera	
IS23601C	1318	PAB124	Alangua	Chodo (53 S Gambella)	Ethiopia	C	39(1):Zerazera	Elite Zerazera	
IS23607C	1319	PAB130	Nyaluwal, Tungo	Abobo (57 S Gambella)	Ethiopia	C	39(1):Zerazera	Elite Zerazera	
SC1205C	1205		CE90-16-3		Senegal	C	39(1):Zerazera	Local Drought Res	
SC1212C	1212		SL-PR-32650		Venezuela	C	33:Caudatum	High Yield Hegari	
SC1320C	1320		P967083		Ethiopia	C	39(1):Zerazera	Striga Resistance	
SC1321C	1321		Col. El Obeid 8-1, Korky	El Obeid Area, N. Kordofan	Sudan	C	35:Caud-Guin	Drought Res*	
SC1322C	1322		Col. El Obeid 8-2, Ferik	El Kharta, N. Kordofan	Sudan	DB	43:Dur-Mem	Drought Res*	
SC1325C	1325		Col El Obeid 8-5, Umm Tul	El Kharta, N. Kordofan	Sudan	C	40:Caud-Dur	Drought Res*/TS	
SC1328C	1328		Col. El Obeid 8-8, Nachatt Ahmar	El Kharta, N. Kordofan	Sudan	C	33:Caudatum	Drought Res*	
SC1329C	1329		Col. El Obeid 8-9, Gadumel Tatil	Kaba, N. Kordofan	Sudan	DC	40:Caud-Dur	Drought Res*	
SC1330C	1330		Col. El Obeid 8-10, Marg Herchir Aswad	El Kharta, N. Kordofan	Sudan	DB	44:Dur-Bicolor	Drought Res*	
SC1333C	1333		CSM-207		Mali	G	4:Guineense	Elite Mali Var/JFS	
SC1337C	1337		CSM-388		Mali	G	4:Guineense	Elite Mali Var/JFS	
SC1339C	1339		CSM-414		Mali	G	4:Guineense	Elite Mali Var/JFS	
SC1341C	1341		CSM-417		Mali	G	4:Guineense	Elite Mali Var/JFS	
SC1342C	1342		CSM-419		Mali	G	4:Guineense	Elite Mali Var/JFS	
SC1345C	1345		CSM-90		Mali	C	33:Caudatum	Elite Mali Var/JFS	
SC1351C	1351		Shot Damon #2-2, N. Black	Kaduguli Area, S. Kordofan	Sudan	C	33:Caudatum	Div/Elite Local/DTR	
SC1356C	1356		Shot Damon #3-2, N. Black	Kaduguli Area S. Kordofan	Sudan	C	33:Caudatum	Div/Elite Local/DTR	

* = Represents reported drought tolerant material from dry, sandy areas in Northern Kordofan area of Sudan.

[1]Desig. = Designation of converted lines was obtained by adding C to the IS number used in the World Sorghum Collection. Those without an IS number were given a C following the SC number.

[2]SC No. = The serial number given to the exotic variety when entered into the Sorghum Conversion Program and used during conversion.

[3]The local name, number, code, or description of the exotic variety.

[4]Origin indicates the location of the collection if known and country of origin of each exotic line insofar as records indicate.

[5]Classification of exotic line. R = Race is based on Harlan & DeWet (2) where B = Bicolor, G = Guinea, C = Caudatum, K = Kafir, and D = Durra. WG = Working Group number and name is based on Modified Snowden's Classification by Murty and Govil (3).

[6]General reason for conversion: Div - Diversity; Mod Nur = Modified Nursery selected by Rachie et al., from World Sorghum Collection, 1963-64. M1 = representative of each classification group as described by Mûrty and Govil (3); M = lines representing major variation in each group; M2 = other variations of possible breeding value; A = breeding value to Indian program; IES and JCS = I. E. Stokes and J. C. Stephens, former USDA-ARS sorghum researchers at Meridian, MS and Chillicothe, TX, respectively; Dis Res = disease resistant selected material by R. A. Frederiksen based on disease evaluation at ICRISAT (L. R. House—Downy Mildew, Rust, Leaf Blight, Cercospora) and foliar reaction (Bacterial Stripe, Cercospora, Rust, and Zonate) in South Texas; Midge Res = reported midge resistant; Drought Res = reported drought resistance; TS = Twin seeded; OJW = Orrin J. Webster; JFS = John F. Scheuring; DTR = Darrell T. Rosenow.

[7]Fert. Rx = Fertility reaction as determined from crosses between a milo-kafir cytoplasmic-genetic, male sterile (A1) and the exotic line: R = restorer (progeny all male fertile); B = maintainer (progeny all male sterile) PB or RP = partial restorer

Coordinated training and research in sorghum breeding, drought resistance, and germplasm for one visiting scientist, Mr. S. Laxman, sorghum breeder from India, July-September, 1995.

Organized the training (B.Sc and M.S.) for Mr. Niaba Temé (sorghum breeding Technician) from Mali at Texas Tech University and TAES at Lubbock.

Several public and private sorghum workers from the U.S. and internationally visited our program during the past year.

Other Collaborating/Cooperating Scientists

Cooperation or collaboration with the following scientists in addition to the collaborating scientists previously listed was important to the activities and achievements of Project TAM-122.

Mr. Issoufou Kapran, Sorghum Breeder, INRAN, Maradi, Niger.

Dr. A. Tunde Obilana, Sorghum Breeder, SADC/ICRISAT, Bulawayo, Zimbabwe.

Dr. Chris Manthe, Entomologist, DAR, Gaborone, Botswana.

Dr. B.N. Verma, Sorghum Breeder, Chilanga, Zambia.

Dr. El Hilu Omer, Pathologist, ARC, Wad Medani, Sudan.

Dr. D.S. Murty, Sorghum Breeder, ICRISAT, Bamako, Mali.

Dr. Sam Z. Mukuru, Sorghum Breeder, ICRISAT, Nairobi, Kenya.

Dr. Jeff Dahlberg, Sorghum Curator, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Dr. L.E. Claflin, Pathologist, KSU-108, Kansas State University, Manhattan, KS.

Dr. L.M. Gourley, Sorghum Breeder, Mississippi State University, Mississippi State, MS.

Prof. D.J. Andrews, Sorghum/Millet Breeder, UNL-115, University of Nebraska, Lincoln, NE.

Dr. J.D. Eastin, Physiologist, University of Nebraska, Lincoln, NE.

Dr. K.F. Schertz Geneticist, USDA/ARS - Texas A&M University, College Station, TX. (Now retired).

Dr. John H. Mullet, Biochemist, Molecular Biology, Texas A&M University, College Station, TX.

Dr. Andrew Paterson, Molecular Biology, Texas A&M University, College Station, TX.

Dr. Henry T. Nguyen, Molecular Biology, Texas Tech University, Lubbock, TX.

Dr. Wenwei Xu, Molecular Biology, Texas Tech University, Lubbock, TX.

Dr. Xian Zhang, Molecular Biology, Texas Tech University, Lubbock, TX.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Forty fully converted exotic lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released and distributed and seed placed in permanent storage at the NSSL at Ft. Collins, Colorado. Fifty partially converted bulks from the Conversion Program also were distributed.

Seven hundred and eighty-three photoperiod insensitive sorghums from the Sudan Collection were evaluated for response to drought (Lubbock and Chillicothe), head smut (Beeville), and selected ones for downy mildew (Edroy).

The approximately 800 entries selected as potential Working Collection items from the Sudan Collection were evaluated in Puerto Rico in January, 1996 by J. Dahlberg, D. Rosenow, G. Peterson, and B. Rooney, and about 250 eliminated.

Plans have been made to assemble all sorghums of known Malian origin from the ICRISAT Center, ORSTROM/France, CIRAD/France, U.S. introductions, and those currently stored or in use in Mali. These will all be planted together at one time in Mali in 1997, to evaluate, classify, describe, and increase seed. The increased seed would be made available to all parties, and put into long term storage at ICRISAT, NSSL, and ORSTROM. A small Working Collection would be selected for maintenance and active use in Mali. It would be a joint effort among INTSORMIL, IER, ICRISAT, ORSTROM and CIRAD. Some of the collections in the past never were received at ICRISAT and their only known source is ORSTROM in France.

Forty-eight new exotic sorghums were entered into the cooperative TAMU/TAES-USDA/ARS Sorghum Conversion Program in the fall of 1995. These were selected by Jeff Dahlberg as the most agronomically elite and highest yield potential from the 3000+ entry Sudan Collection. Marker assisted selection using maturity and height molecular markers, will be attempted during the backcrossing of these entries.

Recent introductions from Southern Africa (Botswana, Zimbabwe, Zambia-B.N. Verma) (40), China (24), Ethiopia (5) and ICRISAT (D.S. Murty)(5) were grown and evaluated in Puerto Rico and seed increased. Twelve were selected as potential candidates for entry into the Conversion

Program. New introductions were made, and are growing in the quarantine greenhouse, include elite breeding lines from Mali (18), 7 A-B Pairs from South Africa, and 6 head smut resistant lines from China.

Seed Production and Distribution

Sets of the 50 converted lines and the 253 partially converted bulks released in May, 1995 from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were distributed to 11 private companies and 4 public workers. The male sterile version (A-lines) of five new female parental lines containing drought resistance and lodging resistance were requested and distributed to 13 private companies via a pre-release distribution agreement. A large number of sorghum breeding and germplasm lines, including F2 to advanced generation breeding progeny, A.B., and R lines, converted lines, and experimental hybrids were increased and distributed to international and domestic collaborators. These contained sources of desirable traits such as resistance to downy mildew, anthracnose, leaf blight, rust, and charcoal rot, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance. Seed was increased and many sets of standard replicated trials containing elite germplasm and source lines were packaged and distributed in the U.S. and internationally. These include the ADIN (All Disease and Insect Nursery), IDIN (International Disease and Insect Nursery), GWT (Grain Weathering Test), DLT (Drought Line Test), DHT (Drought Hybrid Test), and the UHSN (Uniform Head Smut Nursery). Countries to which large numbers of germplasm items were distributed include Mali, Zimbabwe, Botswana, Zambia, Brazil, Mexico, and Nigeria.

Assistance Given

Joint evaluation of germplasm and nursery and test entry decisions was done collaboratively with national scientists in Mali. Training on disease and drought screening and rating methodology, as well as information on sources of new useful germplasm and sources of desirable traits was provided to Mr. Laxman and Dr. Yadev (India) and B.N. Verma (Zambia) in the Corpus Christi area. Pollinating bags, coin envelopes, and breeding supplies were provided to the Mali breeding program.

Publications and Presentations

Abstracts

Crasta, Oswald, Wenwei Xu, Darrell Rosenow, John Mullet and Henry Nguyen. 1995. QTL analysis of yield and related drought resistance traits in grain sorghum. p. 31. In: Plant Genome III, January 15-19, 1995, San Diego, CA.

Crasta, Oswald, Wenwei Xu, Darrell Rosenow, John Mullet, and Henry Nguyen. 1996. Molecular genetic analysis of the relationship stay green trait and grain yield in sorghum. p. 65. In: Plant Genome IV, January 14-18, 1996, San Diego, CA.

Peterson, G.C., D.T. Rosenow, J.A. Dahlberg, G. Ejeta, M.A. Mahmoud, and O.I. Ibrahim. 1995. Unique sorghums from Sudan. Agronomy Abs. p. 183-184.

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, and L.E. Clark. 1995. Conversion-An efficient technique to enhance use of exotic sorghum. Agronomy Abs. p. 183.

Xu, Wenwei, Oswald Crasta, Darrell Rosenow, John Mullet, and Henry Nguyen. 1996. Molecular mapping of drought resistance genes in grain sorghum. p. 24. In: Plant Genome IV, January 14-18, 1996, San Diego, CA.

Journal Articles

Miller, F.R., K.L. Prihoda, L.W. Rooney, D.T. Rosenow, and R. D. Waniska. 1996. Registration of a food quality sorghum restorer parent, Tx2907. Crop Sci. 36:479

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, L.E. Clark, F.R. Miller, A. Sotomayor-Rios, A. Quiles-Belen, P. Madera-Torres, and C.A. Woodfin. 1996. Registration of fifty converted exotic sorghums. Crop Science (accepted).

Rosenow, D.T., J.A. Dahlberg, J.C. Stephens, F.R. Miller, D.K. Barnes, G.C. Peterson, J.W. Johnson, and K.F. Schertz. 1996. Registration of sixty-three converted sorghums from the sorghum conversion program. Crop Science (accepted).

Books, Book Chapters, and Proceedings

Nguyen, Henry T., Wenwei Xu, Oswald Crasta, Darrell T. Rosenow, and John M. Mullet. 1995. p. 1-5. In. Proc. International Congress on Integrated Studies on Drought Tolerance in Higher Plants, Aug. 31-Sept. 2, 1995, Montpellier, France.

Rosenow, D.T., and L.E. Clark. 1995. Drought and lodging resistance for a quality sorghum crop. p. 82-97. In: Proc. Fiftieth Annual Corn and Sorghum Industry Research Conference, Dec. 6-7, 1995, Chicago, IL.

Dissertation and Theses

Crasta, Oswald R. 1995. Molecular genetic analysis of stay-green, a post-flowering drought resistance trait in grain sorghum *[Sorghum bicolor (L.) Moench]*. Ph.D. Dissertation, Texas Tech University, Lubbock, TX.

Mkhabela, Sipho Milton. 1995. Genetic variation, heritability estimates, and yield relationship of pre-flowering and post-flowering drought resistant traits in grain sorghum. Ph.D. Dissertation, Texas Tech University, Lubbock, TX.

Miscellaneous Publications

Pietsch, Dennis, Leon Synatschk, D.T. Rosenow, and G.C. Peterson. 1996. 1995 Grain Sorghum Performance Tests in Texas. Dept. of Soil and Crop Sciences Department Technical Report, DTR 96-02. 106 p.

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, L.E. Clark, A. Sotomayor-Rios, F.R. Miller, A.J. Hamburger, P. Madera-Torres, A. Quiles-Belen, and C.A. Woodfin. 1995. Release of 50 converted sorghum lines and 253 partially converted bulks. International Sorghum and Millets Newsletter, ISMN No. 367. p. 19-31.

Presentations

Rosenow, D.T. Drought resistance in sorghum. Post-Australian Conference Sorghum Producers Meeting, Feb. 23, 1996, Moree, NSW, Australia.

Rosenow, D.T. Breeding for lodging and drought resistance in sorghum. Post-Australian Sorghum Conference Producers Meeting, Feb. 24, 1996, Dalby, QLD, Australia.

Rosenow, D.T. The relationship between drought and lodging resistance in sorghum. Post-Australian Sorghum Conference Producers Meeting, Feb. 25, 1996, Emerald, QLD, Australia.

Rosenow, D.T. Sorghum conversion program update. Sorghum conversion and biotechnology tour. Sept. 20, 1995, Lubbock, TX.

Rosenow, D.T. The TAES sorghum research program. Queensland Dept. Primary Industry Group, June 20, 1996, Lubbock, TX.

Rosenow, D.T. Grain quality research and progress in sorghum. Mexico grain buyers. Sept. 25, 1995, Lubbock, TX.

Germplasm Enhancement through Genetic Manipulation for Increasing Resistance to Insects and Improving Efficient Nutrient Use in Genotypes Adapted to Sustainable Production Systems

Project TAM-123
Gary C. Peterson
Texas A&M University

Principal Investigator

Dr. Gary C. Peterson, Sorghum Breeding and Genetics, Texas A&M Agricultural Experiment Station, Rt. 3 - Box 219, Lubbock, TX 79401-9757

Collaborating Scientists

Dr. Francisco Gomez, Sorghum Breeding, Escuela Agricola Panamericana, P.O. Box 93, Tegucigalpa, Honduras
Dr. Aboubacar Toure, IER, Sotuba, B.P. 438, Bamako, Mali
Mr. Sidi B. Coulibaly, Agronomy/Physiology, IER, Cinzana, Mali
Dr. M.D. Doumbia, IER, Sotuba, B.P. 438, Bamako, Mali
Dr. Y. Doumbia, IER, Sotuba, B.P. 438, Bamako, Mali
Dr. G.L. Teetes, Department of Entomology, Texas A&M University, College Station, TX 77843 (TAM-125)
Dr. D.T. Rosenow, Sorghum Breeding, Texas Agricultural Experiment Station, Rt. 3, Box 219, Lubbock, TX 79401-9757 (TAM-122)
Dr. R.A. Frederiksen, Department of Plant Pathology, Texas A&M University, College Station, TX 77843 (TAM-124)
Dr. L.W. Rooney, Cereal Chemist, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (TAM-126)
Dr. G.N. Odvody, Plant Pathology, Texas Agricultural Experiment Station, Route 2 Box 589, Corpus Christi, TX 78406-9704 (TAM-128)
Dr. R. D. Waniska, Cereal Chemist, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. A.H. Paterson, Molecular Biology, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. W.L. Rooney, Sorghum Breeding, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843

Summary

This project is the breeding for resistance to insects component of the integrated Texas A&M University sorghum improvement program. The objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars or hybrids resistant to selected biotic and abiotic stress factors, and to determine the genetic factors responsible for the resistance and their associated mechanisms. Breeding and selection activities are done using conventional methodology, and a collaborative research project has been established to use molecular biology to map insect resistance traits of economic importance. Insect pests for which resistance has been identified and is utilized include sorghum midge (*Stenodiplosis sorghicola*), biotype E and I greenbug (*Schizaphis graminum*) and yellow sugarcane aphid (*Sipha flava*).

Extensive research has been done to develop improved sorghum lines resistant to sorghum midge which are suitable for hybrid production. In addition to insect pest resistance, the lines and hybrids should possess excellent yield potential under high pest density, acceptable yield in the absence of the pest, and the other needed plant traits for yield, adaptation, foliar quality, etc. This project, in collaboration with entomologists (TAM-125), has identified three A/B-line pairs which will be of use as sorghum midge resistant hybrid seed parents. In three years of trials each line produced hybrids with grain yield significantly greater under high pest density than most resistant and susceptible checks. When the insect pest is absent, grain yield of the experimental hybrids is comparable to that of the susceptible hybrids. Several hundred pounds of two experimental hybrids, using one A-line crossed to two R-lines was produced for use in large scale evaluation. Hybrid seed has been distributed to commercial seed companies and extension personnel to evaluate hybrid performance in a large range of environments with or without the sorghum midge present. The lines will be released to other breeders during the fall, 1996. These will be first sorghum midge resistant A/B pairs with the traits

needed to produce commercially acceptable resistant hybrids.

Introduction

Sorghum production and yield stability is constrained by many biotic and abiotic stresses. Insects pose a production risk in sorghum production environments, the severity of damage depending on the insect and locale. To reduce the impact of stress, research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems. To further reduce environmental risk and contribute to improved productivity in LDC and DC production systems, genetic resistance to multiple stresses should be combined in a single genotype. This is especially important as local production ecosystems (relative to cultivars and technology) experience induced change with the natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe.

To meet the demands of increased food production in an economically profitable, environmentally sustainable production system genetic resistance can be utilized at no additional cost to the producer. This requires a multi-disciplinary research program to integrate resistance hybrids into the management system. Cultivars resistant to insects will readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Among the major constraints to sorghum production in Sahelian Africa are: soil acidity, extremely deficient levels of N and P, spatially variable soil toxicity and limited available water. These factors frequently interact with food shortages being the result. Solutions to these problems must meet site specific needs of soil, rainfall, resources, labor and capital.

Objectives, Production and Utilization Constraints

Objectives

Obtain and evaluate germplasm for resistance to arthropod pests. Determine the resistance source or mechanisms most useful to sorghum improvement.

Determine the inheritance of insect resistance.

Develop and release high yielding, agronomically improved sorghums resistant to selected insects.

Utilization biotechnology to increase understanding of the genetics of plant resistance traits.

Identify and define sorghum genotypes with varying levels or tolerance to drought and chemical stress of Sahelian soils.

Constraints

Sorghum yield stability is constrained by many biotic and abiotic stresses. Insects pose a risk in all areas of sorghum production with damage depending on the insect and local environment. To reduce stress impact, research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems. Genetic resistance to multiple stresses in a single genotype will further reduce environmental risk and contribute to improved productivity. This is especially important as production ecosystems experience induced change due to cultivars and/or technology, the natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe.

Sorghum midge, *Stenodiplosis sorghicola*, is the only ubiquitous sorghum insect pest and may be the sorghum species most destructive insect pest. As LDC programs introduce exotic germplasm with improved agronomic traits into sorghum improvement programs, progeny and eventually cultivars which are more photoperiod insensitive will be developed and sorghum midge damage will become increasingly severe. Depending on the environment other insect pests (including aphids, headbugs and borers) will damage grain sorghum. For all of the insect pests genetic resistance exists and can be integrated into the production system in an ecologically safe, economically inexpensive, and environmentally sustainable manner. Cultivars resistant to insects will readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Research Approach and Project Output

Research Methods

The research approach is to conduct collaborative research in LDCs on specific problems. On-site research is supported by participation in graduate education, germplasm exchange and evaluation, site visits, and research conducted at various nursery locations in Texas. Primary LDC involvement is in Africa for resistance to headbugs and identification of sorghum genotypes resistant/tolerant to soil toxicity. For the United States, sorghum midge, biotype E and/or I greenbug and yellow sugarcane resistant sources have been identified and are used in developing elite resistant sorghums. Through collaborative ties with other projects genetic inheritance and resistance mechanisms are determined, and mapping research for the greenbug resistance genes is on-going.

Germplasm is evaluated for resistance to insects of economic importance in the collaborative breeding/entomology program in field nurseries or greenhouse facilities, depending on the insect mode of infestation. Sources of germplasm for evaluation are elite accessions from other programs (including ICRISAT), introductions, and partially or fully converted exotic genotypes from the sorghum conversion program.

New sources of resistance are crossed to elite material in the breeding program, and to other germplasm lines with superior trait(s). Studies to determine the genetics of resistance and the resistance mechanism are conducted when possible. Advanced elite materials are evaluated at diverse locations for stability of resistance, adaptation and reaction to additional stress factors. Based upon data collected, crosses are made among elite lines to produce additional germplasm for subsequent evaluation. Improved adaptation, other stress resistance (disease resistance and/or drought tolerance), and additional favorable traits are incorporated into insect resistant germplasm whenever possible.

Elite lines and hybrids are provided to LDC cooperators for evaluation in indigenous environments. The germplasm is evaluated under the local production system (fertilizer, tillage, plant population, etc.) and agronomic and yield data collected.

For insects important in LDCs but not in the U.S., an array of germplasm is provided to the LDC cooperator. The germplasm is evaluated for resistance to the specific insect by the cooperator. Based upon experimental results crosses are made to produce relevant populations for inheritance and entomological studies. These populations are provided to the cooperator for further evaluation. For studies on head bug resistance using biotechnology, segregating populations will be grown in Mali and the U.S. with tissue samples collected for analysis in the U.S.

For soil toxicity research, diverse cultivars from the breeding programs at Lubbock and introductions from LDCs are evaluated in field nurseries at Cinzana, Mali. Lines which show promise are selected for further evaluation. When possible crosses will be made between soil toxicity resistant sorghums and other elite genotypes to combine the trait into genotypes suitable for use in the local production system.

Research Findings

Research to broaden the genetic base of the sorghum midge resistance breeding program, to incorporate additional sources of resistance into elite lines, to identify new superior R-lines, and to identify new A-lines with excellent resistance and yield potential continued. Significant progress has been made in improving the agronomic eliteness of sorghum midge resistant germplasm, and in improving the yield potential of experimental A-lines.

To evaluate introductions, breeding lines, and hybrids sorghum midge resistant tests are grown at three locations under high (Corpus Christi), moderate (College Station) and low (Tifton, GA) sorghum midge density. Lines and hybrids that perform well under high midge density will generally perform well under moderate/low midge density. However, lines that perform well under moderate/low midge density may not perform well under high midge density.

Ninety-six lines were evaluated in the Midge Line Test for resistance to sorghum midge and agronomic desirability, Table 1. Included in the test were four susceptible and nine resistant checks, ten introductions from other research programs, and 83 experimental breeding lines. The most resistant check, Tx2880, was not significantly more damaged than the most resistant entries. PM12713, an introduction from ICRISAT, had an excellent midge damage rating (2.3) although its later maturity (72 days) may have resulted in fewer sorghum midges at anthesis. Forty-seven experimental entries were selected for additional evaluation. Seventeen experimental B-lines, designated B94, were evaluated for the first time in the replicated trial. Eleven were selected for subsequent evaluation. The lines have been sterilized (A1 cytoplasm) and are also in evaluation as A-lines (females) in hybrids. New A/B-line pairs, designated MB104-91NF6, MB110-B92NF3 and MB110-B93NF6, in increase for release again exhibited excellent resistance. Each was significantly less damaged than Tx2755 (resistant check) under high population density and similar at low density. The resistance source for each line is TAM2566. TAM2566 originated as SC175-9 , a partially converted zera zera (IS12666) from Ethiopia. Hybrid combining ability of the lines for yield potential and sorghum midge resistance has been studied for three years and each has excellent resistance and yield potential as a hybrid parent. A major constraint to production and use of sorghum midge resistant hybrids has been the lack of superior A-lines which possess excellent resistance and grain yield potential under pest infestation, and excellent grain yield potential in the absence of the pest. These lines possess the needed characteristics to make a significant advance in A-line breeding material and could make a potentially major contribution to use of sorghum midge resistant hybrids.

Grain yield, midge damage rating, and days to 50% anthesis for some entries in the Midge Hybrid Test are shown in Table 2. The standard resistant hybrid check is ATx2755*Tx2767 and the standard susceptible check is ATx2752*Tx430. Most experimental hybrids produced significantly more grain than the susceptible checks within and over locations. Additionally, several experimental hybrids produced significantly more grain than the resistant checks. Differences between hybrids were greater at Corpus Christi under high pest density. While the differences were not as large under moderate density (at College Station) the experimental hybrids still expressed better yield potential and resistance than previously available resistant hybrids or susceptible checks. Differences at College Station under

Table 1. Midge damage rating and days to 50% anthesis of selected entries in the Midge Line Test, 1995.

	Midge Damage Rating†			Anthesis		
	Corpus Christi	College Station	Georgia	Corpus Christi	College Station	Georgia
Tx3042	9.0	7.7	3.0	58.3	65.3	59.0
Tx430	9.0	5.7	2.3	65.0	68.7	69.7
Tx2801	9.0	2.7	1.7	66.3	69.0	70.3
Tx378	8.7	6.3	1.3	65.0	69.7	61.7
Tx623	8.7	5.7	1.0	65.0	68.3	68.0
Texas Blackhull Kafir/FC8962/ASA No. 15	8.3	4.0	1.0	66.0	66.0	70.3
BQL40	8.0	7.0	5.0	65.3	70.7	67.0
BQL41	8.0	3.0	2.0	65.0	68.7	69.7
(MR112-90M5*R8505)-CM8-SM1	8.0	2.7	2.7	72.0	83.0	74.3
Spur Feterita	8.0	3.0	2.0	63.3	63.7	67.7
Standard Yellow Milo/PI24960/ASA No. 25	8.0	6.3	1.7	59.7	71.0	66.7
B94NF9 (MB110-1-)	7.7	2.0	1.3	63.0	72.0	67.7
B94NF12 (MB110-11-)	7.7	2.3	1.7	60.3	65.7	66.0
B52230-2	7.3	4.0	3.3	61.0	66.3	65.7
94ML34/(MB110-21-L1-BM2-CC1*Tx623)	7.3	2.3	1.3	69.7	73.7	69.0
Tx2767	6.7	2.3	3.3	68.7	72.3	74.7
MB108B	6.7	1.0	1.7	70.7	73.0	72.3
TAM2566	6.7	2.7	1.3	61.0	62.3	63.0
(86E0362*MR106-1/Tx2883)-SM6-CM1-SMBK	6.7	2.0	2.7	68.0	76.3	71.3
94ML51/(Tx2872*Tx2876)-BM13-CM2-SM2	6.7	2.7	1.7	68.0	75.3	69.0
94ML72/(MB108B/P.G.*MB116A-BM10-CS1-CS2-SMB	6.7	1.0	1.0	69.7	74.7	70.7
(MB108B/P.G.*MB116A-BM10-CS1-CS2-SMBK)	6.7	1.7	1.0	69.3	75.7	70.0
(Tx2882*6E0374)-SM11-SM1	6.7	1.7	1.0	71.0	76.3	74.0
(MR112-90M5*R8505)-SM9-SM1	6.7	2.0	1.0	61.7	69.7	65.7
ICSV745	6.3	6.3	4.3	72.0	75.7	75.0
(Tx2882*6E0374)-SM11-SM2	6.3	1.7	1.0	70.0	73.7	70.0
Tx2755	6.0	2.7	1.3	63.0	69.0	67.3
94ML70/(PM12713*Tx2767)-CM1-LMBK-CMBK	6.0	1.7	1.3	72.0	74.3	76.3
(MR112-90M5*R8505)-CM7-CM1	6.0	1.7	1.0	65.7	70.0	68.7
R90562-1	5.7	4.0	3.0	63.7	69.7	70.7
(Tx2782*Tx2878)-BM28-LMBK-CMBK	5.7	2.0	2.3	69.0	80.0	77.7
94ML64/(MR114-90M11*Tx2767)-SM8-SM1	5.7	1.3	1.0	70.0	68.7	67.3
94ML31/(Tx2782*Tx2876)-BM13-CM2-SMBK	5.7	2.3	2.3	69.0	74.7	68.7
B94NF10 (MB110-1-)	5.3	1.3	1.7	64.0	69.3	67.7
B94NF11 (MB110-1-)	5.3	1.3	1.3	64.7	70.7	67.3
(Tx2782*Tx2878)-BM40-CM2-CM1	5.3	2.3	1.7	65.7	73.3	71.3
94ML56/(Tx2872*Tx2880)-SM10-SM2	5.3	1.3	1.3	65.0	72.3	70.3
94ML61/(Tx2887*Tx2890)-BM2-LMBK-SM1	5.3	1.3	1.0	63.7	69.3	65.7
94ML71/(MB108B/P.G.*MB110-49-B2-CC2-CC1-LMB	5.3	2.3	2.0	63.7	67.7	63.3
((SC62-14*Tx2782)-B12=CC1-CC1*Tx2878)	5.3	2.0	1.0	68.3	74.7	68.7
B94NF1 (MB104-11-)	5.0	1.0	2.3	62.7	68.0	65.7
B94NF4 (MB104-11-)	5.0	2.3	1.3	64.0	67.7	66.7
B94NF5 (MB109-1-)	5.0	2.0	1.3	66.0	71.0	65.0
(86EO362*MR103-3/Tx2880)-SM8-CM1-CM2	5.0	2.7	1.3	64.0	78.0	70.3
Tx2883	4.7	1.0	1.3	69.0	71.3	71.0
B86815-1-3-CCBK-	4.7	2.3	1.3	62.7	75.0	72.7
MB104-B9INF6	4.7	3.0	1.7	61.7	65.0	66.0
B94NF2 (MB104-11-)	4.7	2.3	1.0	63.3	65.0	65.3
(86EO362*MR103-3/Tx2880)-SM8-CM1-CM1	4.7	2.0	1.0	64.0	75.3	73.0
(((Tx2767*SC693-14)-B6-L1-BM1-CC1)*Tx2872)	4.7	1.0	1.7	65.0	75.0	68.7
(MR118-90M12*Tx2882)-BM8-CM1-SM2	4.7	1.0	1.3	66.0	72.0	68.0
(MR118-3-R2-CC2-CS1-CS1-SM1*Tx2882)-SM15-SM	4.7	2.0	1.3	67.0	76.0	69.7
BQL39	4.3	3.0	1.7	62.0	68.3	67.7
BQL38	4.3	3.0	1.3	61.3	67.0	64.3
IS6919C/SC846-14E/ZZ (Dur original class)	4.3	1.7	1.0	68.0	73.7	65.3
MB110-B92NF3	4.3	1.3	1.0	65.0	67.7	66.7
(MR114-90M11*Tx2880)-SM5-LMBK-SM2	4.3	1.7	1.0	66.0	71.7	71.7
(PM11344*Tx2767)-BM7-LMBK-CM1-CMBK	4.3	1.0	1.0	64.7	72.0	68.7
(MB108B/P.G.*MB110-49-B2-CC2-CC1-LMBK)	4.3	1.0	1.3	66.0	73.3	71.0
(MR118-R2-CC2-CS1-SM1*Tx2872)	4.3	1.0	1.0	68.3	73.0	67.7
(((MB108B)-7-1-L2-BM1-LM1-CCBK)*Tx2782)	4.3	1.3	1.7	64.7	70.7	69.0
B94NF6 (MB110-1-)	4.0	1.7	1.0	66.7	71.0	70.7
B94NF13 (MB110-11-)	4.0	1.7	1.3	60.7	64.0	64.3
B94NF15 (MB110-11-)	4.0	2.0	1.7	60.3	66.0	64.0
B94NF16 (MB110-11-)	4.0	1.7	1.7	61.0	66.0	67.3
94ML43/(((Tx2767*SC693-14)-B6-L1-BM1-BM1)*T	4.0	1.3	1.3	68.0	71.7	70.3
94ML57/(Tx2880*Tx2882)-BM1-LMBK-SM1	4.0	1.0	1.0	62.7	71.3	68.7
94ML66/(MR114-90M11*6EO361/(R5646*SC326-6))	4.0	3.0	3.0	71.3	74.0	71.3

Table 1. Continued

Pedigree	Midge damage rating†			Anthesis		
	Corpus Christi	College Station	Georgia	Corpus Christi	College Station	Georgia
94ML68/((SC228-14*Tx2767)-2-B2-BM2-LM2*Tx28	4.0	1.3	1.0	66.7	74.3	64.7
(PM11344*Tx2782)-CS24-LMBK-CM2-CM2	4.0	1.3	2.0	72.0	83.3	82.3
((SC62-14*Tx2782)-B12-CC1-CC1*Tx2878)	4.0	1.3	1.0	62.7	68.0	65.3
Tx2882	3.7	1.7	1.0	69.3	73.0	71.7
MR112B-92M4	3.7	2.0	1.3	60.7	67.0	65.7
MB104-B92NF9	3.7	2.3	1.3	61.3	64.0	62.0
MB110-B93NF6	3.7	2.3	1.3	61.0	65.7	64.7
94M2/94ML32	3.7	1.3	1.0	65.0	68.3	65.3
B94NF3 (MB104-11-)	3.7	2.0	1.0	61.7	64.7	66.7
B94NF8 (MB110-1-)	3.7	3.0	1.3	71.0	74.3	70.3
B94NF17 (MB110-11-)	3.7	2.3	2.3	61.0	67.0	66.0
(Tx2880*Tx2882)-BM1-CM1-CM1	3.7	1.0	1.0	62.3	69.7	68.7
(((MB108B)-7-1-L2-BM1-LM1-CCBK)*Tx2782)	3.7	1.0	1.0	62.7	72.3	71.3
((IS12573C*PHYR)-15-5-1-1-2-1-1*Tx2766)	3.7	1.7	2.0	63.7	69.0	68.7
Tx2782	3.3	2.0	1.0	61.7	67.3	68.3
94M1/94ML31	3.3	1.0	1.0	68.0	83.0	74.0
94ML69/(PM12713*Tx2766)-CM2-CM1-CMBK	3.3	1.0	1.0	69.7	75.3	71.3
(((SC572-14*SC642-14)-B17-L1-CC1-CC1)*Tx287	3.3	1.0	1.0	63.3	70.0	67.0
(Tx430*Tx2872)-BM3-CM2	3.3	1.7	1.0	62.0	66.3	66.0
(Tx2880*SC170-6-17)-SM10-CM2-SM1	3.3	1.0	1.0	64.0	68.7	66.3
Tx2880	2.7	2.0	1.0	60.3	64.7	68.0
((SC62-14*Tx2782)-B12-CC1-CC1*Tx2878)	2.7	1.7	1.0	62.7	71.3	67.0
(Tx2880*SC170-6-17)-SM15-CM1-CM1	2.7	1.0	1.0	62.0	68.7	67.7
PM12713	2.3	1.0	1.7	72.0	78.3	78.0
MR114-90M11	2.3	2.3	1.7	60.3	63.3	63.0
$LSD_{.05}$	1.2	0.9	1.0			

† Based on a scale of 1 = 0 - 10% blasted kernels, 2 = 11 - 20% blasted kernels, up to 9 = +81% blasted kernels.

Table 2. Mean grain yield, midge damage rating and days to 50% anthesis of selected entries in the Midge Hybrid Test, 1996.

Sorghum hybrid	Resistance	Grain yield (kg/ha)			Midge damage rating†			Days to 50% anthesis		
		Corpus Christi	College Station	Mean	Corpus Christi	College Station	Mean	Corpus Christi	College Station	Mean
A94-6(MB110-1)*Tx2880	R‡ * R	4527	5397	5188	2.7	1.3	2.0	62	62	62
A94-14(MB110-11)*Tx2767	R * R	4375	5120	4966	2.7	1.0	1.8	62	63	62
A91-6(MB104)*Tx2767	R * R	4140	5319	4936	4.0	1.3	2.7	63	62	62
A94-13(MB110-11)*Tx2880	R * R	4350	4537	4660	3.0	1.7	2.3	58	61	60
A94-14(MB110-11)*Tx2882	R * R	4024	4862	4644	3.3	2.0	2.7	60	61	60
ATx2755*Tx2767	R * R CK	3689	5186	4622	4.0	2.0	3.0	63	64	64
A92-3(MB110)*Tx2880	R * R	3876	4965	4614	3.3	1.3	2.3	61	63	62
A93-6(MB110)*Tx2767	R * R	4285	4481	4597	2.7	1.7	2.2	62	63	62
A94-13(MB110-11)*Tx2882	R * R	4488	4245	4590	3.3	2.3	2.8	62	63	62
A93-6(MB110)*Tx2882	R * R	3722	5012	4553	3.0	2.0	2.5	60	62	61
A92-3(MB110)*Tx2882	R * R	3756	4932	4532	3.7	1.7	2.7	62	63	63
A91-6(MB104*Tx2880	R * R	3585	5048	4496	3.7	1.7	2.7	65	62	63
A91-6(MB104)*Tx2882	R * R	3242	5404	4485	3.0	2.0	2.5	60	62	61
ATx2755*Tx430	R * S CK	3394	5206	4470	3.7	2.7	3.2	60	62	61
A94-13(MB110-11)*Tx2767	R * R	3910	4634	4467	3.0	2.0	2.5	62	63	62
A92-3(MB110)*Tx2767	R * R	3484	4869	4351	4.0	1.3	2.7	64	64	64
A94-7(MB110-1)*Tx2767	R * R	3136	5245	4347	4.0	1.0	2.5	65	67	66
A94-7(MB110-1)*Tx2882	R * R	3970	3905	4136	3.0	1.0	2.0	63	64	64
ATx2775*Tx2880	R * R CK	4155	3480	4025	3.3	1.3	2.3	59	61	60
ATx2801*Tx430	R * R CK	2431	5195	3934	6.0	3.3	4.7	63	63	63
A93-6(MB110)*Tx2880	R * R CK	3179	3991	3744	4.0	3.0	3.5	60	62	61
ATx2801*Tx2767	R * R	1165	5488	3385	7.7	2.0	4.8	64	65	65
A1*Tx2864	S‡ * S CK	2215	3944	3190	6.3	3.7	5.0	63	65	64
ATx2752*Tx430	S * S CK	1157	3160	2216	8.7	7.3	8.0	62	63	62
ATx3042*Tx2737	S * S CK	360	3115	1756	8.7	6.7	7.7	60	59	60
ATx399*Tx430	S * S CK	970	1740	1403	9.0	7.0	8.0	60	64	62
Mean		3222	4675	4109	4.5	2.3	3.4	62	63	62
$LDS_{0.05}$		994	1289	1028	1.4	1.0	0.8	2	2	2

† Based on a scale of 1 = 0 - 10% blasted kernels, 2 = 11 - 20% blasted kernels, upt to 9 = +81% blasted kernels.
‡ R = Resistant, S = Susceptible, CK = check.

moderate pest density represent grain yield potential under conditions more likely to be encountered in producers fields.

Hybrids with an A-line designation of 'A94-' were evaluated for the first time. Several produced excellent hybrids including four of the top five yielding hybrids. Hybrids produced on A-lines scheduled for release again performed outstanding and were significantly better that all susceptible checks. Hybrid seed of A93-6*Tx2880 and A93-6*Tx2882 was produced in a commercial type production plot during 1995 and distributed to commercial seed companies and extension personnel for wide evaluation during 1996. Data from this test confirmed conclusions from previous years that the three lines selected for release possess excellent yield potential and resistance under high population density. Under moderate pest density the lines also expressed yield potential significantly greater than that of resistant or susceptible checks.

Eighty-five lines from the Sudan collection were planted in a two replication trial at Corpus Christi and 190 entries in an observation trial at College Station to evaluate genotypes for resistance to sorghum midge. The College Station trial was not rated due to low midge density which prevented identification of lines with a high level of resistance. Data (days to 50% anthesis and midge damage rating) from the Corpus Christi test are shown in Table 3. Although many experimental entries flowered in an acceptable time (60-65 days for sorghum midge resistant germplasm) frame, nearly all of the lines were very susceptible to sorghum midge. Based upon the data it was concluded that while several lines have a low level of resistance no useful sources of resistance are apparent in this group of entries. Thirteen lines from the Sudan collection were planted for observation in 1996.

Table 3. Evaluation of lines from the Sudan collection for resistance to sorghum midge at Corpus Christi, 1995.

Sudan No.	NSSL No.	IS No.	Anthesis	Midge damage†
	Tx378		65.0	9.0
	Tx3042		58.3	9.0
	Tx623		65.0	9.0
	Tx430		65.0	9.0
SU3	PI562735	IS921	75.0	9.0
SU5	PI571012	IS923	55.0	9.0
SU11	PI570733	IS930	52.0	9.0
SU27	PI571364	IS950	56.0	9.0
SU101D	PI217768	IS2336	61.0	9.0
SU101	PI217768	IS2336	65.0	9.0
SU113	PI570828	IS3069	61.0	9.0
SU116	PI571004	IS3072	65.0	9.0
SU180	PI570735	IS3505	60.0	9.0
SU260	PI570860	IS3604	61.0	9.0
SU418	PI570821	IS7067	65.0	9.0
SU421	PI562942	IS7070	65.0	9.0
SU443	PI571026	IS8701	61.0	9.0
SU448	PI563146	IS8799	65.0	9.0
SU451	PI563236	IS9227	65.0	9.0
SU471	PI571046	IS9616	60.0	9.0
SU506	PI571080	IS9653	60.0	9.0
SU578	PI571143	IS9730	65.0	9.0
SU581	PI571146	IS9733	65.0	9.0
SU636	PI571195	IS9789	60.0	9.0

Table 3. Continued

SU667	PI571224	IS9823	62.0	9.0
SU723	PI571272	IS9884	57.0	9.0
SU826	PI563494	IS12448		9.0
SU856	PI569007	IS14449	51.0	9.0
SU862	PI569010	IS14465	62.0	9.0
SU884	PI569026	IS19002	62.0	9.0
SU888	PI569030	IS19006	66.0	9.0
SU902	PI569044	IS19020	70.0	9.0
SU904	PI569046	IS19022	70.0	9.0
SU911	PI569053	IS19029	59.0	9.0
SU943	PI569085	IS19061	66.0	9.0
SU945	PI569087	IS19063	66.0	9.0
SU948	PI569090	IS19066	70.0	9.0
SU949	PI569091	IS19067	66.0	9.0
SU1008	PI569150	IS19126	66.0	9.0
SU1017	PI569159	IS19135	62.0	9.0
SU1023	PI569165	IS19141	59.0	9.0
SU1038	PI569180	IS19157	62.0	9.0
SU1049	PI569191	IS19168	62.0	9.0
SU1145	PI569287	IS19265	59.0	9.0
SU1195	PI569337	IS19315	66.0	9.0
SU1198	PI569340	IS19318	66.0	9.0
SU1231	PI569373	IS19352	59.0	9.0
SU1245	PI569387	IS19366	64.0	9.0
SU1328	PI569469	IS19534	60.0	9.0
SU1343	PI569482	IS19549	56.0	9.0
SU1352	PI569491	IS19558	60.0	9.0
SU1353	PI569492	IS19559	65.0	9.0
SU1383	PI569522	IS19589	64.0	9.0
SU1404	PI569543	IS19611	56.0	9.0
SU1412	PI569551	IS19620	56.0	9.0
SU1417	PI569556	IS19625	64.0	9.0
SU1424	PI569563	IS19632	60.0	9.0
SU1444	PI569583	IS19652	60.0	9.0
SU1533	PI569672	IS20585	65.0	9.0
SU1583	PI569722	IS21749	60.0	9.0
SU1594	PI569733	IS21760	70.0	9.0
SU1607	PI569746	IS21773	65.0	9.0
SU1631	PI569769	IS21797	66.0	9.0
SU1634	PI569772	IS21800	60.0	9.0
SU1668	PI569806	IS22360	56.0	9.0
SU1715	PI569853	IS22407	52.0	9.0
SU1994	PI570132	IS22910	52.0	9.0
SU35	PI571380	IS1324	42.0	8.5
SU405	PI570816	IS7051	65.0	8.5
SU529	PI569002	IS9677	65.0	8.5
SU643	PI571202	IS9797	60.0	8.5
SU1534	PI569673	IS20586	65.0	8.5
	Tx2755		63.0	8.0
	TAM2566		61.0	8.0
SU233	PI570784	IS3568	51.0	8.0
SU502	PI571077	IS9649	56.0	8.0
SU806	PI571343	IS9983	65.0	8.0
SU1060	PI569202	IS19179	66.0	8.0
SU1587	PI569726	IS21753	65.0	8.0
SU1672	PI569810	IS22364	65.0	8.0
SU2650	PI568360		48.0	8.0
SU460	PI563259	IS9283	56.0	7.5
SU979	PI569121	IS19097	53.0	7.5
SU320	PI570789	IS6954	61.0	7.0
	Tx2767		68.7	6.0
SU391	PI570807	IS7035	61.0	6.0
SU53	PI217718	IS2294	58.0	5.5
SU91	PI217768	IS2336	65.0	5.5
	Tx2782		61.7	5.0
SU900	PI569042	IS19018	62.0	5.0
	Tx2880		60.3	3.5
$LSD_{.05}$				0.6

† Based on a scale of 1 = 10% blasted kernels, 2 = 11-20% blasted kernels, up to 9 = 81%+ blasted kernels.

These lines were included in a test with many partially converted (F_2 generation) selections of lines phenotypically similar to AF28 that were identified in the Sudan collection.

Selection continued in the development of new germplasm resistant to biotype E or I greenbug. Advanced hybrid trials were conducted to test new R- and A-lines in hybrid combination. Five superior R-lines resistant to biotype E were selected for final pre-release testing. Two of the lines are in a tan plant, white pericarp genetic background with excellent foliar disease resistance. The lines could be useful in developing food type sorghums with improved biotic stress resistance. Selections to develop biotype I resistant lines were made in F_3 populations, and in several backcross generation populations. Initial screening against biotype E and I greenbugs identified several genotypes which contain resistance to both biotypes. Preliminary data led to the conclusion that germplasm should be screened against both biotypes to insure that resistance will be useable in commercial hybrids. Numerous crosses were made to introgress the resistance gene(s) into an array of elite germplasm.

Research continued to introgress genes for resistance to yellow sugarcane into elite adapted material. Selections were made in F_3 populations to combine the PI457709 yellow sugarcane aphid resistance gene with biotype E greenbug resistance. The selections will be screened against both biotype E greenbug and yellow sugarcane aphid. F_2 progeny derived from PI453951 were selected. Due to the high photoperiod sensitivity of PI453951 selection was primarily for types which are short and will flower in a temperate environment. Germplasm from the yellow sugarcane aphid breeding program was planted at a Beeville, TX nursery site to determine the ability to evaluate for resistance in a field environment. The nursery site was lost due to drought and will be repeated in 1997.

Populations were grown to provide additional genetic material to map the greenbug resistance genes using RFLPs. Preliminary data indicate that segregation will be found for resistance to both biotypes, and that progeny should be screened against both biotypes to insure recovery of resistance. Molecular markers have been identified for the biotype E resistance gene in Tx2783 (derived from Capbam), and segregating populations are in evaluation for biotype C resistance. Molecular markers have also been identified for the biotype E and/or I resistance genes in PI550607. Research is on-going to identify moleculars of use in the resistance source PI550610. Two F_2 populations, Tx2737*Tx623 and Tx2752*Tx623 were grown in the Puerto Rico winter nursery to develop F_3 populations of use in identifying molecular markers for resistance to biotype C. The goal of this research is to identify markers for the five major sources of resistance to the three greenbug biotypes. Significant progress has been made in accomplishing this objective.

A 46 entry paired plot screening nursery for soil toxicity was grown on the Cinzana Experiment Station at a previously selected site. The research was a continuation of activity previously conducted jointly with the Soil Management CRSP. Bagoba was used as the resistant check and Malisor 84-5 was used as the susceptible check. The nursery was evaluated in October, 1995. The site provides an extremely harsh environment in which to evaluate sorghum for resistance to the soil toxicity problem. Without a cover crop to break the toxicity cycle stands were very poor and no useable data was collected. Malian collaborators want to continue the study another year. It has been suggested that the screening trial be planted in a Cinzana nursery site with less toxicity problems, and that a legume cover crop be planted on the original nursery site as preparation for the 1997 season.

Breeding lines were grown at Lubbock to initiate development of populations to use in the study of head bug resistance in sorghum. Populations will be sent to Mali to classify the genotypes for resistance. Molecular marker techniques will be used to identify resistant genotypes when appropriate.

Approximately 467 hybrids of germplasm from the Sudan sorghum collection crossed to U.S. A-lines (A1 cytoplasm) were grown at Lubbock to classify the lines for fertility restoration. Data will be provided to the USDA Sorghum Curator. Selections were made in F_2 populations from the sorghum conversion program of lines originally from Sudan. The lines were entered into the conversion program based on a phenotypic appearance similar to AF28, a line with a high level of midge resistance. Most of the lines are probably from southern Sudan and have a more open panicle than typical midge resistance sources. The selections were planted at three locations in Texas (Corpus Christi, College Station, and Lubbock) to evaluate for midge resistance and agronomic type.

Networking Activities

Workshops

Participated in the ASA/CSSA/SSSA Annual Meeting Oct. 29-Nov. 3, 1995 at St. Louis, MO.

Served as breeding/genetics field tour speaker to discuss the Texas A&M University sorghum midge resistance breeding program at the 3rd Australian Sorghum Conference and Tour, Feb. 20-24, Tamworth, NSW and Southern Queensland, Australia.

Research Investigator Exchanges

Travel to Mali - Oct. 8-20, 1995. Worked with IER breeding collaborators in use of computer software for breeding program management. Evaluated cooperative IER/INTSORMIL research at Sotuba, Cinzana, Sikasso and Longrolla. Met with ICRISAT/WASIP scientists at

Samanko. Developed future collaborative research plan for research on soil toxicity and resistance to insects.

Travel to Honduras - Nov. 27-Dec. 3, 1995. Evaluated collaborative research at Zamorano, Rapaco, Choluteca and Olancho. Discussed collaborative research program activities with representatives of the Escuela Agricola Panamericana (EAP) and USAID/Honduras.

Travel to Puerto Rico - Jan. 22-27, 1996. Worked with Dr. Jeff Dahlberg (USDA-ARS) and Dr. D.T. Rosenow (TAM-122) to select entries for Sudan Collection Work Group.

Travel to Australia - Feb. 15-29, 1996. Participate in 3rd Australian Sorghum Conference, Feb. 20-22, at Tamworth, NSW. Participate as post-Conference speaker at Farmer Field Days, Feb. 23-24, in Moree, NSW and Dalby, QLD. Discussed collaborative sorghum research with Dr. R.G. Henzell (sorghum breeder) and Dr. B. Franzmann (entomologist) from the Queensland Dept. of Primary Industries, and Dr. H. Sharma (entomologist) from ICRISAT.

Served as host for Dr. H.P. Yadav, Millet Breeder, Haryana Agricultural University, Hisar, India, July-October, 1995. Dr. Yadav studied operation of the multi-disciplinary, multi-location TAES sorghum improvement program.

Served as host for Mr. Jorge Moran, EAP/SRN Honduras, April-May, 1996. Mr. Moran studied the use of computer software in management of a breeding program and organization of planting material using computers and plot planters.

Mr. John Jastor and Mr. John Kruger, Pioneer Hi-Bred Intl., Taft, TX, July 1995.

Dr. Joe Raab, Dekalb Plant Genetics, Robstown, TX, July 1995

Dr. A. Touré, IER, Bamako, Mali

Dr. G. Thomas, Asgrow Seed Company, September, 1995

Dr. Jeff Dahlberg, USDA-ARS, Mayaguez, PR, September, 1995

Dr. El Hilu Omer, ARC, Wad Medani, Sudan, July, 1995.

Participated in Sorghum Crop Germplasm Committee (CGC) meeting Oct. 29, 1995, at St. Louis, MO.

Met with representatives of the Queensland Graingrowers Association to discuss sorghum research at Texas A&M University, June 20, 1996.

Mr. Jack Eberspacher and Mr. Tim Lust, National Grain Sorghum Producers, June 20, 1996.

Germplasm and Research Information Exchange

Germplasm Conservation Use

Accessions from the Sudan collection and the sorghum conversion program were grown for increase and evaluation. Releases from the sorghum conversion program will be deposited in the National Seed Storage Laboratory. Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Mali, Botswana, China, Argentina and Niger. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.

Seed of three A/B-line pairs was planted to increase for release. Seed of one A-line and two previously released R-lines was provided to a private company to produce two sorghum midge resistant hybrids for large scale testing. Hybrid seed was distributed to commercial companies and extension personnel for large scale planting to evaluate agronomic performance of the hybrids.

Cooperator in the release of fifty converted sorghum lines from the sorghum conversion program.

Germplasm previously developed and released by this project is used widely used by commercial seed companies in hybrid seed production. Biotype E greenbug resistant R-lines from this project are widely used in the production of greenbug resistant hybrids.

Provided computer supplies to Malian breeding collaborators. Trained Malian IER breeding collaborators in the use of computer software. Served as host for Dr. H.P. Yadav, Millet Breeder, Haryana Agricultural University, Hisar, India, July-October, 1995. Dr. Yadav studied operation of the multi-disciplinary, multi-location TAES sorghum improvement program. Assistance was given to Mr. Jorge Moran, EAP/SRN Honduras during his study leave at Lubbock. Assistance consisted of research support for the duration of his research program at Lubbock and travel to College Station.

Other Cooperators

Collaboration with the following scientists was important in the activities of TAM-123:

Dr. B.R. Wiseman, Entomologist, Insect Biology and Population Management Research Laboratory, P.O. Box 748, USDA-ARS, Tifton, GA 31793-0748

Dr. J.A. Dahlberg, Sorghum Breeding and Germplasm, Tropical Agriculture Research Station, USDA-ARS, P.O. Box 70, Mayaguez, PR 00681-3435

Dr. C.S. Manthe, Ministry of Agriculture, Department of Agricultural Research, Private Bag 033, Gaborone, Botswana

Dr. R.G. Henzell, Sorghum Breeding, Hermitage Research Station, via Warwick, QLD 4370, Australia

Publications and Presentations

Abstracts

Anderson, R.M., J.W. Jones, B.B. Pendleton, K. Schaefer, G.C. Peterson, and G.L. Teetes. Development of germplasm resistant to sorghum midge. Proc. of the 19th Biennial Grain Sorghum Research and Utilization Conference. Mar. 5-7, 1995. Lubbock, TX. p48.

Peterson, G.C., D.T. Rosenow, D. Pietsch, C.A. Woodfin, and J.W. Jones. 1995. Analysis of sorghum performance data using randomized complete block versus nearest neighbor analysis. Proc. of the 19th Biennial Grain Sorghum Research and Utilization Conference. Mar. 5-7, 1995. Lubbock, TX p48.

Woodfin, C.A., J.W. Jones, D.T. Rosenow, and G.C. Peterson. 1995. Leaf burn reaction of sorghum lines to insecticides and chemical defoliants. Proc. of the 19th Biennial Grain Sorghum Research and Utilization Conference. Mar. 5-7, 1995. Lubbock, TX p49.

Peterson, G.C., D.T. Rosenow, J.A. Dahlberg, G. Ejeta, M.A. Mahmoud, and O.I Ibrahim. 1995. Unique sorghums from Sudan. Agronomy Abstracts. Oct. 29-Nov. 3, 1995. St. Louis, MO. p183.

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, and L.E. Clark. 1995. Conversion - An efficient technique to enhance use of exotic germplasm. Agronomy Abstracts. Oct. 29-Nov. 3, 1995. St. Louis, MO. p183.

Refereed Journal

Ervin, R.T., T.M. Khalema, G.C. Peterson, and G.L. Teetes. 1996. Cost/benefit analysis of a sorghum hybrid resistant to sorghum midge (Diptera:Cecidomyiidae). Submitted to Southwestern Entomologist.

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, L.E. Clark, F.R. Miller, A. Sotomayor-Rios, A.J. Hamburger, P. Madera-Torres, A. Quiles-Belen, and C.A. Woodfin. 1996. Registration of fifty converted sorghums from the sorghum conversion program. Crop Sci. (in press).

Rosenow, D.T., J.A. Dahlberg, J.C. Stephens, F.R. Miller, D.K. Barnes, G.C. Peterson, J.W. Johnson, and K.F. Schertz. 1997. Registration of sixty-three converted sorghums from the sorghum conversion program. Crop Sci. (accepted for publication).

Books, Book Chapters and Proceedings

Peterson, G.C., D.T. Rosenow, L.E. Clark, A.J. Hamburger, J.A. Dahlberg and A. Sotomayor-Rios. 1995. Update on the sorghum conversion program. In Proc. of the19th Biennial Grain Sorghum Research and Utilization Conference, Lubbock, TX. Mar. 5-7, 1995. 171p.

Miscellaneous Publications

Pietsch, D., L. Synatschk, D.T. Rosenow, and G.C. Peterson. 1996. 1995 Grain sorghum performance tests in Texas. Dep. of Soil and Crop Sci. Technical Report No. 96-2. 106p.

Breeding Pearl Millet and Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-118
David J. Andrews
University of Nebraska

Principal Investigator

Professor David J. Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE 68583-0915

Collaborating Scientists

Dr. Chris Manthe, Cereals Coordinator, and Mr. Peter Setimela, Sorghum Breeder, Department of Agricultural Research, P.O. Box 0033, Sebele, Botswana
Mr. M. Mogorosi, Millet Breeder, DAR, Maun, Botswana
Mr. Issoufou Kapran, INRAN, B.P. 429, Niamey, Niger
Mr. Amadou Fofana, Millet Breeder, CNRA, BP 51, Bambey, Senegal
Mr. W.R. Lechner, Chief Scientific Officer and S.A. Ipinge, Millet Breeder, Ministry of Agriculture, Water and Rural Development, P.O. Box 144, Oshakati, Namibia
Drs. T. Hash and K.N. Rai, Millet Breeders, J.W. Stenhouse and Belum Reddy, Sorghum Breeders, ICRISAT, Patancheru P.O. AP 502 325, India
Dr. Anand Kumar, Millet Breeder, ICRISAT, Sahelian Center, BP 12.404, Niamey, Niger
Dr. J.D. Axtell, Sorghum Breeder, PRF-103, Department of Agronomy, Purdue University, West Lafayette, IN 47907
Dr. Lloyd W. Rooney, Cereal Chemist, TAM-126, Department of Food Science, Texas A&M University, College Station, TX 77843
Drs. G.W. Burton and W.W. Hanna, Geneticists, USDA/ARS, Coastal Plain Exp. Station, P.O. Box 748, Tifton, GA 31793
Professor W.M. Stegmeier, Millet Breeder, KSU-101, Department of Agronomy, Kansas State University, Hays, KS 67601
Drs. J.W. Maranville, Cereal Physiologist, UNL-114, and S.C. Mason, Cereal Agronomist, UNL-113, Department of Agronomy, University of Nebraska, Lincoln, NE 68583
Dr. D.T. Rosenow, Sorghum Breeder, TAM-122, Texas A&M University, Lubbock, TX 79401.
Dr. Paula Bramel-Cox, Sorghum Breeder, Kansas State University, Manhattan, KS 66502.

Summary

Sorghum and pearl millet are the major traditional cereal crops on which millions of people are dependent in extensive drought prone areas of low-resource agriculture in Africa and the Indian sub-continent. These two cereals are the best adapted to most reliably produce food in the unpredictable conditions of erratic rainfall, low soil fertility and numerous pests and diseases. In such conditions, agronomic interventions such as the use of chemical fertilizers have dramatic effects but their costs and the risks involved are too high for small farmers. Seed of new cultivars is a highly cost effective technology even without agronomic support, but they are more effective with and encourage the use of other agronomic interventions. Where production increases have been obtained in low resource conditions, they have always been dependent on new cultivars. Plant breeding is therefore the key, and the catalyst to improving food production in Africa, and has already done so in India.

Sorghum is widely used as a grain feed in intensive agriculture, in north and south America, southern Europe, South Africa and Australia, with consequent high levels of breeding research, some results of which can be modified and used in research in developing countries. The situation is different for pearl millet, which so far has only been utilized as a forage crop in intensive agriculture. However, pearl millet has a more nutritious grain than sorghum, and so has the potential to become a high yielding feed grain with a somewhat different adaptation pattern than sorghum. It has frequently been shown in India that pearl millet hybrids can produce five tons of grain/ha in three months, and the same yield has been obtained on a field scale in Kansas.

The goals of this project are several: to develop parental material of higher yielding ability that can be used in collaborative breeding programs in developing countries; in the U.S. to increase the genetic diversity in sorghum and to produce the adapted plant type needed to grow pearl millet as a combine feed crop; and to provide students thesis topics

from the on-going research which are relevant to the problems they will face in their research programs at home.

Collaborative breeding with pearl millet was continued in Senegal and Namibia, the latter with the assistance of the SADC/ICRISAT Sorghum and Millet Improvement Program at Matopos, Zimbabwe. Collaborative breeding in sorghum in Botswana is also done with the participation of the SADC/ICRISAT program. Breeding material and information, mostly on pearl millet, is routinely exchanged with the ICRISAT programs in India and the West African center in Niger. Sorghum germplasm is exchanged with several African breeding programs.

In the U.S., both applied and basic research is conducted on both crops. In pearl millet applied research is principally centered on developing hybrid parents which show high levels of heterosis, lodging resistance and early maturity. Basic research is conducted on exploring the usefulness of the new A_4 cytoplasmic male sterility system, which appears to offer advantages in breeding and producing hybrids both in the U.S. and tropical areas. The main thrust of the sorghum program is to introgress new high yielding tropically bred food sorghums into U.S. grain sorghums and also use the resulting early generation segregating populations for selection in Botswana. Three sorghum seed parents have been released in the U.S., and eight more are ready for release. Three pearl millet seed parents and three restorer parents will be released in 1996. There is also collaboration with the Kansas State sorghum breeding program at Manhattan, Kansas, which is accessing new genetic variability from wild sorghums not previously available in the U.S. How to identify combining ability (heterosis) early in the selection process forms the basic research area in sorghum.

Objectives, Production and Utilization Constraints

Objectives

The objectives of the breeding programs with slight modifications remain as in previous years. The following objectives apply to both crops.

To establish a diverse base of agronomically elite inbred and semi-inbred lines from crosses between U.S. stocks (including proven project stocks) and introduced tropically adapted breeders germplasm. The establishment of such a base of diversity with yield potential is fundamental to applied collaboration on genetic improvement in the long term, where populations from specific crosses between superior project parents and collaborating country stocks will be selected in that country. It also permits hypotheses to be tested about the relative potential of various types of varieties and hybrids and parental breeding procedures and also enables the identification of parents to make hybrids adapted to the U.S.

Training LDC personnel in plant breeding and genetics is an important objective. The above breeding approach provides opportunities and material for post-graduate student theses.

Pearl Millet Objectives

Because of its numerous advantages emphasis is being given to development of both seed parents and restorers in the A_4 cytoplasmic male sterile system, and to investigating its various attributes.

Selection for atrazine/propachlor herbicide tolerance, since pearl millet is sensitive to most sorghum herbicides.

Assessing the adaptation of experimental millet hybrids in the U.S. with sorghum checks through the coordination of a regional testing program.

Sorghum Objectives

A principal selection criteria in breeding hybrid parents for any production environment is combining ability (i.e., the capability of the line to make high yielding hybrids). The choice of the tester(s) used to determine this capability is critical, particularly for seed parents. Research is being conducted to see which type of tester might be best.

Constraints to pearl millet and sorghum production are both genetic and physical factors in the growing environment and the effects of fragile indigenous food grain markets. In low resource semi-arid (LRSA) conditions in Africa and Asia there are many environmental constraints to production, the principal of which are low nutrient levels, a variable and uncertain moisture supply and many severe pests and diseases. Actual production is the interaction of these constraints on the genetic yield potential (the comparative yielding ability) of the cultivar. The tolerance of the genotype to the sum of these constraints constitutes adaptation. Good adaptation alone, however, is not enough, since yield potential has to be raised to increase production. Though some constraints are more common than others, there are different combinations of constraints in different regions, and hence there are different areas of adaptation which need to be bred for separately. Many existing landrace varieties, though they are well adapted to low moisture and fertility situations and to numerous pests and diseases, are not efficient in converting the dry matter they produce into grain. Their biomass production may be good but their harvest index (HI) efficiency is poor. There are breeding stocks which are twice as efficient in this process but they generally perform poorly in African conditions because they have little adaptation or pest/disease resistance. A combination of traits conferring adaptation, growth rate, and grain production efficiency is required through breeding, as well as further improvement in basic breeding stocks (particularly seed parents) for grain yield potential per se. Combinations (lines/plants) with good adaptation qualities can only be identified *in situ* in developing countries. Thus, segregating material generated from crosses with stocks known to perform well in the region concerned, to selected

high HI lines, are developed for selection in collaborative projects. For sorghum, many cultivars from ICRISAT's breeding programs, while they have raised yield potentials in many LRSA regions, have not, in general, involved much of the high yield potential available from U.S. combine sorghum parents. In turn the genetic base of hybrid parents in the U.S. is very narrow in terms of the total range of genetic diversity available. There is a fertile breeding area, therefore, that this project seeks to exploit, of crossing higher yielding adapted food quality tropical sorghums and U.S. parents. The resulting segregating populations are selected *in situ* in collaborative LRSA breeding programs to the benefit of developing countries, and segregates from the same crosses are selected for adaptation and combining ability in the U.S. to broaden the genetic diversity in parental lines in the U.S.

The selection criteria used in developing improved basic breeding stocks are numerous and involve morphological and physiological traits and estimates of genetic combining ability for performance. Principal morphological traits involve determinants of seed number/m^2 and seed size. Performance data under moisture stress and lower soil fertility are needed. Both specific and general combining ability estimates are needed. These are principally thought of in the context of hybrid parent development (for pollen and seed parents, respectively), but these estimates are also of use in identifying parents for pearl millet varieties (synthetics), and possibly for indicating parental worth, which is important in generating collaborative material for selection.

Hybrids use growth resources, particularly when they are in short supply, most efficiently. While varieties in pearl millet are internally heterotic, higher yields are given by hybrids, even those where the best variety is used as a parent. Increased yields at the small farmer level, often without other inputs, has been the reason why pearl millet hybrids have been successful in Asia, and provided they are of a stable and durable type, they can also perform in low resource agriculture in Africa. The project, therefore, has been examining aspects of topcross hybrid development and production with this use in mind.

Research Approach and Project Output

Research Methods

The general approach for both crops is to create diversity by crossing high yielding U.S. stocks with new germplasm from developing countries or ICRISAT (and in the case of sorghum, from the Kansas State introgression program). This diversity is then used in collaborative breeding projects in host countries to select for per se adaptation, and also in the U.S. to incorporate new genetic diversity into lines for release. In both crops the principal breeding method is pedigree selection combined with test crosses and hybrid evaluation to select for the parental lines that make the best hybrids Winter nurseries are used to expedite the selection process. In sorghum some selection for host countries is for varieties also. Seed parents are produced in A_1 cytoplasmic male sterile (CMS) cytoplasm in sorghum but both A_1 (Tift $23A_1$ cytoplasm) and increasingly A_4 (monodii cytoplasm) is being used in pearl millet. A_4 male sterility is being transferred into lines derived from a Senegalese long headed dwarf pearl millet variety, IBMV 8401. This will enable A_4 restorer lines and populations to be extracted from adapted varieties in Senegal with the eventual aim of being able to produce top cross hybrids with derivatives of the best varieties as male parents. A similar approach is being used in a collaborative project in Namibia (see SADC region report).

Evidence of stability of performance and adaptation of pearl millet is lacking in the U.S. A regional grain yield test, with entries from UNL (Nebraska), KSU (Kansas) and ARS Tifton (Georgia) is conducted annually at 7-10 locations in seven states as far north as Oregon to provide this information. Pearl millet is sensitive to most sorghum herbicides. While "safening" seed might be possible, genetic resistance to atrazine/propachlor is being obtained through repeated screenings and recurrent selection under high rates of herbicide application.

In sorghum sources of germination and seedling cold tolerance are determined through growth chamber and early field plantings. A food quality B-line population based on ms_7 is being constructed by random mating in isolation. Results of a two year Ph.D. study of Fabien Jeutong, from Cameroon, to compare the effectiveness of various testers to select for combining ability are being analyzed.

Research Results

In pearl millet, 1500 nursery rows at various stages of inbreeding, 750 test crosses and 11 yield trials were planted at Mead, Nebraska. The regional test was planted at 10 locations in 9 states. Additional trials were planted at Tifton, Georgia, and Hays, Kansas. In sorghum, 1250 nursery rows, 260 test crosses and 9 yield trials were planted. Some nurseries and yield trials of early maturing material of both crops intended for western Nebraska, were planted at North Platte, since the Sidney HPAL was too wet to plant in time, but a test at Scottsbluff succeeded. The 1995 season at Mead was characterized by a cold wet spring that delayed planting until June, followed by a hot summer with no effective rainfall until September 22, when a freeze, three weeks early, terminated the growing season. Good differentiation for drought and heat tolerance was obtained in both crops, but normally full season material failed due to the early frost.

In pearl millet, hybrid tests confirmed past year's results in identifying three superior seed parents - 413A, 378-2A and 59022A. Both A_1 and A_4 CMS alternatives have been developed for each of these, which will be released following seed increase in 1996. Similarly, male parents (restoring fertility in the A_1 system) $086R_1$, $58057R_1$, and $60015R_1$ were confirmed for increase. R_4 inbred restorers are still under development but R_4 stocks can be obtained from germplasm NPM-3, released last year.

Results were obtained from five of the regional tests. Mean millet yields ranged from 3.86 t/ha in Georgia to 1.47 t/ha in Kansas. In a date of planting test in Georgia, conducted by W.W. Hanna, mean yields from the early planting (April 12) averaged 6.37 t/ha, but later plantings (May 12 and June 2) gave yields which were reduced by 30 and 46% respectively (Table 1). Contributing reasons were increased moisture stress and disease (rust, leaf blast) on the later plantings, which principally affected seed size.

With funding assistance from the Nebraska Grain Sorghum Board, sorghum test hybrids were grown for 3 years to evaluate the potential of 115 new seed parents, derived from various crosses between U.S. and tropical food quality stocks. Eight seed parents (026A, 373A, 493A, 530A, 585A, 618A, 863A and 9044A) which gave hybrids that equaled or exceeded the yields of the commercial checks were identified for seed increase and release. A further group of 26 seed parents which gave hybrids that were not significantly different from the checks will be released as germplasms. They have the potential to produce good hybrids with other male parents. Testing in western Nebraska, has identified very early maturing hybrid parents for release. These are seed parents 144A and 153A, and male parent 681R. Germination and tolerance testing on a Russian collection and leading project lines identified sources of tolerance in both groups of material. These have been utilized in crosses.

Initial results from combining ability research in sorghum indicate that inbred testers should be chosen with care and are best if they generally give high yielding hybrids. The additional use of an unrelated F_1 tester may improve the early identification of good combiners.

Collaboration was continued and expanded with sorghum breeding at Kansas State University at Manhattan. Nebraska and Kansas grow more than half the sorghum grown in the U.S., and share similar problems and adaptation types. Collaboration consists of joint testing and shared crosses which draw on the complementary genetic diversity of the two programs. In 1995 new seed parents and restorers were identified from the first series of these crosses.

Networking Activities

Conferences/Workshops

PI attended INTSORMIL/ICRISAT/ASARECA East African Regional Workshop in Uganda, November 5-7, 1995.

Kansas and Nebraska Grain Sorghum Boards Annual Conference, Lincoln, Nebraska, September 22, 1995.

Research Investigator Exchanges

Mr. Yang Zhen, from the Sorghum Research Institute, Shenyang, P.R. of China, spent 9 months at UNL as a visiting scientist studying heterosis breeding.

PI visited Uganda, Zimbabwe and Botswana, November 5-20, 1995, and South Africa, Namibia, Botswana and Zimbabwe, March 13 - April 6, 1996.

Germplasm and Research Information Exchange

Thirty-six pearl millet samples from Senegal, 34 from ICRISAT Niger and 117 from ICRISAT India, and 10 sorghum samples from China were introduced through the quarantine greenhouse in the winter of 1995/96.

Four pearl millet samples were supplied to Namibia, 50 to Brazil and 12 to Zimbabwe. Ten sorghum lines were sent to Zimbabwe and three to South Africa. Twenty-two sorghum samples were supplied domestically and 40 received.

Joint Research

Collaborative research in Botswana on sorghum and Namibia on pearl millet are detailed in the SADC region report.

Pearl millet work in Senegal with Mr. A. Fofana continued on the backcrossing of A_4 CMS into S_1 and S_2's from dwarf variety IBMV 8401. The second backcross was completed on 35 pairs of lines. Station and on-farm testing continued on variety ISMI 9305 of joint ISRA/INTSORMIL parentage.

Table 1. Days to flower, 100 seed weight and grain yields of selected entries in a pearl millet date of planting trial at Tifton, Georgia, in 1995.

	Days to flower			Weight/100 seeds (g)			Grain yield tons/ha		
Entry	4/12	5/12	6/02	4/12	5/12	6/02	4/12	5/12	6/02
HGM100	61	55	56	0.83	0.70	0.57	4.42	2.43	1.29
90DAIEx10188	53	50	47	1.29	1.16	0.82	7.15	3.93	3.47
KAN 95x0142	55	53	56	1.45	1.45	1.23	8.25	6.69	3.72
NEB-NPM-2	49	44	40	1.33	1.13	0.89	5.23	3.74	2.40
59022x89-0083	50	45	43	1.32	1.28	1.11	7.52	4.42	3.25
Mean (20 entries)	52	48	45	1.29	1.17	0.99	6.37	4.47	3.46
LSD (0.05)	1.9	2.1	1.8	0.18	0.22	0.20	1.99	1.16	1.30

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Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF-112
Bruce R. Hamaker
Purdue University

Principal Investigator

Dr. Bruce R. Hamaker, Department of Food Science, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Mr. Moussa Oumarou, Chemist; Mr. Adam Aboubacar, Cereal Technologist; Mr. Kaka Saley, Nutritionist; Ms. Ramatou Seydou, Chemist; INRAN, Niger
Dr. Sitt Badi, Cereal Chemist, Food Research Centre, ARC, Sudan
Ms. Senayit Yetneberk, Food Technologist, IAR, Ethiopia
Ms. Betty Bugusu, Food Technologist, KARI, Kenya
Dr. John Axtell, Sorghum Breeder; Dr. Larry Butler, Biochemist; Dr. Gebisa Ejeta, Sorghum Breeder; Dr. Suresh Itapu, Visiting Food Scientist; Dr. Robert Elkin, Poultry Nutritionist; Purdue University, West Lafayette, IN
Dr. Brian Larkins, Plant Molecular Biologist, University of Arizona, Tucson, AZ

Summary

A quick screening assay was developed to measure protein digestibility in sorghum that will be used to differentiate normal from highly digestible lines in a breeding program. This is an enzyme-linked immunosorbent assay (ELISA)-based assay based on the fact that the storage protein of sorghum, α-kafirin, is digested at a much faster rate in the highly digestible genotype than in normal sorghum. The assay consists of digesting sorghum proteins with a three enzyme system for 30 min, then extracting the undigested proteins and assaying for α-kafirin using an ELISA procedure previously developed in our laboratory. α-Kafirin content in the highly digestible sorghum was found to be less than one half that in normal sorghum. The assay was shortened so that about 30 samples can be analyzed in duplicate per day.

A study on progeny from crosses between highly digestible/high lysine and normal sorghum genotypes revealed that it is possible to combine the high protein digestibility and high lysine traits into a fairly hard kernel type. This "intermediate" vitreous endosperm phenotype has a dense floury endosperm surrounding a vitreous or partially vitreous center. Although not like the typical vitreous, hard kernel types usually desired, this novel endosperm type is significantly more dense than a typical floury kernel and may confer adequate processability and grain mold resistance. The high protein digestibility trait was also found in a few typical vitreous lines that had the normal low lysine content.

A couscous processing unit was put in place at INRAN, Niamey, Niger with funding assistance from the Niger InterCRSP initiative. The processing unit consists of a decorticator/mill, agglomerator/siever (designed by CIRAD, France), steamer, solar drier, and packaging sealer. This will be used for research purposes, and also as a demonstration and testing unit to encourage local entrepreneurs to commercialize millet or sorghum couscous. A commercial-type product will also be tested in the marketplace.

Objectives, Production and Utilization Constraints

Objectives

Develop an understanding of traditional village sorghum and millet food processing and preparation procedures and determine the grain characteristics that influence the functional and organoleptic properties of traditional food products.

Determine the relationships among the physical, structural, and chemical components of the grain that affect the food and nutritional quality of sorghum and millet.

Determine the biochemical basis for the relatively poor protein and starch digestibility of sorghum grain and many cooked sorghum products.

Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum and millet grain.

Constraints

Research on the food and nutritional quality of sorghum and millet grains is of major importance in developing

countries. Factors affecting milling qualities, food quality, and nutritional value critically affects other efforts to improve the crop. If the grain is not acceptable to consumers, then grain yield and other agronomic improvements to the crop are lost. In addition, breeding grains that have specific and superior quality traits will more likely give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum which is perceived in some areas to have poor quality characteristics. The overall goal of this project is to improve food and nutritional quality of sorghum and millet through a better understanding of the structural and chemical components of the grain that affect quality. This knowledge will be applied to develop useful methodologies for screening germplasm for end-use quality, develop techniques to make the grain more nutritious, and improve grain utilization through processing.

Research Approach and Project Output

Sorghum/Millet Couscous

Couscous, a very popular food of Sahelian West Africa, is prepared from sorghum or millet flour that has been agglomerated, steamed, and dried. Couscous is usually consumed with milk for breakfast, or with a sauce or stew for the evening meal. In Niger, although couscous is consumed by the majority of the population, no known commercial sorghum or millet couscous products are available. In urban areas, imported wheat-based couscous is commonly bought, so there exists a ready-made market for a locally made commercial product. Surveys conducted by the INRAN Cereal Quality Laboratory in Niger indicate that texture and color are the two most important attributes that determine consumer acceptability of couscous.

With financial assistance from the USAID-funded Niger InterCRSP project, we recently purchased a couscous processing unit to be used at the INRAN facility for research, demonstration, and testing. The unit is small in scale and consists of a decorticator/mill, an agglomerator/siever designed by CIRAD (France), a couscousierre (steamer), a solar drier built by ONERSOL (Niamey), and a sealer for packaging. Adam Aboubacar spent the month of August 1996 setting up the unit; one week for training at the CIRAD laboratories, Montpellier, France and three weeks at INRAN, Niger. This unit will be used for research and demonstration, and, in an effort to promote the commercialization of millet or sorghum couscous, will also be made available to entrepreneurs and small groups or cooperatives for testing of products Our other short-term goal is to a produce a commercial product to be tested in the marketplace. A longer term goal is to expand this project to include a village level site or sites.

Studies were continued at Purdue on relating grain component properties to couscous product texture. The overall goal of this work is to identify superior cultivars for couscous processing, and to aid breeders in screening lines for good couscous making ability. Previous studies in our laboratory have shown that couscous texture (stickiness, hardness) significantly differed among sorghum genotypes. Since starch granules contribute about 70-80% of the weight of milled sorghum flour, their physicochemical properties can be expected to influence the textural characteristics of sorghum couscous. Starches were isolated from seven sorghum cultivars and subjected to detailed analysis. Two fractions representing amylopectin and amylose were obtained by low pressure size exclusion chromatography of solubilized starch. Significant differences in relative peak areas of amylopectin and amylose, hot water soluble amylose, gel strength, and pasting and gelatinization characteristics were obtained. Couscous hardness and stickiness were determined using a Texture Analyzer. Couscous hardness significantly correlated with starch gelatinization temperature ($r=-0.78$, $p<0.05$), and relative peak area of amylose ($r=0.84$, $p<0.05$), whereas couscous stickiness significantly correlated with relative peak area of amylopectin ($r=0.78$, $p<0.05$).

Digestibility of Sorghum Proteins

Studies have continued on the sorghum genotype with high protein digestibility that we identified two years ago. Our main accomplishment this year was the development of an ELISA-based screening test for protein digestibility that can differentiate between normal and highly digestible sorghum lines. *In vitro* digestibility data places the highly digestible sorghum genotype within range of the digestibility of wheat and above that of maize. In populations with marginal or substandard protein intakes the introduction of sorghum with both enhanced digestibility and lysine content could be of real benefit. There may also be potential use of this genotype in animal feed.

From previous characterization of the biochemical and structural differences between normal sorghum and the highly digestible genotype, we found that α-kafirin, the major storage protein of sorghum, is digested at a much faster rate in the latter genotype. This is due to the fact that protein bodies of the highly digestible genotype are structurally different from normal protein bodies containing deep folds rather than a typical spherical shape γ.-Kafirin, the highly disulfide-bonded structural protein, is found at the base of the folds in protein bodies of the highly digestible genotype opposed to at the periphery of normal protein bodies. Apparently, exposure of the α-kafirin, in the absence of γ-kafirin, to digestive enzymes results in the rapid digestion of this protein, and overall high digestibility of this genotype.

Using this knowledge of the differences in rate of α-kafirin digestion between the normal and highly digestible genotypes, we developed a rapid digestibility assay that can be used to screen sorghum breeding lines. This is based on an ELISA procedure, where flour samples are predigested with a combination of trypsin, α-chymotrypsin, and peptidase for 30 min, the undigested proteins are extracted from

the pellet, and α-kafirin is measured by an ELISA procedure previously developed in our laboratory. Low α-kafirin values then correlate to high protein digestibility. The difference in α-kafirin levels between normal and highly digestible sorghums is shown in Figure 1. Using this procedure one technician can analyze approximately 30 samples in duplicate per day.

In a study on 40 lines developed by J. Axtell from crosses between highly digestible, high-lysine and normal sorghum genotypes, we found that lysine content varied from 0.22 to 0.46% (as is flour basis) and *in vitro* protein digestibility, in relative units of titratable base, increased approximately 100% from the low to high sorghum line. Digestibility and lysine content did not correlate well, suggesting that the two traits are not linked. However, there were a number of lines that had both high digestibility and high lysine content.

A chick study was conducted at University of Illinois (Dr. Carl Parsons) to examine differences in growth parameters among diets containing normal sorghum, two highly digestible, high-lysine lines, and normal maize. Lysine contents were slightly different at 0.34 and 0.33 (flour basis) for the improved sorghum, 0.28 for normal sorghum, and 0.29 for normal maize. Sorghum or maize in the diet (cereal plus starch/dextrose, soy oil, vitamins and minerals) provided 7.0 crude protein and were fed to 8 day old chicks for 9 days. Feed efficiency (gain/feed intake) for the improved sorghum was equal to maize at 0.19 and significantly higher than for normal sorghum at 0.14. Protein efficiency ratio (PER) (gain/crude protein intake) of the two highly digestible, high-lysine sorghum lines (2.71 and 2.75) was statistically similar to normal maize (2.73), and significantly higher than normal sorghum at 1.96. Net protein retention [(gain-weight gain of N-free diet)/crude protein intake] was 3.58 and 3.60 for the two improved sorghum lines, 3.47 for normal maize, and 2.97 for normal sorghum. While this study indicates the superiority of the improved sorghum lines in a laboratory setting, further assessment of the practical gain from the improved sorghum will be done using a broiler "to market" study in fall 1996.

In last year's summary we reported the discovery of a high molecular weight, non-kafirin protein in sorghum protein bodies that may be related to protein digestibility. Immunolocalization studies showed that this protein is found at the periphery of the protein body in the same location as γ-kafirin. A structural role was postulated for this protein. N-terminal sequence and match with a protein sequence database indicated that the protein is of the heat shock or chaperone class of proteins, that assist in formation and maintenance of protein conformations. One possible explanation for the presence of this protein is that it may be involved in the formation of the highly disulfide-linked γ-kafirin rigid shell that makes protein bodies hard to digest. ELISA was performed with antiserum developed against the high molecular weight protein on normal sorghum (P721N) samples with significant year-to-year differences in protein digestibility. There was an inverse relationship between amount of high molecular weight protein and *in vitro* protein digestibility among the samples tested. Therefore, higher concentration of this protein may relate to lower digestibility.

Grain Quality

In last year's report we described a novel sorghum endosperm type within the highly digestible, high-lysine popu-

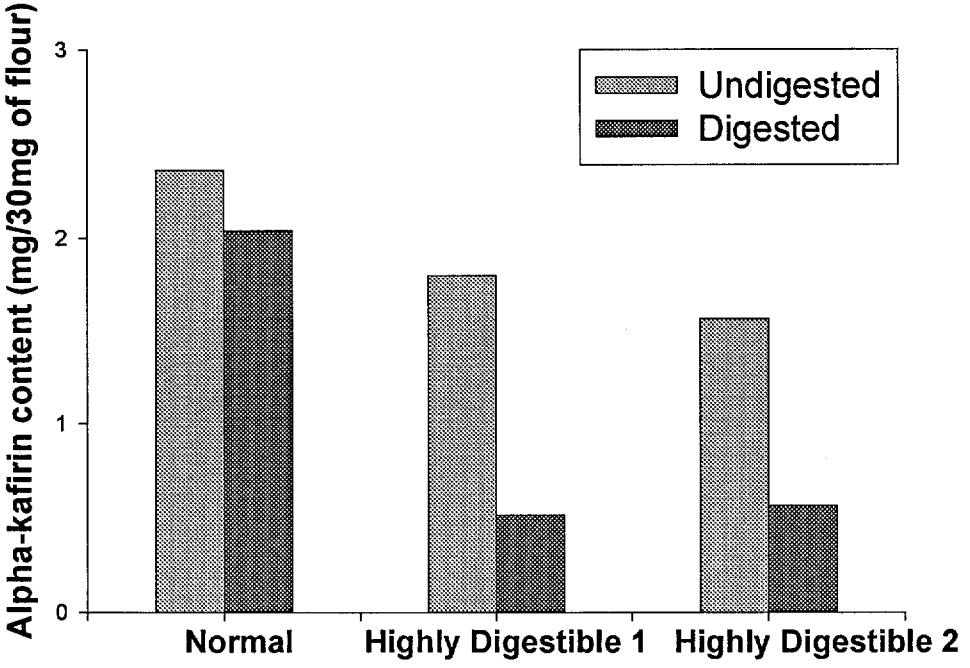

Figure 1. Sorghum α-kafirin protein in normal and highly digestible sorghum lines before and after digestion with proteases as measured by an ELISA screening assay.

lation at Purdue. This phenotype has either a vitreous center or a vitreous ring near the center of the kernel surrounded by floury endosperm radiating to the periphery. Visually, this endosperm is neither a typical vitreous or floury, and we have thus called it an "intermediate" vitreous type. Scanning electron micrographs revealed that the endosperm microstructure of the vitreous center portion of this endosperm is quite different from typical vitreous endosperm. Starch granules are compact and polygonal in shape like a normal vitreous section, however, the protein matrix is discontinuous opposed to a continuous one in the normal type (Figure 2). In practical terms this may mean that the starch component is easier to digest as its starch granules are not embedded in a dense matrix. Starch from the "intermediate" vitreous genotypes may also be easier to separate from other components due to this unique packing and could give high starch yields in a wet milling process.

We found that the two traits of high protein digestibility and high lysine content can be combined with the "intermediate" vitreous phenotype, but not a typical vitreous one. This was encouraging to us since it means that a nutritionally superior sorghum genotypes exists that has a relatively hard kernel characteristic. Kernel density among the floury and "intermediate" sorghum lines ranged from 1.20 to 1.32 g/cc suggesting that a dense floury or relatively hard "intermediate" vitreous grain can be bred for. Among the more dense selections, there were lines that had, for example, 0.45% lysine (flour basis, compares to 0.22% for a normal line)/0.156 ml titrant (digestibility value, compares to 0.115 for a normal line), 0.38%/0.202 ml titrant, and 0.36%/0.172 ml titrant.

Finding the "intermediate" vitreous sorghum kernel type is important because, up to this point, this is the best kernel quality that we have found which incorporate the desirable traits of high digestibility and high lysine content. Further studies on grain mold resistance and processability are presently being done to see if this increase in kernel hardness over normal floury types reflects actual improvements in quality.

Networking Activities

Workshops

B. Hamaker traveled to Niamey, Niger in September 1995 to participate in the InterCRSP Natural Resources Management workshop. Our involvement in the Niger InterCRSP activity has resulted in the purchase and setting up of a small scale couscous processing unit as described above.

B. Hamaker participated in a planning workshop of the West and Central Africa Pearl Millet Research Network (ROCAFREMI), July 1996 in Abidjan, Cote d'Ivoire. He presented a talk (joint author with L. Rooney) on traditional and modern methods of millet processing. ROCAFREMI will initiate a new project on millet processing and in this workshop project feasibility and research priorities were discussed. The focus of the project will be on processing of locally grown millet to products for sale to urban consumers.

Research Investigator Exchange

INRAN/Niger food scientists, S. Kaka and R. Seydou, participated in a 2 month training at the cereal lab at Purdue in September-October 1995.

As part of the MIAC/KARI project, B. Hamaker spent 2 weeks in February-March 1996 in Kenya on short-term technical assistance in the area of sorghum and millet processing. This year we will begin working with KARI food technologists, Betty Bugusu and Joyce M'alinga, as part of the Horn of Africa project.

A. Aboubacar (Ph.D. candidate, Purdue) traveled to Montpellier, France in August 1996 for training with CIRAD scientists on couscous processing. We have purchased an agglomerator/siever designed at CIRAD. Adam then traveled to Niamey, Niger for three weeks to install the entire couscous processing unit at INRAN and to test and train Cereal Lab scientists on the unit.

Attended and presented findings from the project at the annual American Association of Cereal Chemists meeting in San Antonio, Texas in November 1995.

Publications and Presentations

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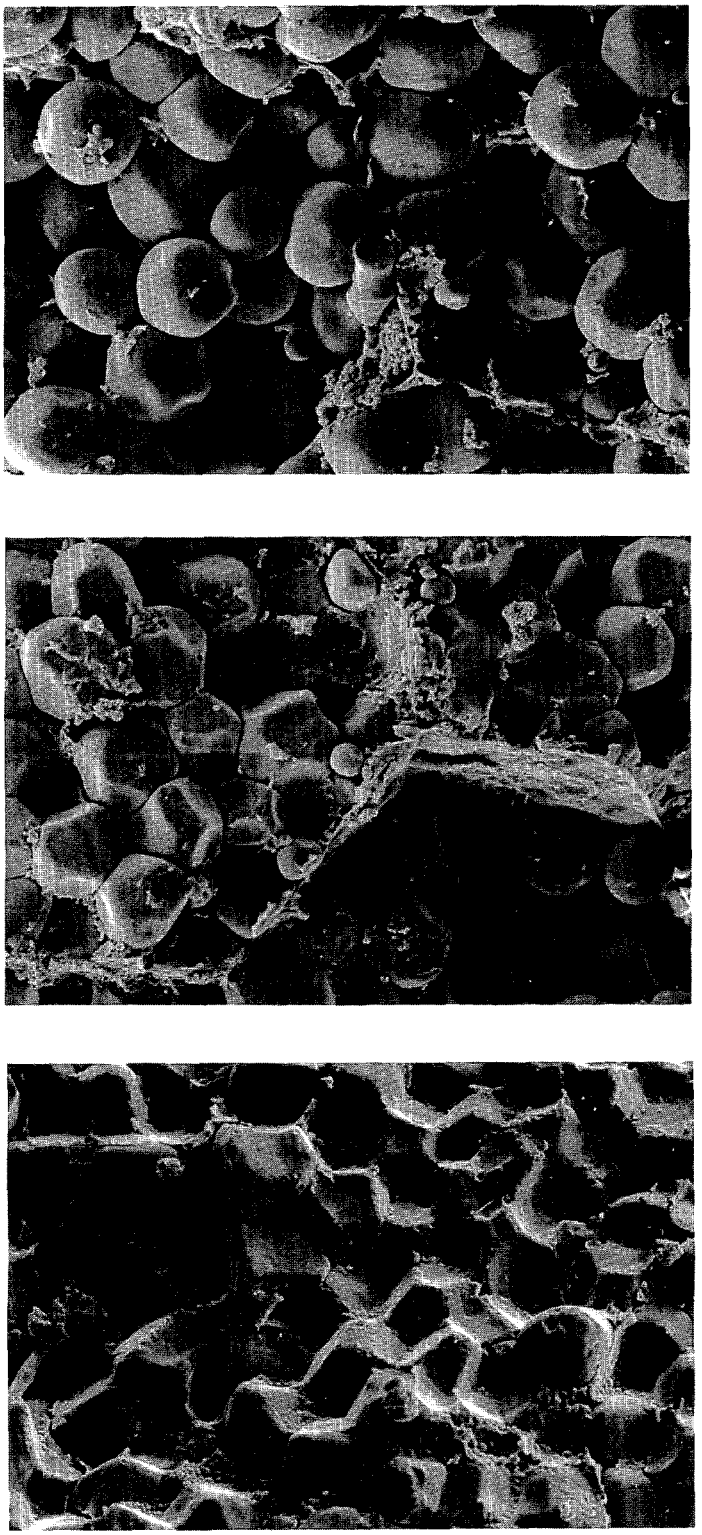


Figure 2. Scanning electron micrographs of endosperm sections of a floury kernel (top), vitreous portion of an "intermediate" vitreous kernel (middle), and a vitreous kernel (bottom).

Food and Nutritional Quality of Sorghum and Millet

Project TAM-126
Lloyd W. Rooney
Texas A&M University

Principal Investigator

Dr. Lloyd W. Rooney, Professor, Food Science and Agronomy, Cereal Quality Lab, Soil and Crop Science Department, Texas A&M University, College Station, Texas 77843-2474
Cooperator: Dr. Ralph D. Waniska, Professor, Food Science, Cereal Quality Lab, Texas A&M University, College Station, Texas 77843-2474

Collaborating Scientists

Ms. A. Berthe, Food Technologist and Dr. A. Toure, Sorghum Breeder: Institute Economic Rurale, Republic of Mali, Bamako, Mali
Dr. F. Gomez, Sorghum Breeder, EAP/RN, Zamarano/ Tegucigalpa, Honduras
Drs. G. Teetes and R.A. Frederiksen: Texas A&M University, College Station, Texas
Drs. D.T. Rosenow and G. Peterson: Texas A&M University, Agriculture Research and Extension Center, Lubbock, Texas
Dr. G. Odvody, Texas A&M University, Texas A&M Agriculture Research and Extension Center, Corpus Christi, Texas
Dr. Sergio Serna-Saldivar, Professor, Institute of Technology, Monterrey, Mexico

Summary

Commercial food sorghum hybrids (36 samples), experimental waxy hybrids (40 samples) and the International Food Sorghum Test (50 samples) grown at Lubbock and Halfway, Texas were evaluated for milling properties. Most of the white, tan plant food type sorghums produced decorticated endosperm with light to moderate yellow color that is undesirable for flour used in thick porridges in Southern Africa. Only a few hybrids had white endosperm. Samples from the International Food Sorghum Test classified as having a white endosperm had the light yellow pigmentation.

Jowar Foods, Inc., a small food company, is marketing Jowar flour and bakery mixes to ethnic groups familiar with sorghum products. They have contracted with growers to produce the new food-type hybrids that have been developed by INTSORMIL.

Sorghum varieties vary significantly in steam flaking properties, with waxy types producing flakes with consistently greater diameter, more durability, excellent appearance and improved *in vitro* digestibilities. The heterowaxy sorghums also had improved steam flaking properties, but more closely resembled the non-waxy grains. Nonwaxy food-type sorghum hybrids produced flakes with excellent appearance. No significant differences in flake quality other than appearance were found for commercial cream, red and yellow hybrids.

N'Temimissa, a white, tan plant, locally photosensitive sorghum cultivar has been released in Mali to provide grain for value-added processing.

MILEG, a weaning food from dehulled pearl millet and cowpea flours (3:1 blend), is still produced and sold by a small food company in Bamako, Mali. The product prototype was developed cooperatively by the Institute of Rural Economy food technology laboratory with assistance from TAM-126.

Progress to evaluate the antifungal proteins of sorghum and the role they play in reducing grain molds and deterioration continues.

Objectives, Production, and Utilization Constraints

Objectives

Develop new food products from sorghum and millet using appropriate technology for use in less developed areas.

Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.

Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum; and seek ways of modifying its properties or improving methods of processing.

Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

Factors affecting food quality, processing properties, and nutritional value of sorghum and millet critically affect the significance of other attempts to improve the crops. If the grain cannot be processed and consumed for food, then the agronomic and breeding research has been wasted. This project relates quality to measurable characteristics that can be used to select for sorghum and millet with acceptable traditional and industrial utilization attributes. It has defined quality attributes and incorporates those desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptabilities that can generate income for village entrepreneurs.

Grain molds cause staining and significantly reduce the quality of sorghum for food and feeds. Information on the factors that affect mold damage of sorghum and methods to develop mold resistant sorghums is needed. This project addresses those critical issues.

Research Approach and Project Output

Sorghum and millet grains grown locally and from various areas of the world were analyzed for physical, chemical, structural, and processing properties. Various food and feed products were prepared to test the quality of the different grain samples. Some of these findings are summarized below.

Starch from New Sorghum Hybrids

Sorghum starches were isolated from new food type sorghum hybrids which consisted of normal, heterowaxy and waxy endosperm types. Commercial red, cream and yellow sorghum hybrids were also wet milled into starches. The wet milling was accomplished by using a laboratory technique to obtain prime grade starches which were compared to commercial corn starch. The L, a, and b values of the sorghum starches were similar to corn starch. There were no differences in starch color among the sorghum hybrids. We expected that starches from the tan plant sorghums would have had lighter color than those from the red and purple plant color sorghums. The milling recovery of starch was low because of extra washing, so this probably masked the expected differences in starch color. Our previous data indicated that sorghum starches from red pericarp sorghums had an off white pinkish starch.

The apparent amylose content of the seven sorghum starches ranged from 2.8 to 30.4% of the starch. The values are higher because the method for rice was used to determine amylose content. When HPSEC was used to determine amylose content, the values for amylose were <1.0%, 22.9 and 23.1% for waxy, heterowaxy and nonwaxy starches, respectively. The starches have significantly different cooking and processing characteristics with the heterowaxy starch in between the waxy and nonwaxy starches. For example, the reduction in paste viscosity when 200 units of Diazyme enzyme was added to the starch prior to starting the Rapid Viscosity Analyzer (RVA) was 96, 79 and 43% for waxy, heterowaxy and nonwaxy starches, respectively. Gels made from the starches had significantly different texture profile analyses. The waxy gel was softer and more adhesive than the other gels. The heterowaxy gel was intermediate in hardness with the same adhesiveness as the normal sorghum starch.

The significance of these sorghum starch studies is that sorghum starch can be used interchangeably with corn starch because it has similar properties. It also indicates that waxy sorghum starch has acceptable processing properties, while the heterowaxy starch has lower levels of amylose that give different physico-chemical properties to the starches.

The utilization of a RVA to study starch pasting is practical, but it gives different results from those obtained with the Brabender Visco-Amylograph. Concentration of starch is critically important and affects the relative viscosities significantly. The RVA is useful to quickly evaluate the extent of cooking of sorghum or millet during processing by use of enzymes added to the blend prior to cooking. This concept has been applied successfully to steam flaked sorghum. These methods can be used to more efficiently study the changes that occur in porridges or weaning foods when malt is added.

Brewers Adjuncts from Sorghum

Waxy and nonwaxy sorghums were milled into grits and evaluated for use as adjuncts in brewing by Dr. Serna-Saldivar and students in collaborative work completed at the Institute of Technology in Monterrey, Mexico. They found that the waxy sorghum grits were more quickly hydrolyzed during mashing and were significantly better than the two normal sorghum grit samples. Additional work conducted in Mexico recently has shown clearly that waxy and heterowaxy sorghum grits have significantly improved brewing properties over nonwaxy sorghum grits.

The major problem with the waxy sorghum hybrids is reduced yields of grain. In our 1995 trials, the waxy hybrids had significantly reduced grain yields. However, some heterowaxy hybrids had competitive grain yields so that offers a way to utilize the advantages of the waxy characteristic while maintaining adequate production. A commercial white, heterowaxy sorghum hybrid is being produced this summer.

Extrusion Processing of Sorghum

A food type sorghum was expanded using a single screw extruder at various feed moisture levels and screw speeds. Sorghum was decorticated, coarsely ground, tempered and extruded to produce extrudates which were evaluated for use in snacks and other products. The reduced feed moisture and higher screw speed caused the extrudates to have low bulk density, lighter texture and much greater solubility in water. The addition of 3% barley malt to the meal prior to extrusion did not affect the quality of the extrudates significantly. The malt did increase the viscosity of ground extrudates probably because it partially hydrolyzed some of the starch during extrusion prior to inactivation. The extrudates from the food type of sorghum had excellent color, bland flavor and could be useful in a wide variety of foods.

In another set of experiments, conducted at the Institute of Technology in Merida, Mexico and at TAMU, extruded white sorghum and soy flour were ground and blended (70:30%). The sorghum-soy blend was mixed with 0 to 20% (bakers formula) ground diastatic barley malt and made up to 80% moisture content. The viscosity of the slurry made with tap water at room temperature was measured over 30 min. The slurries without malt were quite viscous and could not be used as a beverage. The addition of as little as 5% malt converted the sorghum-soy blends into easily drunk beverages. Moreover, during beverage preparation, malt addition to the sorghum-soy flour dry mixture caused rapid hydrolysis during stirring with water at room temperature. For example, more than a 50% loss of viscosity was recorded during the first minute of stirring the sample into the water. In experiments here in the Cereal Quality Lab, sorghum malt gave a similar response when added to ground sorghum extrudates.

We are proposing that the producer of MILEG in Mali should consider utilizing sorghum malt in his weaning food product to decrease the viscosity and allow for a more calorically dense product. Here, the high α-amylase activity of sorghum malts readily lend themselves to this application. Mr. Asante, Ph.D candidate from Ghana, is conducting experiments on sorghum malts and fermentation combined with simple heat processing techniques to produce weaning foods of high caloric density.

Commercial Food Products Available in Mali and U.S.

Commercial hybrid seed companies have expanded their efforts to produce white, tan plant, food-type hybrids. We have nearly reached the point where significant quantities of food-type sorghums will be available because a few hybrids have good agronomic and yield properties. Additional hybrids are needed to increase the availability of food sorghums.

MILEG, a weaning food made from dehulled pearl millet and cowpeas, is on the market in Mali. It is a low-cost weaning food for children. Most weaning foods in Mali are imported and cost more than most people can afford. MILEG is easy to prepare and the cost is reasonable because it does not contain expensive imported ingredients. It provides significantly improved nutritional value over the usual practice which is to feed children only cereals. MILEG was developed in the IER Food Technology laboratory in Sotuba and several Malian village trials. TAM-126 has assisted over the years in the effort to develop local value-added products for profitable commercialization.

In Mali, Dr. Toure released N'Temimissa, a new white, tan plant, locally adapted photosensitive sorghum cultivar specifically designed for value-added processing. The major problem of the food company producing MILEG in Mali is to access reliable, good quality supplies of millet and cowpeas. The combination of new or improved processes with good quality grain is absolutely necessary if sorghum and millet are to compete with rice and wheat based foods. The key to introduction of new products is to have a good supply of good quality sorghum and millet to process. Trials in Bamako, Mali to produce parboiled sorghum (SORI) were unsuccessful because only poor quality grains available in the market were used.

Dry Milling Properties of Sorghum

Sorghum samples from several performance trials were analyzed and evaluated for milling characteristics. The new food-type sorghums consistently had equal or improved grain yields, improved milling yields, and the color of the decorticated kernels were far superior to those of white sorghums with purple plant color.

Commercial or experimental hybrids were grown in a replicated nursery at Lubbock and Halfway, Texas in 1995. The 37 hybrids represented the materials available from commercial hybrid seed companies which included white sorghums with and without tan plant color, heteroyellow endosperm hybrids and white endosperm hybrids as well as a waxy endosperm hybrid. There was some weathering of the grains post-maturity, so milled products from white, tan plant sorghums had a very significant improvement in milled product appearance. Some had excellent milling yields. The trials were organized by the Texas Sorghum Producers to obtain information on current hybrids available in the U.S..

In cooperative work with a dry milling company in Botswana we confirmed that many of our food type sorghums did not have a bright white endosperm. Many of them had various levels of yellow pigments in the endosperm which caused the porridges (pap, sadza) of Southern Africa to have an undesirable yellow color. We evaluated the International Food Sorghum Trials grown at Lubbock, Texas in 1994 and 1995 for endosperm color and for milling properties. Only a few of the sorghums actually have a bright white endosperm; most have some yellow in the endosperm. This yellow is apparently different from that of the yellow endosperm characteristic.

Dr. William L. (Bill) Rooney, Sorghum Breeder, College Station, initiated crosses to determine the heritibility of these yellow pigments and to determine its relation to the yellow endosperm characteristic. In the past, we were not concerned about endosperm color as long as the pericarp was easily removed with little or no anthocyanin pigments in the grits.

Some experimental red, tan plant sorghum hybrids had good dry milling properties and produced decorticated products with significantly reduced red stains. The yield levels and improved appearance of the grain and milled products of the tan red sorghum hybrids make them extremely promising for areas that cannot grow white sorghums.

Steam Flaking of Sorghum

Three years of research on steam flaking quality of sorghum sponsored in part by the Texas Sorghum Producers Board has confirmed that various sorghum hybrids respond differently to steam flaking. The waxy endosperm flakes were the most thoroughly processed; had largest diameter, most durability, and excellent appearance. The food-type sorghum was similar in flaking characteristics to the red, cream and yellow commercial sorghum hybrids; the major difference between them was the improved appearance of the food-type sorghum flakes. The waxy sorghum flakes had slightly greater *in vitro* digestibilities than the other sorghum flakes.

Waxy and heterowaxy sorghums have improved flakes that would significantly improve the performance of sorghum in livestock feeds. A new white, waxy male was released in 1994 from the TAES, and two female waxy sorghums were released previously. The yields of waxy hybrids are not as high as those of nonwaxy hybrids; therefore, the most feasible way to utilize the waxy characteristic is to use heterowaxy hybrids which would have very competitive grain yields and agronomic characteristics. The grain sold by the farmer would have a mixture of waxy, nonwaxy and partially waxy kernels. We have found that heterowaxy grain processes better than comparable nonwaxy grains.

Tempering sorghum prior to steaming reduced energy consumption and produced flakes with significantly less breakage during handling. These observations confirm that tempering is absolutely necessary for proper evaluation of steam flaking properties of sorghum.

The effect of various conditioners and chemicals on grain structure after tempering and steaming varied. The regular commercial conditioning agent did not alter the structure of tempered, steamed sorghum kernels while the use of chemicals that break disulfide bonds (sodium bisulfite, ß-mercaptoethanol) caused significant changes in sorghum kernel structure. The sulfurous acid has a marked effect on the pericarp of steamed grain, and significantly enhanced flake quality. This shows that disruption of the proteins in sorghum has a major effect on steam flaking. These observations suggest that we may be able to find chemicals that significantly enhance the processing efficiency and digestibility of sorghum. It strongly indicates that existing commercial conditioning agents are no more effective than using an ordinary emulsifier. This could be a significant savings to feedlots.

A procedure for steaming and flaking 100g samples of sorghum was used to determine the effect of various conditioning agents, tempering and steaming times on moisture uptake, kernel structure and flake quality. The waxy grains in general had significantly greater water uptake than the nonwaxy counterparts. The steaming procedure caused rapid water uptake which may have masked small but significant differences among nonwaxy grains. This work is completed; several publications on steam flaking of sorghum are in preparation. No differences in water uptake occurred for nonwaxy grains that had intermediate endosperm texture.

Role of Antifungal Proteins in Minimizing Grain Molding of Sorghum

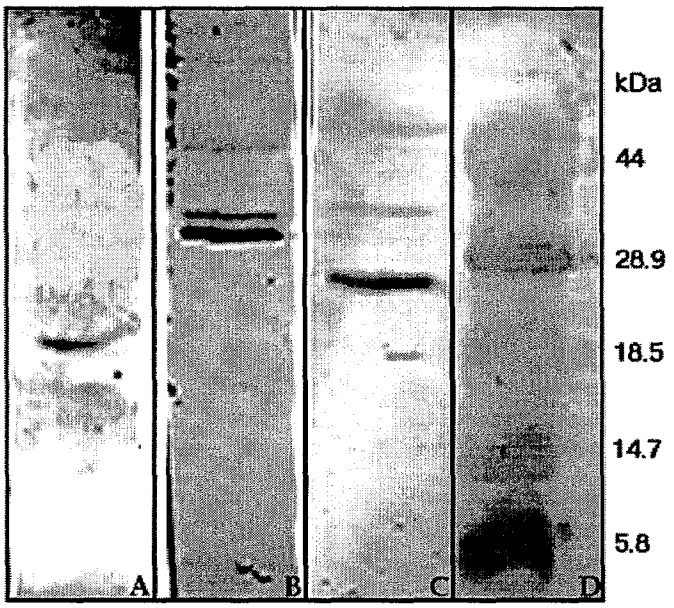
Antibody Production

Research on antifungal proteins, thus far, has been conducted using antibodies raised against other seed antifungal proteins (AFP) such as zeamatin (maize permatin), bean chitinase, tobacco glucanase or maize ribosome inactivating protein (RIP). This poses a limitation to our research due to the limited amount of antibody that can be obtained from different sources. We therefore, purified AFPs from sorghum to raise antibodies against them in rabbits. We took advantage of the fact that several AFPs eluted from an anionic column upon applying a salt gradient.

The eluants were separated into four fractions. Fraction four contained bands cross reacting with sormatin, chitinase, glucanase and RIP. There was also some evidence of proteolytic breakdown of RIP due to the lower molecular weight cross-reactions observed.

Earlier attempts to raise antibodies against these proteins were unsuccessful because of extensive cross reactions in the preimmune serum of the rabbits used in the study. Therefore, this year, we used rabbits on a special diet devoid of cereals to eliminate antigenic activity by cereal proteins.

Individual protein bands from fraction 4 were cut, macerated, freeze dried and injected into rabbits for antibody production. The first bleed was tested for its antigenic activity and positive cross reactions were detected with sormatin, chitinase and glucanase antibodies (Figure 1). Attempts to raise antibodies against RIP were unsuccessful, again. Sorghums at mid-maturity (15 days after anthesis) will be harvested this season (1996) and used for RIP purification.



A= Sormatin; B= Glucanase; C= Chitinase; D= Molecular marker

Figure 1. Cross reactions of anti-sormatin, anti-chitinase and anti-glucanase antibodies with crude sorghum.

Changes During Germination

Earlier, we reported that steeping and germination during the malting process significantly affected sormatin and chitinase levels in the caryopses. Similar results were detected when germinated sorghum caryopses were screened using glucanase antibody (Figure 2A). Glucanase levels increased in caryopses up to five days of germination. RIP antibody cross reacted with two lower molecular weight proteins (~17 and 15 kDa) in germinated caryopses, indicating proteolytic breakdown of the 32 kDa protein (Figure 2B) and their levels increased up to five days of germination.

Shoots contained significant amounts of sormatin, chitinase and glucanase (Figure 3). Sormatin and glucanase levels increased in shoots up to five days of germination. The 28 kDa chitinase decreased while the 34 kDa isozyme increased as observed in caryopses. Several bands cross reacting with RIP were detected in shoots. In addition to the two lower molecular weight proteins observed in the seeds, another band at ~8 kDa was detected. It is suggestive that these proteins are synthesized in the shoot tissues and are not transported from the caryopses.

Cross reactions with RIP antibody occurred at lower molecular weights (~17 and 15 kDa) indicating proteolytic breakdown. Traces of these proteins were also detected in shoots after four days of germination, along with another protein with a molecular weight of approximately 8 kDa. This is in agreement with other studies which have shown that the zymogen of maize RIP (34 kDa) is broken down during germination into two residues (16.5 and 8.5 kDa) which are the active moiety, with bioactivity 10,000 fold higher than the zymogen. The breakdown of RIP in germinating seeds coincides with increased proteolytic activity in seeds which are associated with protein mobilization. Since there is no known physiological role for RIPs in plants, it is hypothesized that they play a role in defending germinating seeds against pathogen invasion.

Bioactivity Assays

Bioactivity assays were conducted using partially purified sorghum extracts eluted from an anionic column. Water soluble sorghum proteins were sequentially precipitated using ammonium sulfate. Proteins precipitated between 30 and 55% ammonium sulfate concentration were loaded on to a Sephadex column and eluted using a linear salt gradient (10-400 mM). Four fractions were collected (G1-G4) and tested for bioactivity.

Sorghum extracts only weakly inhibited hyphal elongation of *Fusarium moniliforme* or *Curvularia lunata*. However, significant inhibitory effects were observed when other types of assays were used.

Spore Germination Inhibition. Fraction G4 was the most inhibitory to spore germination against all four fungi tested.

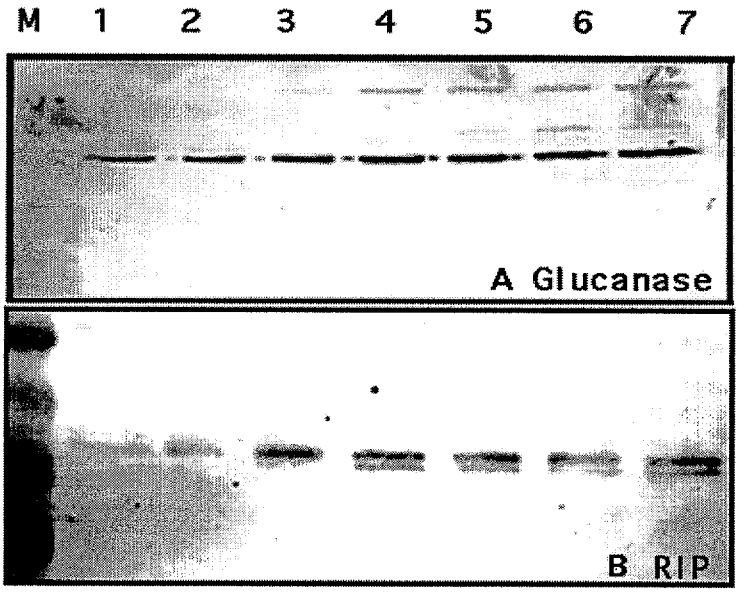


Figure 2. Changes in glucanase and RIP during seed germination. Lanes: 1 = raw grain, 2 = steeped grain, 3 = day 1, 4 = day 2, 5 = day 3, 6 = day 4, 7 = day 5.

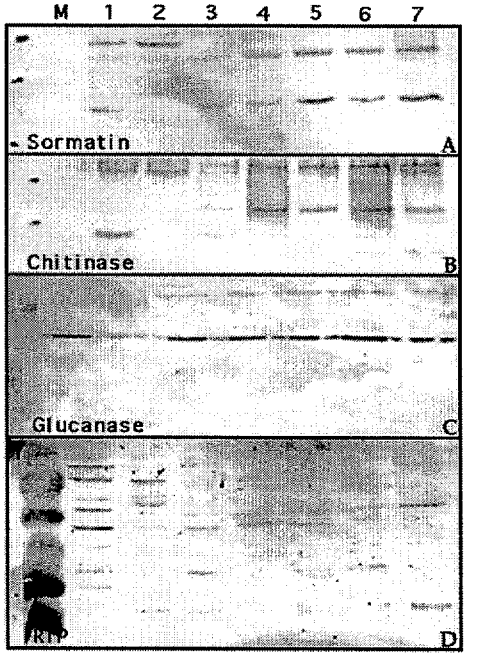


Figure 3. Changes in sormatin, chitinase, glucanase and RIP in sorghum (Dorado) shoots during five days of germination. Lanes M = Molecular marker; 1 = raw grain; 2 = steep; 3 = Day 1; 4 = Day 2; 5 = Day 3; 6 = Day 4; 7 = Day 5.

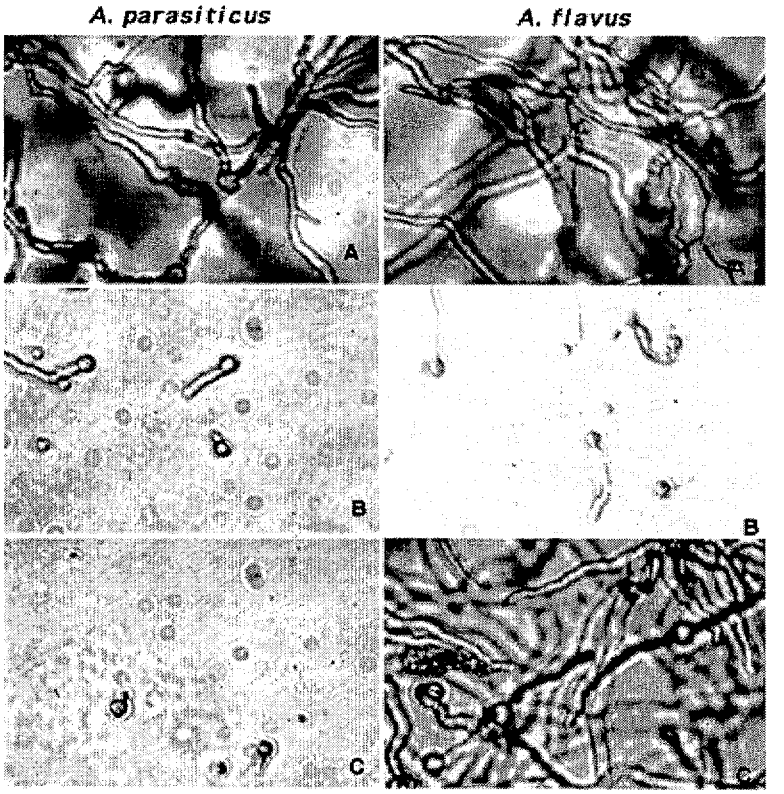


Figure 4. Spore germination inhibition of Aspergillus species by partially purified (fraction 4) sorghum proteins.

This fraction also contained significant amounts of three antifungal proteins, i.e., glucanase, chitinase and sormatin.

Gemination of spores of *C. lunata* and *F. moniliforme* were completely inhibited by <100 µg protein (Table 1). Spore germination was not inhibited when the protein fraction was boiled, suggesting the involvement of denaturable proteins.

Activity of fraction G4 was also tested against *Aspergillus flavus* and *Aspergillus parasiticus*. Spore germination was completely inhibited in both species at concentrations less than 100 µg (Figure 4). However, the boiled fraction still exhibited some inhibitory effect, especially on *A. parasiticus*. There is considerable interest in alternatives to eliminate *Aspergillus* species in seeds such as maize and peanuts because of the problem with aflatoxins. The inhibitory action of compound(s) from sorghum needs to be further investigated to identify the compound(s) and their modes of action.

Table. 1. Effect of different concentrations of fraction 4 on spore germination of *C. lunata* and *F. moniliforme*.

Protein (µg/100 µl)	F. moniliform	C. lunata
0	+++++	+++++
4.4	+++	+++
22	+	+
44	+	+
110	-	-
220	-	-
Boiled (220)	++++	++++

Hyphal Rupture. C. lunata required protein levels of 20-50 µg and ruptured only at hyphal tips. *F. moniliforme* exhibited hyphal rupture at the growing tip and other regions of mycelium, at protein levels as low as 20 µg. Neither *Aspergillus* species exhibited hyphal rupture.

These differences in modes of action of AFPs may have implications in that the activities of AFPs also depend on the stage of development of the pathogen. High levels of AFPs at the time of infection may be more inhibitory, and therefore result in lower incidences of molds on seeds, since these proteins inhibit spore germination more effectively than hyphal elongation.

Future Research

Several observations from our investigations implicate the presence of AFPs in caryopses to be an integral part of

seed defenses. The circumstantial evidences observed thus far suggest that enhancing the levels of these proteins at certain stages of sorghum development can help minimize grain molding incidence. The differences in the levels of these proteins between sorghums can be exploited using conventional breeding techniques to enhance constitutive levels of these proteins in caryopses.

Advances in genetic techniques to create transgenic plants also offer promising alternatives. Successful transformations of tobacco, rice and rape seed with genes encoding RIP, chitinase and/or glucanase have been reported. It has been shown that a "multi-transgene", i.e., plants containing more than one gene, can be created and they are more resistant to disease than transgenes containing only one AFP. Success of similar strategies against seed diseases may prove to be more difficult, although research is in progress presently to address this question.

Results from our studies indicate that any strategy undertaken should consider the changes in these proteins during development and aim to target these proteins in specific tissues and/or to be active at specific stages of development to have maximum effect on pathogens. Further studies to confirm the bioactivity of AFPs *in vitro* and their mode of action *in vitro* are being conducted.

Therefore, several studies are underway in our lab to study changes in AFP levels following seed inoculation with pathogens under field and green house conditions; and study the heritability of these proteins in sorghum. Investigations are also underway in other labs on campus at Texas A&M to identify the genes and create transgenic sorghum plants containing one or more of these AFPs.

Sorghum Improvement Research

This project cooperates closely with other members of the sorghum program to incorporate the best quality characteristics into new cultivars. Samples from the breeding nurseries and from the food quality tests grown at different locations are tested for kernel characteristics and for processing properties such as decortication and nixtamalization. The alkaline cooking tests are especially sensitive and pick up off-colors easily.

From this research, Texas A&M has released several inbreds that produce white, tan-plant sorghum hybrids with excellent food and feed processing quality. For example, recent work in Mexico has confirmed that the new food sorghums had significantly higher yields of grits compared to existing commercial sorghum hybrids. In addition, the color of the grits from the white food sorghums was significantly improved. These sorghums produce excellent quality grain when grown under dry conditions. Because of reduced anthocyanin pigments, the grain can withstand some humidity during and after maturation. However, these sorghums need more resistance to molds and weathering to be grown in the hot humid areas of the world including the Coastal Bend of Texas and Tamalipas in Mexico. The work to evaluate the role of AFPs in sorghum molding and weathering is critically important.

Networking

Southern Africa

Lloyd W. Rooney traveled to Zimbabwe and South Africa to participate in a Workshop on Food Technology of Sorghum and Millets in the SADC Region. Seven of 10 students from the SADC region who had been trained by INTSORMIL in Food Technology participated to review their training and develop plans and priorities for research in the region. An overview of the INTSORMIL research activities in sorghum and millet was presented. In general the students were complimentary of their training, but disappointed in that they were in most cases not integrated into the national programs upon their return from studies. Nearly all of the students are working in the region in some aspect of food science and technology. Several have joined the food industry where they are making important contributions.

A research project proposed by Ms. Trust Beta, Lecturer, University of Zimbabwe, was approved by INTSORMIL to initiate research on sorghum and millet dry milling in Zimbabwe. It is cooperative with SMIP and the National Agricultural Research Service in Zimbabwe and will involve private industry. Ms. Beta has plans to utilize the SMIP laboratory in Matopos. Industry appears interested in supporting the activities.

In South Africa, Lloyd Rooney discussed collaboration in the SADC area with Professor John R.N. Taylor from the University of Pretoria since he has applied for a project on sorghum and millet from the European Economic Community. We will try to coordinate our efforts and targeted work with former INTSORMIL trained students in the region. There are ample opportunities to collaborate with other South African institutions as well.

Mali

Dr. Oumar Niangado, Director General, IER, Mali and other high level administrators visited our laboratory to discuss value-added research activities in food processing. Dr. A. Toure, Sorghum Breeder, Mali, discussed his new white, tan, plant sorghum cultivar which he released. The grain appears to process into food products of high quality. We are awaiting results from the Food Technology program in Mali on its milling properties. It has been used to make excellent flour for composite bread and biscuits.

L.W. Rooney traveled to Mali funded by the Texas A&M USAID SPARC program to inventory current programs in food science and technology and make recommendations for improvements. The laboratory has undergone significant changes in personnel, and required additional assistance to achieve its objectives. Major recommendations included the

assignment of marketing and economists to the food technology program, and shifting emphasis to development of market driven products for manufacture by local business.

Major changes in Mali relate to the price and availability of wheat for bread and biscuits. There is an economic demand for sorghum, millet or maize flour to extend wheat flour in biscuits (cookies) and French breads. The industry personnel wanted to use maize because they had reports discouraging the use of sorghum because the local sorghum flour has been of poor quality. This poor image of sorghum and millet is a major problem.

A new cereal and legume composite flour product called CERELEG originally, and now called MILEG, is currently being sold in Mali by a small businessman. The product was developed in the Food Technology Laboratory and tested in several villages over the years in Mali. The product which consists of 1 part cowpea flour and 3 parts millet flour is sold as a weaning food for children. The businessman formerly worked as a technician in the IER Food Technology Lab and was financed by a loan from a Canadian agency. The product has been in production for nearly two years. It is being prescribed by medical staff for children suffering malnutrition. It is not a complete weaning food, but it definitely has improved nutritive value at a reasonable cost compared to other more completely balanced imported weaning foods. The viscosity of the weaning food is too high, hence our work on sorghum malt to reduce the viscosity and improve nutrient density is of practical importance.

Increased emphasis on developing improved local photosensitive sorghums with tan plant and straw glume color by the plant breeders will provide grain with adequate quality for processing into high quality milled products which can be sold at competitive prices compared to rice, maize grits and meal. These value-added sorghum cultivars will be the basis for identity-preserved production for processing into higher value products. New products from existing sorghums have off-color and poor quality that cannot be overcome until improved grains are obtained.

Honduras and Mexico

Dr. Lloyd W. Rooney and Dr. Helbert D. Almeida-Dominguez, Research Scientist, TAMU, Cereal Quality Laboratory assisted Dr. Francisco Gomez in procuring equipment for a food processing laboratory at EAP in San Zamarano. Samples and other items were exchanged between the laboratories. The acquisition of extrusion and tortilla cooking equipment at EAP will be a major step forward to increase knowledge of utilization in Central America. We hope to have another student from EAP.

Dr. Almeida-Dominguez traveled to Merida, Mexico to interact with food scientists and graduate students at the Institute of Technology who are conducting research on sorghum food and malting quality. This research was partially funded by the International Foundation for Science in Sweden. Students from Merida have conducted special analysis in the Cereal Quality Laboratory.

Dr. Lloyd W. Rooney gave a special keynote lecture on Cereal Quality at the Sixth International Symposium on Food Industry and Engineering held at Monterrey Institute of Technology in Queretaro, Mexico in September. More than 200 participants from industry and academic institutions in Mexico and South America were present. Lloyd W. Rooney participated in a Tortilla Seminar sponsored by the American Soybean Association in Mexico City where a brief description of sorghum tortilla production prospects was presented along with maize tortilla processing quality. Three graduate students from Mexico joined the Cereal Quality lab in 1995-96.

L.W. Rooney has a cooperative project with Dr. S. Serna-Saldivar, Professor and Head, Food Science, Instituto Tecnologico y de Estudios Superiores de Monterrey (ITESM), Monterrey, Mexico, to evaluate the usefulness of the new improved food sorghum hybrids in wet and dry milling and as adjuncts in brewing. Dr. Serna-Saldivar and three MS students conducted sorghum and maize analyses in the Cereal Quality Laboratory for two weeks. The research is supported by industry in Mexico. We have provided samples of sorghum for planting and for analysis in addition to the use of our laboratory for some analytical tests.

Australia

Lloyd Rooney was the keynote speaker for the 3rd Australian National Sorghum Conference held in Tamworth, New South Wales in 1996. His presentations were on: 1) food utilization, and 2) the effect of the protein matrix on sorghum digestibility and processing. He presented seven additional seminars to farmers, agribusiness leaders, feed and grain dealers, feed processors and industrial groups in Queensland and New South Wales. Sorghum utilization in Australia is primarily for feed, but there is a significant interest in the improvement for food and feeds. Australian feeders and feed processors generally do not understand the need to process sorghum differently from barley or wheat.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in San Antonio, Texas. Drs. Helbert Almeida-Dominguez and Ralph D. Waniska participated in the Food Technology Exposition in New Orleans, LA. L.W. Rooney presented sorghum quality/utilization discussions to Texas Sorghum Producers Board Members, to sorghum production conferences in Corpus Christi and Weslaco and other farm groups. Dr. Waniska presented information on sorghum utilization and potential commercial products at the Husker Feed Grain conference in Kearney, NE.

Training, Education and Human Resource Development

Mr. Haiyan Zhao, a visiting scientist from the Peoples Republic of China joined the Cereal Quality Laboratory for a nine month study program to learn about post harvest technology of sorghum. He works in the National Research Center for Sorghum in Laioning, China. He is especially interested in the industrial utilization of sorghum for food and feed. He is currently working with Dr. Waniska and others on weathering and grain mold resistance studies in relation to grain quality. He will learn food processing research activities.

We have provided information to a number of scientists around the world who have been involved in sorghum and millet research. Several students from Mexico have used our facilities for part of their research projects especially those from Monterrey Institute of Technology.

A Honduran graduate student, Mr. Javier Bueso, EAP graduate identified by F. Gomez, is working on his MS degree in food science and technology. He is continuing the work on the role of antifungal proteins on grain mold resistance in sorghum which is lead by Dr. Waniska. In addition, he is involved with food processing and quality evaluations of sorghum and maize. His English is excellent and he has done well academically. He has laboratory and field research underway with the sorghum breeding program led by Bill Rooney.

Five graduate students are currently working on INTSORMIL related research, although they are only partially financially supported. Projects include milling properties of sorghum, steam flaking, starch technology, malting, weaning food production, extrusion, and grain molds.

L.W. Rooney completed his term as chairman of the Sorghum and Millet Working Group of the International Association for Cereal Science and Technology.

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Host Country Program Enhancement

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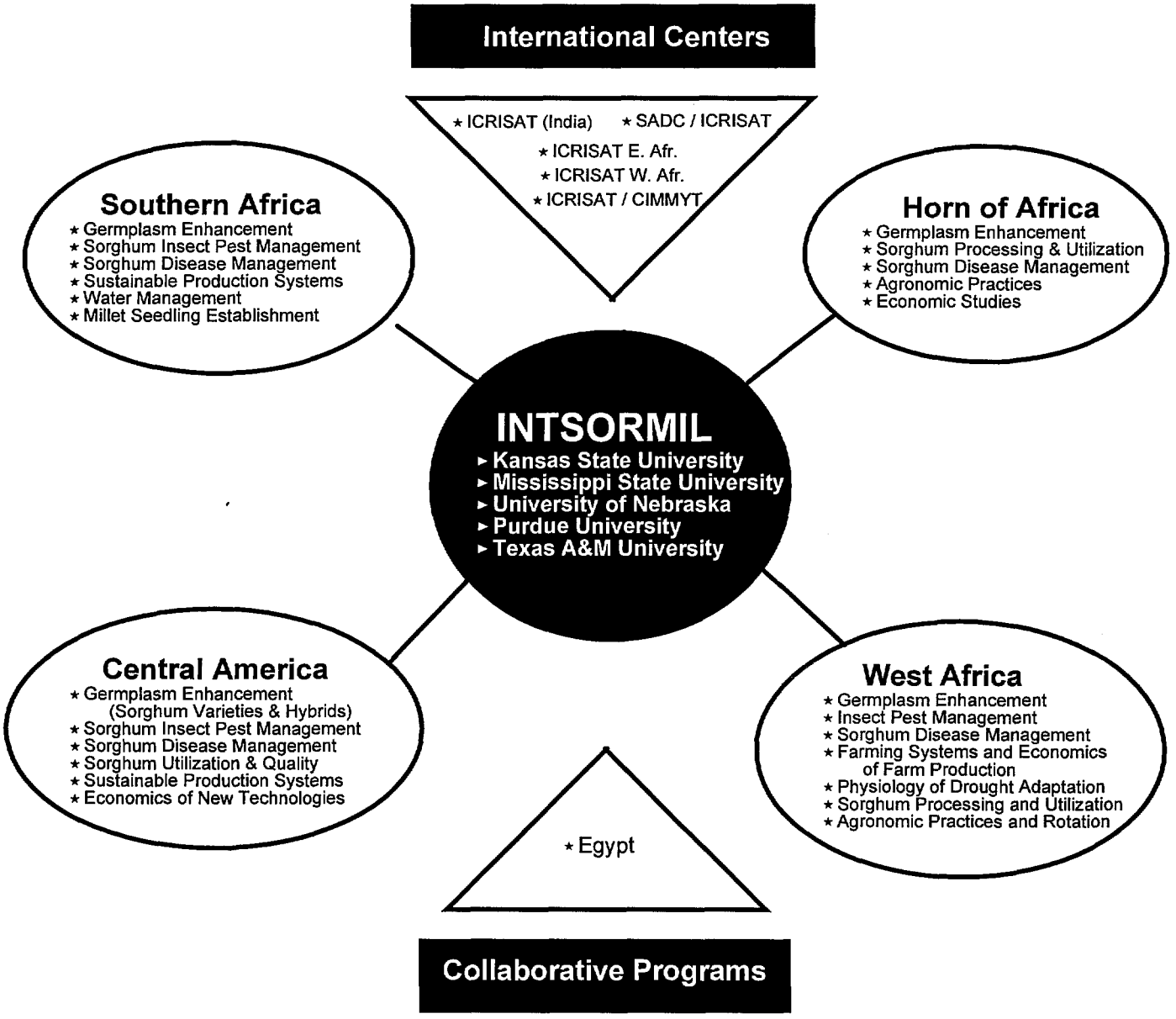
International Centers
★ ICRISAT (India)
★ SADC / ICRISAT
★ ICRISAT E. Afr.
★ ICRISAT W. Afr.
★ ICRISAT / CIMMYT
Southern Africa
★ Germplasm Enhancement
★ Sorghum Insect Pest Management
★ Sorghum Disease Management
★ Sustainable Production Systems
★ Water Management
★ Millet Seedling Establishment
Horn of Africa
★ Germplasm Enhancement
★ Sorghum Processing & Utilization
★ Sorghum Disease Management
★ Agronomic Practices
★ Economic Studies
INTSORMIL
► Kansas State University
► Mississippi State University
► University of Nebraska
► Purdue University
► Texas A&M University
Central America
★ Germplasm Enhancement (Sorghum Varieties & Hybrids)
★ Sorghum Insect Pest Management
★ Sorghum Disease Management
★ Sorghum Utilization & Quality
★ Sustainable Production Systems
★ Economics of New Technologies
West Africa
★ Germplasm Enhancement
★ Insect Pest Management
★ Sorghum Disease Management
★ Farming Systems and Economics of Farm Production
★ Physiology of Drought Adaptation
★ Sorghum Processing and Utilization
★ Agronomic Practices and Rotation
★ Egypt
Collaborative Programs

Honduras and Central America

Francisco Gómez
Texas A&M University

Coordinators

Dr. Francisco Gómez, Host Country Coordinator, National Sorghum Program (NSP), Escuela Agrícola Panamericana (EAP), P.O.B. 93, Tegucigalpa, Honduras.
Dr. Gary C. Peterson, Country Coordinator, Texas A&M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79401-9757.

Collaborating Scientists

Agr. Jorge Morán, Agronomist, EAP, Department of Agronomy
Ing. Alberto Morán, Agronomist, EAP, Department of Agronomy. Stationed at the La Lujosa Experiment Station, Choluteca, Honduras (until March, 1996)
Dr. Alan Hruska, Department Head, EAP. Plant Protection Department
Dr. Ronald Cave, Biocontrol, EAP, Plant Protection Department
Dr. Rubén Núñez, Agricultural Economist, PRODEPAH/AID (Agricultural Development Policy Project), Tegucigalpa
Ing. Patricio Gutierrez, Ph.D. Degree Candidate, Agronomy Department, University of Nebraska, Lincoln, NE
Ing. Hector Sierra, M.S. Degree Candidate, EAP, Department of Range Science, Texas A&, College Station, TX 77843
Ing. Pedro Calderón, M.S. Degree Candidate, Department of Entomology, Mississippi State University, Mississippi State, MS 39762
Ing. Oscar Vergara, M.S. Degree Candidate, Department of Entomology, Mississippi State University, Mississippi State, MS 39762
Ing. Roberto Cordero, M.S. Degree Candidate, Department of Entomology, Mississippi State University, Mississippi State, MS 39762
Ing. Javier Bueso, M.S. Degree Candidate, Cereal Quality, EAP, Department of Agronomy
Ing. Guillermo Cerritos, Asgrow of Central America, Honduras
Ing. M.S. Alejandro Palma, Breeder, Dekalb of Central America, Honduras
Ing. Carlos Merlo, Agronomist, Cargill of Central America, Honduras
Ing. Mark Weiholtz, Agronomist, Pioneer of Central America, Honduras
Ing. Antonio Cristiani, Manager, Cristiani Burkard, Guatemala
Ing. José Montenegro, Director, DICTA, Honduras
Ing. Laureano Pineda, Agronomist, INTA, Nicaragua
Ing. Oscar Martínez, Agronomist, ICTA, Guatemala
Agr. René Clará, Agronomist, CENTA, El Salvador
Agr. Nivaldo de Gracia, Agronomist, IDIAP, Panamá
Dr. Darrell T. Rosenow, Texas A&M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79401-9757
Dr. Lloyd Rooney, Cereal Quality Laboratory, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. Henry Pitre, Entomologist, Department of Entomology, Drawer EM, Mississippi State University, Mississippi State, MS 39762
Dr. Richard Frederiksen, Plant Pathologist, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843

Objectives, Production and Utilization Constraints

Objectives

Conduct maicillo research including breeding nurseries, advanced yield tests and on-farm demonstration trials with new maicillo technologies in southern Honduras.

Conduct the sorghum downy mildew nurseries at Comayagua.

Evaluate sorghum cultivars and advanced lines for anthracnose.

Validate and promote sorghum grain standards for Honduras and Central America

Production of basic seed of a broomcorn cultivar with long fiber.

Train small entrepreneur on broom manufacture.

Publish the results of grain sorghum performance trials for CLAIS Central America.

Support the Latin American Sorghum Commission (CLAIS).

Develop an agricultural experimental and training station at Zamorano

Train next generation sorghum scientists for Central America

Constraints

In 1993, grain sorghum production in Central America reached 446,136 MT. This grain is produced on about 356,000 ha in Central America (UPSA, 1994). Since 1990, this region is experiencing a dynamic change in sorghum consumption due to changes brought about by globalization of international markets, regional and local agricultural policies, availability of enhanced production technologies and adaptation attributes of the sorghum. For the time period of 1990-1993 sorghum production in Central America grew 18 percent, at a rate of 4.42 percent a year. On the other hand, maize, the most important cereal crop in the region, only grew 5 percent, or a yearly rate of 1.16 percent (UPSA 1995).

Utilization

Sorghum is successfully replacing maize in animal feed and releasing an equivalent amount of white maize for human consumption. Estimated sorghum consumption by the agroindustry in Honduras has increased 1361 percent for the time period of 1985 to 1993–from a meager 4091 MT to 55681 MT. These values represent an average increase of 5732 MT per year. On the other hand, utilization of maize by the agroindustry has been leveled off at 100000 MT, primarily by the sorghum and feed wheat replacement in animal rations (UPSA, 1995).

Similar trends are observed for the whole region where sorghum consumption has increased 2.3 times that of maize. For the time period of 1990-1993, sorghum consumption in the region increased 16.3 percent while maize increased 7.2 percent. These data illustrate the importance of sorghum in the cereal production and utilization system in Central America.

New alternative uses of sorghum need to be develop to encourage a sustainable growth of the industry including both improved maicillos and commercial hybrids. White grains with tan plant color sorghums are well adapted to central American food and feed systems.

Marketing

Trends in increasing sorghum utilization have made this cereal a key commodity to overcome maize shortages and consequently an important food security crop. New Central American free market policies require that sorghum and maize prices fluctuate according to world prices, but applying an import tax within the range of 5 and 45 percent, to promote local production and demote speculation.

Grain quality standards for regional commercial transactions are needed to promote market prices. Agricultural commodity exchange offices are being established in each Central American country and demanding grain quality standards.

A very important regional market is being developed, where Honduras and Nicaragua are the main exporters and El Salvador and Costa Rica are the importers. This is a logical evolution of the incipient Central American agricultural free market economies, since Honduras and Nicaragua's GNPs are based on agricultural commodities outputs.

Sorghum Landraces (Maicillos)

Conservation and Evaluation of Maicillo Diversity. Maicillo Criollo is the local name for tropical landrace sorghum populations found in semi-arid regions of Central America which range along the Pacific side of the isthmus from southeastern Guatemala through El Salvador and southern Honduras, south to Lake Nicaragua. Maicillo is the last remnant of tall, photoperiod sensitive sorghum brought to the new world and for the most part is an unexplored gene pool that covers some 235,000 ha or 67% of the sorghum acreage in Central America. Although maicillo is of African descent, it possesses unique traits for adaptation to traditional maize intercropping systems and local food processing customs. These changes have come about through allopatric differentiation and artificial selection by small farmers in Central America. As the need to boost sorghum productivity increases in Central America, maicillo is slowly being replaced by higher yielding but uniform sorghum cultivars This process not only threatens the extinction of many undiscovered useful genes, but increases the probability of an epidemic occurring.

Low Yield Potential. National sorghum yield in Honduras has increased from less than one metric ton per hectare to 1.1 metric ton per hectare in the last 5-year period. Not only is this a reflection of the adverse environment in which sorghum is grown, but it is also a result of the preponderant use of landrace sorghum populations which have low but stable yield. The inability of maicillo criollo to respond to management practices with increased grain yield is the primary constraint to sorghum production. Before new tech-

nologies like soil and water conservation interventions can improve soil fertility and become economically feasible, the genetic potential of traditional cultivars to respond with increased grain production must be enhanced. Increase in sorghum yield and area is primarily due to the utilization of commercial cultivars (hybrids and varieties), which are boosting sorghum production in Central America.

Traditional Farming Systems. Maicillo is an old world crop that has adapted to neotropical slash and burn agroecosystems. More than 60 percent of the sorghum planted in Central America is late maturing landrace populations which are intercropped with early maturing maize. Although maize is the preferred staple, it is often intercropped with sorghum by subsistence farmers in hot, erratic rainfall areas as a hedge against drought. Maicillo's sensitivity to photoperiod and its ability to withstand shading are essential for its adaptation to traditional maize intercropping systems. In contrast, introduced cultivars require genetic modification before they can be used in these systems. Study of sorghum-maize intercropping systems is necessary to develop an understanding of how they work and what agronomic and genetic changes will increase their productivity.

Photoperiod Sensitivity. Maicillo Criollo has an acute sensitivity to photoperiod and day lengths of 12 h or less are required for floral initiation. In Central America, floral initiation occurs during the first fortnight of October regardless of the spring planting date. Because of maicillo's short day requirement, it fails to flower before the first frost in the United States. Consequently, its improvement must be carried out within its domain in the Tropics (12-15° N lat.).

Additionally, the photosensitive response prevents maicillos from spreading beyond their very defined agroclimatological range. For maicillos to produce good quality edible grain, dry conditions during maturity must occur. Other high rainfall areas with different precipitation patterns need appropriate sorghum types to take advantage of better environments for biomass production.

Improved Sorghum Cultivars

Cultivar evaluation. Commercial seed companies marketing improved varieties and hybrids require an unbiased evaluation of their materials for yield and adaptation. Six seed companies–Asgrow, Dekalb, Pioneer, Cargill, Seminal and Cristiani Burkard are now marketing a wide variety of hybrids. Multilocation testing is of paramount importance to expose new hybrids to farmers and seed distributors. Publications and field days are key to expose farmers to the newest most adapted cultivars and guide the national certification offices to allow specific hybrids to be marketed.

Parental lines for hybrid production The seed industry in Central America is experiencing a revitalization through the new open market initiatives. Even though international seed companies are doing an excellent job in disseminating sorghum hybrids, national small seed industries are also demanding parental lines for hybrid production.

Uniform regional seed standards. The Central American open market is promoting an exchange of agricultural goods including seeds, among participant countries. Furthermore, some Central American companies are encroaching into the southern Mexican and south American markets of sorghum seed. This represents a good opportunity to export tropical adapted sorghum hybrid seeds developed in Central America. Uniform seed standards are becoming important to promote seed exchange among these different regions. AOSCA (International Association of Seed Certification Agencies) standards provide the baseline support to use uniform standards.

Management practices. Exploiting high yield potential bred into the improved varieties and hybrids through enhanced management practices, requires a systematic on-farm testing and demonstration program. The low average grain yield (2.5 MT ha^{-1}) attained with improved cultivars is a reflection of several poor agronomic practices ranging from seedbed preparation, plant densities, weed control, early season pest control and harvesting time.

Insect Pests. An early season lepidopterous pest complex, called the langosta by Honduran farmers, is an important constraint to sorghum and maize production in the region. The fall armyworm, along with other lepidopterous larvae—*S. eridania, Metaponpneumata rogenhoferi,* and *Mocis latipes*—wreck havoc each spring by chaotically attacking seedling fields with little or no warning. Understanding the complex, its species diversity, density, time of occurrence, and origin, is necessary to develop an adequate control strategy.

New low-toxicity seed treatment insecticides have proved to provide outstanding early season pest control. This technology needs to be demonstrated and transferred to ensure appropriate plant densities and increased yields.

Sorghum Downy Mildew. Sorghum Downy Mildew (SDM) is a recently introduced disease that is endemic in the region. Not only is maicillo susceptible to SDM, but the threat of this disease is compounded by the existence of the most virulent pathotype, P5, of *Peronosclerospora sorghi* reported in the Americas which was discovered at Las Playitas Experiment Station, Comayagua, Honduras in 1986. Because maicillo and most sources of resistance in the United States are susceptible to P5, the pathogen threatens the stability of sorghum production in Honduras and Central American. The introduction and deployment of resistant genes offer the best alternative for control. Evaluation of commercial and experimental entries in Comayagua is providing an insurance against this disease.

Anthracnose. Anthracnose poses a major disease threat in Honduras and probably throughout Central America; therefore, a program to increase the level of resistance to

sorghum is an urgent need. Deployment of a susceptible hybrid in the Olancho area, for example, can be devastating. Consequently, the anthracnose reaction of all commercial hybrids needs to be obtained, if for no other reason than to avoid the growing of an otherwise excellent hybrid that may have a susceptible reaction to anthracnose. The maicillo sorghums have been evaluated for their reaction to *Colletotricum graminicola*, the pathogen causing anthracnose. Pathotypes attacking maicillos genetically resemble those ones attacking *Sorghum halapense* in the United States. Evaluation of commercial hybrids to anthracnose damage in traditional farming systems is much of great importance for the region. Concurrently, a program on the extent of pathogen variability, much like what was done for the downy mildew pathogen is being implementing for Honduras. However, aspects of this program should include the evaluation of isolates from other countries in Central America, since isolates from Honduras have shown to be genetically similar (Rosewich, 1994 personal communication).

Leaf blight. Even though leaf blight is not a wide spread disease, it has the potential to cause significant losses at higher altitudes. There have been some trends that indicate a slowly but steady increase in leaf blight susceptibility, specifically in the parental lines Tx623, Tx626 and some commercial hybrids bearing susceptible parents. A systematic screening scheme and gene deployment is needed to anticipate epidemics.

Broomcorns

Seed availability of broomcorn cultivars. Broomcorn fiber is either imported from Mexico by two or three companies in Central America, or produced by small farmers using seed removed from the imported fiber. The result is an increase in costs from imported fiber and poor fiber quality produced by small farmers. A constant seed supply of appropriate broomcorn cultivars offers an alternative to foster the broom industry.

Varietal development and adaptation. Two broomcorn varieties developed by the Sorghum Project possess excellent yield and downy mildew resistance; however, most of their fiber yield does not qualify as hurl, that is the longest fiber used for the broom exterior. For this reason a long fiber broomcorn with the same yield and defensive attributes has been developed. Non-government agencies request a steady seed supply of broomcorn varieties with higher yield of hurl type fibers that compete with Mexican imported fiber. Training of small entrepenuers is needed to foster broom production.

Experimental Station Management

Training. Sorghum scientists in the region are constantly facing the lack of experimental station management capabilities. These scientists, in addition to conducting their own sorghum research, are frequently asked to manage the experimental station where they work. Basic knowledge on planning and running an experimental station needs to be built into the sorghum scientist curriculum at EAP.

Mechanization. Proper field operations are of great importance in the process of on-farm demonstration in high yielding sorghum producing areas. Implementing a totally mechanized experimental station at Zamorano, will serve to demonstrate basic agronomic practices such as plant densities, weed control and fertilizer application to sorghum producers. Procurement of equipment for precision planting, soil preparation and harvesting needs to be pursued in the short term.

Research Approach and Project Output

The Honduras/Central America Sorghum Program is a small program headquartered at Zamorano Panamerican Agricultural School. At Zamorano, the Sorghum Project is adjoined to CITESGRAN (International Center for Seed and Grain Technology) heading by Dr. Francisco Gómez. This new arrangement favors a multidisciplinary approach to solving sorghum production and it fosters utilization research.

The program continues to be very productive. Much of its success stems from the continuity and stability provided by multi-institutional arrangements, AID/HO local funding, as well as the contributions that the Sorghum Project is continuously offering to the Agronomy Department at Zamorano. The program has established an elaborate network of collaborators in Honduras that includes both GOH and PVOs. At present, four sites are used to evaluate commercial hybrid performance and are also utilized to screen maicillo breeding materials for an array of biotic and abiotic stress factors. Numerous other collaborators and sites are used to validate new sorghum cultivars and other technologies on-farm. Multi-location testing is essential for developing cultivars with broad adaptation and resistance to multiple diseases.

Two technical thrusts that this Project focuses on are: a) conservation of local landrace sorghum populations and their enhancement; and b) development and adaptation of high yielding improved cultivars. The first thrust deals with maicillo or photoperiod sensitive sorghum and the success of one activity depends upon the other. The approach to conservation is a passive, *in-situ* approach, whereas enhancement is an active, more aggressive approach. The second thrust deals with photo period insensitive sorghum germplasm and has achieved great importance in augmenting production and productivity

Conservation

The success of all breeding programs depends on available genetic resources. When working with unique cropping systems, such as sorghum-maize intercropping, it is essential to have access to germplasm that is adapted to these peculiar conditions. Central America accommodates an ar-

ray of such genetic resources that is cared for in a gene pool that spans some 235,000 ha. The program objective is to continue to conserve, even enhance, this genetic diversity *in-situ* where it will continue to evolve and serve mankind.

Replacement of maicillo by exotic photoperiod insensitive germplasm represents a threat to genetic diversity, and to the maize-maicillo intercropping system used by small farmers in the semi-arid regions of Central America. The programs approach strives to conserve maicillo *in-situ* and is relevant to areas where landrace populations dominate traditional farming systems. Its success hinges on our ability to upgrade local landraces populations that are then returned to farmer's fields.

The sorghum project has assumed the responsibility for conserving this sorghum gene pool. The goal of our conservation effort is to create a mosaic of maicillo, enhanced maicillo, and improved variety fields in which genes flow freely among these different kinds of sorghum. Ostensibly, an informal network of village level landrace custodians will care for this germplasm as they have cared for maicillo. The creation of enhanced maicillo cultivars and their subsequent deployment on-farm, not only is intended to increase genetic diversity *in-situ*, but to stave off maicillo's replacement by introduced cultivars not adapted to local cropping system and with a narrow genetic makeup.

A long term program was initiated in 1981 to genetically enhance and reduce genetic erosion in the maicillo germplasm, through a systematic deployment of enhanced maicillo cultivars as vectors of elite exotic alleles. Deploying these elite alleles for yield, quality and resistance to biotic stresses among maicillo populations are the first steps in conserving the adaptive gene pool of maicillo. Quantification of the degree of fixation of the exotic elite alleles deployed in previous years, will help us to determine threshold levels for the survival of elite maicillo alleles. First enhanced maicillos were first tested on farmers' fields in 1987.

In situ conservation of maicillo germplasm has contributed several useful traits to sorghum world gene banks. In addition, there is some indirect evidence that different alleles at the Ma_1 locus–responsible for the acute photosensitivity response are present in the maicillo populations. Although the value of these genes is still not known, they are genetic resources that would have been lost had we disregarded maicillo. These traits were found through a team effort forged by the INTSORMIL scientist network.

Enhancement

Our enhancement work is based on a set of short-, mid-, and long-term goals. Each time frame is concerned with a different kind of sorghum. Short-term goals deal with the introduction and release of elite cultivars, whereas mid-term goals deal with the development of enhanced maicillo varieties. Long-term goals concentrate on developing maicillo hybrids.

Introductions Previous near-term goals have been met with the introduction and release of three food type cultivars: Tortillero, hybrid Catracho, Sureño and a sorghum-sudangrass forage hybrid Ganadero (ATx623*Tx2784). Our present short-term goals are to round out our sorghum portfolio with the release of a red seed grain sorghum hybrid (ATx626*R8503), and three broomcorn varieties. This next generation of releases reflect a change in our attitude towards development which is shifting from self-sufficiency to self-reliance.

Fifty pound bags of this new hybrid were given to sorghum producers from several locations across Honduras to measure its acceptability. Farmers expressed very positive opinions about its performance and yield attributes.

Zam-Rojo, the name with which this new hybrid is to be marketed, continued to show outstanding yield performance and adaptation under dry and irrigated areas. During the 1995 Grain Sorghum Performance Trials at eight locations in Central America, Zam-Rojo yielded 5.2 t ha^{-1}. Table 1 presents the average yield performance of Zam-Rojo over eight locations in Central America.

Zamorano will start producing seed of this hybrid in September 1996. Initially, Zamorano will produce foundation and certified seed, and as soon as any local seed company request seed of the parental lines, they will be sold and production will be supervised to assure quality seed.

Broomcorn. A significant amount of information on broomcorn production and marketing has been accumulated in the Sorghum Project.

Broomcorn research was aimed to select a long fiber variety to compete more successfully with imported fiber. Late in 1994, we carefully began increasing seed of a long fiber broomcorn from our collection at Zamorano, that also exhibits good level of downy mildew resistance. This new cultivar is significantly taller than ZAMES-1 and ZAMES-2 and has been named ZAMES-3. An isolated field of this broomcorn was planted to produce breeder seed in August 1995 at Zamorano. Later on January 1996, another field was planted to produce approximately 200 kg of basic seed to later produce certified seed.

Enhanced Maicillo Varieties. Development of enhanced maicillo varieties or photoperiod sensitive sorghum dominates our mid-term goals. This activity is the crux of our conservation effort because it creates the plant vectors that will further the introgression of new genes into the maicillo population *in-situ*, while simultaneously improving crop yields.

Specific maicillo breeding objectives are: 1) reduce plant height which, in effect, shifts the stem to panicle sink ratio

Table 1. Average grain yield performance of 28 grain sorghum cultivar over eight locations in Central America during 1995 (t ha^{-1}).

Hybrid	Company	Guatemala	Honduras	Nicaragua	Panama	Average
CBX-896-3	Cristiani Burkard	5.6	4.9	8.4	4.8	5.9
CBX-896-4	Cristiani Burkard	5.5	4.6	7.6	4.6	5.6
8418	Pioneer	5.0	5.0	8.0	4.4	5.6
CBX-896-5	Cristiani Burkard	5.5	4.4	7.0	5.2	5.5
PPS 92-12	Dekalb	5.4	4.5	8.3	3.5	5.4
8641	Pioneer	5.4	5.1	6.4	4.7	5.4
Apolo	Cargill	5.0	4.1	8.3	4.1	5.4
8232	Pioneer	5.3	4.9	6.1	4.5	5.2
CBX-896-1	Cristiani Burkard	4.9	4.3	7.6	4.0	5.2
ATx623*SC414-12	EAP/SRN	5.0	4.5	7.1	4.1	5.2
DK 64	Dekalb	4.6	4.2	7.7	4.2	5.2
ATx626*R8503	EAP/SRN	4.3	4.6	7.1	4.6	5.2
CBX-896-2	Cristiani Burkard	4.7	4.8	7.2	3.8	5.1
8428	Pioneer	4.8	3.6	7.1	4.7	5.0
CBX-896-6	Cristiani Burkard	4.8	4.0	6.7	4.7	5.0
X 469	Dekalb	5.4	4.7	6.5	3.3	5.0
DK 55	Dekalb	4.5	4.0	8.4	2.7	4.9
8433	Pioneer	4.4	4.0	6.2	4.4	4.8
Marte	Cargill	4.6	4.1	8.6	1.8	4.7
8305	Pioneer	4.7	3.6	6.3	4.3	4.7
Turqueza	Asgrow	4.4	3.7	6.0	4.7	4.7
Jupiter	Cargill	4.2	4.8	7.1	2.5	4.7
X 528	Dekalb	4.1	4.2	6.3	3.8	4.6
X 9504	Dekalb	4.1	4.6	6.2	3.3	4.6
8310	Pioneer	4.1	3.7	6.2	4.2	4.5
Topaz	Asgrow	3.6	3.6	7.1	3.5	4.4
Pagador	Cargill	4.5	3.4	7.6	0.4	4.0
5560	Cargill	3.7	3.0			3.3
Average		4.7	4.2	7.1	3.9	5.0

in favor of producing more grain; 2) add tan plant color which reduces the amount of polyphenols in the pericarp and thereby improves grain quality for making tortillas; 3) increase resistance to foliar diseases like rust and cercospora which enhances forage quality, as well as, grain yield; 4) incorporate resistance to sorghum downy mildew which is endemic in the region and threatens stable maicillo production; 5) select for longer panicles and better head exertion which augments yield through increased seed number; and 6) maintain several important maicillo characteristics such as maturity, white seed color (w/o testa), and shade tolerance. Other characteristics that have carried over from maicillo, that we have not directly selected for, are resistance to anthracnose and an increased level of soluble carbohydrates (Brix) in the stem. Because photoperiod sensitivity is maintained in enhanced maicillo cultivars, this work can only be done in the region.

Three locations are used to screen segregant populations. Selections for drought stress and shade tolerance is done at at Rapaco, resistance to sorghum downy mildew at Comayagua, and resistance to foliar diseases at Choluteca. In 1995 about 10 ha of nurseries were planted at these three locations and 5759 selections were made. Most of these selections had tan plant color, white grain and most were 2-3 dw.

As superior lines are identified in more advanced generations, F_6-F_7, they are placed in the International Improved Maicillo Yield Trial (EIME). This is a multi-location yield test (referred to as EIME in Spanish) used to select materials for on-farm demonstration plots. The 1995 EIME consisted of 22 entries and was planted at five locations in Honduras: Choluteca, Comayagua, Olancho, Rapaco, and Zamorano (Table 2).

Zamorano produced the highest grain yield of all locations (4493 kg ha^{-1}), while Rapaco, the driest environment, showed the lowest. Wet environmental conditions in all other environments prevented adequate nitrogen absorption.

Gigante Mejorado as well as Porvenir Mejorado showed outstanding performance across all five location. One new enhanced maicillo derived from Sureño*Caturra crosses, showed for the third year notable characteristics. Other new enhanced maicillo- [(Sepon 77*Santa Isabel)-derivatives and TAM428*MC100 expressed excellent grain yield advantage in at least two locations. Seed of these new generation of maicillos are now being tested on farmer's fields through an on-farm demonstration system.

On-Farm Research

On-farm demonstration plots. The on-farm testing program is an integral part of *in-situ* conservation. Not only does this activity enable the program to collect maicillo from farmers most likely to trade-in their old cultivars, it provides the mechanism whereby enhanced maicillo cultivars—the vectors for transferring exotic genes—are introduced into the maicillo population. Since maicillo is a living system, the approach to conservation stresses the deployment of an

Table 2. Grain yield of 22 maicillo cultivars in the EIME, over five locations in Honduras, 1995.

DMV	Color	Pedigree	CH	CM	OL	RA	ZA	Ave.
MC	wh/Pss	Pelotón	4968	2470	2692	2063	5890	3616
137	whT/R	(TAM428*Porvenir)-29-2-3-b-b	3149	2945	3134	3008	5844	3616
179	whT/T	(SPV346*Gigante Pavana)-1-1-2	3154	3403	2787	2016	6169	3506
238†	wh/R	[(Sepon 77*Santa Isabel)-6*ICSV-151}-6-2-1-2-4-1	3111	2486		1535	6128	3315
198	wh/T	(TAM428*Porvenir)-29-1-1-b-b-1-b	2814	3001	2614	1963	4986	3075
MC	whT/P	San Bernardo III	3158	2929	2326	1722	4633	2954
239†	wh/T	[(Sepon 77*Santa Isabel)-6*ICSV-151}-6-2-1-2-4-4	2439	2627		1866	4811	2936
240†	whT/P	[(Sepon 77*Santa Isabel)-6*ICSV-151}-6-2-1-2-4-8	2795	2358		1645	4944	2936
MC	wh/P	Porvenir	3213	2708	2160	1882	4647	2922
235†	wh/T	[(TAM428*S.B.III)-17*(CS 3541*Lib.)-6]-19-1-2 (prov.F7 93R 3448-5)	2325	1980	3100	1642	5203	2850
221	wh/T	(Sureño*Caturra 68)-3-3-2-1	2434	1185	2123	1858	6449	2810
237†	wh/T	[(Sepon 77*Santa Isabel)-6*ICSV-151}-6-2-1-2-1-1	2801	1814		1735	4780	2782
234†	whT/T	[(TAM428*S.B.III)-17*(CS3541*Lib.)-6]-19-1-2(prov.F7 93R3448-1)	2148	2417	2483	1911	4811	2754
213	whT/R	{[SPV346(81LL691*Billy)]*(SC414*P.N.)}-7-1-b	3068	2204	2170	1685	4181	2662
241†	wh/T	{[(TAM428*77CS3)GPR1480 Billy]-24*(SPV346(81LL691*Billy)-7]-36}-46	3613	1736	2077	1173	4129	2546
218	whT/R	{[SPV346 (81LL691*Billy)]*(SC414*P.N.)}-4-1-1	2092	1667	2970	1464	4114	2462
219	whT/T	{[SPV346 (81LL691*Billy]*(SC414*P.N.)}-25-3-4	3394	1601	2758	1543	2754	2410
210	whT/T	(TAM428*MC100)-2-2	2094	1670	1544	1710	5014	2407
MC	wh/P	ES 727	3203	1545	2221	1250	2217	2087
228	whT/T	{[SPV346(81LL691*Billy)]*(SC414*P.N.)}-41-1-2-2	2315	1434	2811	1179	2248	1997
236†	wh/T	{[(SC326-6*SC103-12)Liberal-40]*SC1207-2}-10-2-1-5-1	2095	1015	2266	1136	2576	1817
002	wh/P	Lerdo Ligero	1022	1996	2373	1163	2325	1776
		Average	2791	2145	2478	1689	4493	2738

CH=Choluteca, CO=Comayagua, OL=Olancho, RA=Rapaco, ZA=Zamorano, Ave=Av erage

array of enhanced maicillo germplasm, by testing different cultivars on-farm each year, rather than formally releasing varieties which would eventually saturate the formal seed market and slow the introgression of new genes into the maicillo population.

Every year several on-farm demonstration plots are planted to expose small farmers to enhanced maicillo cultivars along with a gradient of new improved production technologies. New technologies are: enhanced maicillos, chemical protection to the "langosta" insect complex and 60 kg ha^{-1} of nitrogen applied at floral differentiation (last week of September.)

Results obtained from 95 on-farm demonstration plots during 1992 though 1995, indicate that enhanced maicillos out yielded maicillo criollos at all technological levels. There is an average increase in grain yield of 0.45 t ha^{-1} by merely replacing the maicillo cultivar by either one of the enhanced maicillos. Increase in plant population as a result of controlling the "langosta" insect complex and expressed as the number of harvested heads, shows a significant relationship with grain and forage yield. Finally, the application of 60 kg ha^{-1} of N, clearly demonstrates the efficiency in N assimilation of improved maicillos over the criollos. Maicillo grain yield is easily doubled by planting the enhanced maicillos with "langosta" control and 60 kg of N ha^{-1}.

Enhanced maicillos also show a reduction in height of 0.5 m with respect to maicillo criollos. Forage quality is substantially increased by 3-4° Brix, which turns the stover more nutritious and palatable to cattle. Maturity has been kept at one week earlier than maicillos criollos. This earliness is adequate for escaping late dry periods, and minimizing grain molds.

Agronomy. To move the sorghum yield plateau in hillside farms in southern Honduras, it is first necessary to increase the genetic potential and defensive capabilities of maicillos. Furthermore, it is necessary to stabilize the farm with soil and water conservation techniques (Gómez, 1990). Studies conducted by Thompson (1991), in Namasigüe, Choluteca, demonstrate that the use of soil conservation structures built by "Proyecto L.U.P.E" and other NGOs, minimize soil losses, increase organic matter accumulation, improve water holding capacity, resulting in a significant increment in biomass production of 35 percent (8,687 versus 5,563 kg ha^{-1}).

Special Projects

The sorghum project has been successful in establishing several special projects and a thorough collaboration with CITESGRAN (International Center for Seed and Grain Technology), i.e., commercial hybrid performance tests, which is sponsored by private seed companies and establishment of a new seed plant and grain processing plant. These activities augmented the effectiveness, stability and outreach of the program. These projects are administered by the EAP and managed by Dr. Gómez and are exemplary of the kinds of sustainability being built into the program.

Commercial Hybrid Testing. Central American Governments have privatized the seed industry. The national sorghum program assists this endeavor by conducting a commercial hybrid performance test for private seed companies. This testing program began in 1989 and is the only public listing of commercial cultivars available, along with their performance, and seed distributors in Honduras and Central America. This is another example how the sorghum project continues to lead by example. In 1995, testing took place in eight locations of Central America: Comayagua, Zamorano, Catacamas in Honduras, Tiquisate and Cuyuta

in Guatemala, Posolteca and Managua in Nicaragua and El Ejido in Panamá. This is the first time that the INTSORMIL program efforts are crossing borders in Central America.

The commercial hybrid performance test has helped foster the fledgling Central American sorghum industry in several ways. First, it allows the commercial seed companies to up-grade their hybrids. Thus, farmers have access to better adapted hybrids with higher yield potential. Second, new companies desiring to participate in the Central American market can use the test to attract dealers. Third, the performance test reduces the risks farmers perceive when accepting new technologies. This is especially true when farmers attend field days and see the hybrids for themselves. Fourth, farmers often adopt some of the management practices used to achieve higher yields; e.g., treating seed with insecticide, adjusting plant densities, and using higher fertilizer rates. Fifth, the Agricultural Offices use these results to grant seed import permits. And sixth, credit institutions are beginning to look at performance reports and consider the possibility of making loans to sorghum producers. Presently, the three largest sorghum seed companies in Honduras, Cristiani Burkard, DeKalb, and Pioneer subscribe to the commercial hybrid performance test.

Seed Plant at Zamorano. With the help of different institutions and donors Zamorano is building a new modern seed plant with the objective of upgrading seed science and technology in Central America. The sorghum project has actively participated in designing, construction and equipment purchase for the facility. Once this new facility is fully operational, training of Central American scientists and technicians will be carried out regularly. This facility is expected to boost the establishment of regional seed companies to produce sorghum seed as well as an improvement in services.

Grain Processing Plant at Zamorano. With the help of ASHA, CASP and INTSORMIL, EAP has started to design and equip a grain processing plant with extruder and tortilla equipment that will be used to process different types of cereal, including sorghum. Training, product development and marketing will be the main objectives. The Cereal Quality Laboratory at Texas A&M is fully involved in developing a curriculum in grain processing for Zamorano students.

Sureño Update

Sureño (PI 561472 and NSSL 259979.51) has found widespread acceptance throughout the sorghum growing regions in Honduras. It is the first sorghum cultivar released by the MNR that has found its way into informal seed markets. Consequently, it not only has sustained its survival, but continues to increase its acreage share with nominal institutional help. Seed production continues to be a problem which is expected to be overcome through a harder push from the new seed plant at Zamorano. Only two seed growers produced Sureño in 1995. Two thirds of the production did not meet the certification requirements due to poor germination caused by weathering to grain molds. To obtain good quality seed, Sureño must be planted in places were its maturation occurs in dry environments.

Networking Activities

Institutional Arrangements

MNR-EAP MOA. In 1991, the MNR signed an MOA with the EAP which places the responsibility of sorghum research with the school. This MOA was elevated to the status of Acuerdo (no. 3524-91) when it was approved by the Honduran President 9 Dec. 1991. This restructuring of the NAR sorghum component is consistent with AID/H and GOH objectives on privatization and serves as a model for privatizing other agricultural services in the ministry. INTSORMIL's long-term relationship with the MNR has enabled Honduras to develop a long-term comprehensive sorghum research program that is beginning to gain support from the sorghum industry in Honduras and other international donors.

PL480 support. The GOH and AID/H are no longer providing local currency support for the sorghum project through the Title I PL480 program.

Additional funding. Special projects are being developed to create new funding sources. To date, these projects have focused on commercial hybrid testing.

PCCMCA. Dr. Francisco Gómez, and Jorge Morán attended the 41th annual meeting of the PCCMCA. March 1995. San Salvador, El Salvador. Dr. Gómez acts as the liaison officer between ASA and PCCMCA.

CLAIS. The Latin American Commission for sorghum Research (CLAIS) is being rejuvenating to assume its coordination role in the area. Central American research and extension systems are now reorganized to include more participation of the private research and extension systems. National Centers are now forming strategic alliances with the private seed industry. New scientific and technical personnel are being hired that will benefit from CLAIS coordination and technical assistance. INTSORMIL remains the only source of technical collaboration with NARS.

PCCMCA. The 44-year old Central American and Caribbean Agricultural forum is undergoing the consequences of a decrease in public funding. INTSORMIL participation in this forum to rejuvenate CLAIS and the sorghum group requires especial efforts.

Electronic Linkages. New information highway technology is becoming available in Central America through INTERNET connection. National Sorghum Projects can benefit by connecting to the worldwide sorghum data base at U.S. Universities, ICRISAT and other sorghum projects through the region. E-mail communication technology and

an electronic newsletter are seen as a preliminary step to link regional sorghum projects.

Scientist Exchange

Dr. Gómez traveled to Kansas City, Missouri in July to participate as a member of the INTSORMIL Technical Committee, where he represents the Latin American Region.

Ing. Jorge Morán spent two months at the Texas Agricultural Experiment Station in Lubbock. He underwent intensive training on nursery management and mechanized planting, under the direction of Dr. Gary Peterson.

Publications and Presentations

Publications

Gómez, F. and J. Morán. 1996. 1995 Grain sorghum performance tests for the PCCMCA (In Spanish). Tech. Rep. N°AG-9601. Escuela Agrícola Panamericana, El Zamorano, Honduras.

Moran, J. 1995. Reaction of Honduran *Colletotrichum graminicola* (Cesati) isolates on sorghum lines from the International Sorghum Anthracnose Virulence nursery (ISAVN) and other nurseries. B.S. Thesis. Pan American Agricultural School Zamorano. December, 1995.

Rosewich U.L. 1996. The population genetics of *Coletotrichum graminicola* (Cesati) from different ecosystems of sorghum. Ph.D. Dissertation. Texas A&M University. May, 1996.

Presentations

Gómez, F. Conservation and enhancement of maicillo. CRS meeting, November 1995. Jícaro Galan, Honduras.

Moran, J. 1995. Estudio sobre resistencia a poblaciones hondureñas *de Colletotrichum graminicola* (Cesati) en las líneas de sorgo del Ensayo Internacional de Antracnosis y otros viveros. Reunión Anual del PCCMCA, Marzo de1995. San Salvador, El Salvador

Mali

D.T. Rosenow
Texas A&M University

Coordinators

Dr. D.T. Rosenow, Sorghum Breeder, U.S. Country Coordinator, Texas A&M University, Texas Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX
Dr. Aboubacar Touré, Sorghum Breeder, Mali Host Country Coordinator (thru December, 1995), IER, B.P. 438, Sotuba, Bamako, Mali
Mr. Sidi Bekaye Coulibaly, Agronomy/Physiology, Mali Host Country Coordinator (from January, 1996), IER, Cinzana Station, B.P. 214, Segou, Mali

Collaborative Program

Program Structure

The program in Mali is a coordinated effort between INTSORMIL and IER. It is multi-disciplinary and multi-institutional in scope and includes all aspects of sorghum and millet improvement, production, and utilization. Each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart and in concert with and as a part of the overall IER Mali research plan. Major INTSORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress, and plan future collaborative activities with their Malian counterparts. Occasionally, IER scientists travel to the U.S. for research review and planning. These plans are reviewed by the country coordinators, consolidated, and coordinated with IER research project plans for approval or modification. This insures that the research fits into the annual overall IER plan. The plans then become part of the annual Amendment to the MOA. The USAID sponsored bilateral IER/Texas A&M, SPARC project assists IER in research project development, execution, and research financial management for the entire IER program including other donor funding and agencies.

Memorandum of Agreement

A Memorandum of Agreement formally establishing INTSORMIL collaboration with IER and allow transfer of funds was signed in Mali on October 10, 1984. The annual Amendment to the MOA, which consists of the 1995-96 work plan and budget, was developed jointly by the country coordinators in March-April, 1995, and approved by IER and INTSORMIL in May, 1995.

Financial Input

The USAID Mission provides significant financial support to the total IER research program, of which sorghum and millet are a part, through the SPARC Project. IER and SPARC make decisions on which specific project or locations are funded by SPARC, depending on needs, and where INTSORMIL country funds are allocated. Eventually, plans are for all external funding to be managed thru the SPARC/IER financial system. Approximately 50% of the yearly Mali Country Budget is transferred directly to Mali from the INTSORMIL Management Entity. The remainder is retained at Nebraska and used for major equipment purchases, supplies, IER scientist travel, IER scientist short term training, or special needs as they arise. Also, some individual U.S. INTSORMIL investigators transfer pass-through funds to Malian counterparts or purchase equipment or supplies for Mali directly from their project funds.

Collaborating Institutions

Institute of Rural Economy (IER), Bamako, Mali
Texas A&M University
University of Nebraska
Purdue University
Kansas State University
SPARC (USAID/TAMU) Project
USAID/Bamako
ICRISAT/WASIP/Mali
Soil Management CRSP (formerly TropSoils)

Research Disciplines and Collaborators

Germplasm Enhancement - Sorghum: Aboubacar Toure, IER; D.T. Rosenow, G.C. Peterson, G. Ejeta, INTSORMIL

Crop Protection Systems: Entomology - Yacouba Doumbia, IER; G.L. Teetes, INTSORMIL; N. Diarisso, TAMU student (IER).

Crop Protection Systems: Pathology - Mariam Diarra, Ousmane Cisse (Sorghum), Mamadou N' Diaye (Millet), IER; R.A. Frederiksen, INTSORMIL; M. Diourte - KSU student (IER).

Crop Protection Systems: *Striga*/Weed Science - Bourema Dembele, IER; G. Ejeta, INTSORMIL.

Crop Production Systems: Agronomy/Physiology and Soils - Sidi Bekaye Coulibaly, Abdoul Wahab Toure, Mi-

namba Bagayoko, Zoumana Kouyate (TropSoils), Mamadou Doumbia (Soil Lab) IER; S.C. Mason, J.W. Maranville, INTSORMIL; Abdoul Sow, TAMU student, (IER) (TropSoils), Abdoulaye Traore, UNL student, (IER) (Agronomy), Samba Traore, UNL student, (IER) (Weed Science/Agronomy).

Utilization and Quality: Mde. Aissata Bengaly Berthé, IER; L.W. Rooney, INTSORMIL.

Economics: Bakary S., Coulibaly, IER, Purdue student; J.H. Sanders, INTSORMIL.

Sorghum/Millet Constraints Researched

Production and Utilization Constraints

Yield level and stability in sorghum/millet production is of major importance in Mali where food production is marginal in the presence of a rapidly growing population. Low and unstable yields are the result of complex interactions of low soil fertility (particularly nitrogen and phosphorus), drought stress, diseases, insect infestations, *Striga*, and lack of availability of improved cultivars.

Head bugs and associated grain molds adversely affect sorghum yield and grain quality, and are a major constraint to the development of improved high yielding sorghum cultivars. *Striga* is a major constraint for both sorghum and millet. Other major constraints are phosphorus and nitrogen deficiency, water stress, and millet head miner infestations.

Lack of farm credit for millet and sorghum, compared to cotton and maize, discourages adoption by farmers of improved millet and sorghum technology, especially in the higher rainfall areas. Grain prices which cycle between high and low yield-level years are a deterrent to adoption of improved technology.

Transformation of sorghum and millet grain into new shelf-stable foods and industrial products is required to encourage local production of grains and to enhance agribusiness activities of food processing and poultry feeding which would help stabilize prices.

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology, *Striga*, food processing, and food technology. An effort to develop new food products from cereals and legumes is emphasized. Selection for enhanced drought resistance is a major concern. Major activities involve the introduction and use of new genetic materials in breeding programs to develop cultivars to increase or stabilize grain yields with desirable food quality.

New Opportunities

New tan-plant Guinea-type breeding cultivars have been tested on-farm and offer an opportunity to develop new food products and industrial products which could enhance demand and stabilize prices. New commercial products using sorghum and millet are being developed and marketed. Work to develop *Striga* resistant sorghums and photoperiod sensitive late maturing sorghums to escape head bugs and molds was expanded the last four years.

Research Progress

Details of much of the research related to Mali are presented in individual P.I. project reports in this publication. This section will report primarily on research done by IER in Mali.

Sorghum Breeding

The IER program under the direction of A. Touré is producing many segregating populations. Genetically diverse germplasm with unique adaptation or unique traits from around the world is being used in crosses. There were 117 new F_1s grown and 121 new crosses made in 1995. Segregating progenies were grown at four locations, with 895 selections made in F_2s, 438 selections made in F_3s, and 158 selections made from F_4 or advanced generation families.

Sorghums giving the best new progenies are 'Nagawhite', 'Gombolo', 'ICSV 1063BF', all introductions, as well as 'Malisor 84-7' and 'Bimbiri Soumale'. Emphasis is on intercrosses using the experimental guinea-type white-seeded tan-plant cultivar named 'N'Tenimissa' (Bimbiri Soumale *87CZ-Zerazera) with elite local guineas and with other high yielding non-guinea breeding lines which lack the necessary head bug tolerance. In the Preliminary and Advanced National Trials the best new entries identified were: (Bimbiri Soumale*87CS-Zerazera), (Malisor 84-7*Nagawhite), (Malisor 84-7*ICSV1056BF), and (Gombola*ICSV1063BF). From the Advanced Trials, two lines from the Medium Maturity Trial, 93-EADT-19 and 93-EADT-20 will be proposed for on-farm testing during the 1996 rainy season. In the Early Trial, five were selected for probable on-farm testing in 1996, namely 94-EARSP-27, 94-EARSP-29, 94-EARSP-30, 94-EARSP-32 and IPS0020.

Grain of N'Tenimissa will be increased on about five ha in 1996 for use in utilization and value-added product development.

Dr. Touré recently (January 1996) accepted a two-year Rockefeller Foundation Post Doc Fellowship on sorghum biotechnology, at Texas A&M. This will slow the sorghum breeding progress to some extent, but Mr. Sidi Bekaye Coulibaly (M.S.-Nebraska in physiology) has very capably stepped in as coordinator of the sorghum breeding program and INTSORMIL Mali Host Country Coordinator.

Millet Breeding

Mr. Karim Traore continues his position with WARDA, so a Technician plus some help from former millet breeder, Dr. Oumar Niangado, IER Director General, has continued the millet breeding effort. Emphasis is on selection within local landraces for disease (primarily downy mildew) resistance and yield and adaptation. The population technique is used to improve traits in crosses among Malian lines and introductions.

On-Farm Trials

Three new sorghum breeding lines were given names and evaluated the first time in on-farm trials in 1995. One family from the cross (Bimbiri Soumale*87CZ-Zerazera) was named "N'Tenimissa" ("I do not regret" in Bambara). It is a white-seeded, tan plant, tan-glume cultivar with strong guinea plant, panicle, and grain traits. The other two are non-guinea types names "Dusa Suma" ("satisfactory" in Bambara) previously designated as 89-SK-F4-53-2PL (ICSV1038*Vartan-M50009), and "Darilla" ("Confident" or "I trust you" in Bambara) previously designated as 89-SF-F4-184-1PL (Malisor 84-7*85-F4-77).

At Kati (Table 1), N'Tenimissa and improved CSM388 produced significantly higher grain yield than the local check, and farmers responded favorably to them due to their performance and phenotypic similarity to local cultivars. At Yirimadio (Table 2), all four improved varieties yielded higher than the local check. An identical trial at Tamala was not harvested, but the farmer liked the new varieties, especially N'Tenimissa and wants to plant 1.5 ha of it in 1996. The three non-guinea types were not well accepted due to their short height, non-guinea head type, and apparent poorer grain quality (more head bug and/or grain mold), even though their overall grain yield as measured by weight was good. In southern Mali (Longorola area) where late maturity sorghum are grown, three improved guinea varieties (by mass selection) yielded more than the local check (Table 3). This shows the potential for use of improved locals.

World Vision plans to distribute N'Tenimissa in 20 on-farm trials in 1996. In northern Mali, CARE also will cooperate with IER with new sorghum cultivars at about 20 sites.

Table 1. Results of on-farm tests at Kati (mean of eight farmers), 1995.

Varieties	Days to 50% flowering	Grain yield, T/ha
N'Tenimissa	76 a	0.94 a
CSM 388	69 b	0.98 a
Malisor 84-7	59 c	0.54 b
Local check	71 b	0.61 b
CV (%)	6.77	20.21
Significance	**	**
$LSD_{(0.05)}$	3	0.07

Table 2. Results of on-farm test at Yirimadio, 1995.

Varieties	Grain yield, T/ha
Dusu Suma (89-SK-F4-53-1PL)	2.94
N'Tenimissa	2.67
89-SK-F4-192-2PL	4.67
NDarila (89-SK-F4-184-2PL)	4.11
Local check	2.33

Table 3. Results of on-farm tests (mean of 12 farmers) at Longorola, 1995.

Varieties	Days to 50% flowering	Grain yield, T/ha
Seguetana	63 b	1.14 b
Foulatieba	72 a	1.41 a
Kassoroka	63 b	1.14 b
Local check	76 a	0.92 b
Mean	68	1.15
CV (%)	9.67	25.66
Significance	**	**
$LSD_{(0.05)}$	5	0.24

Entomology

Studies continued on the bio-ecology of head bug and evaluation of breeding lines for resistance. Several breeding lines showed reduced number of bugs per panicle and a resistance level similar to that in Malisor 84-7. Promising lines included (M84-7*CSM388)-1, (M84-7*TP21-106-3), and (CSM388*Sureno)-1. The head bugs appeared late at Sotuba in 1995 compared to previous years, possibly due to the late planting date in the Nursery and adjacent fields.

For the second consecutive year, head bugs were light on some on-farm trials. The head bug populations under farmer conditions when improved or non-guinea types are used needs immediate research.

Populations were developed to attempt to identify molecular markers linked to head bug resistance, for use as a selection aid.

Pathology

Selected breeding lines were evaluated for resistance to anthracnose and sooty stripe, with some progeny showing good resistance. In a study of traditional fungicides, it was found that "Gon" (*Canavalia ensiloformis*) was effective in reducing covered kernel smut in sorghum.

Dr. John Leslie collected 569 samples of Fusarium cultures (sorghum-391, millet-157, and maize-21) from mostly immature grain in October 1995 to evaluate strains and evaluate the role they play in pathology and mycotoxicoses in West Africa. Preliminary evaluation indicated that 98% of the seeds were colonized by Fusarium.

Weed Science/Striga

Preliminary and advanced breeding lines were screened for resistance to *Striga*. Several lines had significantly fewer *Striga* plants than the local check. In Southern Mali, some locally collected guinea cultivars showed a promising level of resistance, especially CMDT 30, CMDT 48, when compared to Seguetana (*Striga* tolerant guinea) and Framida. World Vision distributed seed in 1995 of several *Striga* resistant food type sorghum cultivars developed by Gebisa Ejecta at Purdue in the Bla area, but no reports official reports on performance were received.

Grain Quality Studies

A survey on Sorghum Diversification of Processing and Utilization was done using the new white-seeded, tan-plant variety N'Tenimissa. Two hundred 500 gram packets of sorghum grits and flour were placed in a supermarket. Results indicated that 80% of the people that bought the samples liked it very much, and the other 20% did not respond. This test will be expanded in 1996 to about 10 supermarkets.

Grain samples from the National Advanced and Preliminary sorghum trials were analyzed for decortication yield and "tô" consistency and color. In general, "tô" quality was good on most entries, but there were large differences in dehulling yield, with some entries giving 50% or less.

Dr. Lloyd Rooney did an intensive evaluation in December, 1995, to develop information and potential on value-added processing research that could done by IER in collaboration with agribusiness and small farmers. He found the opportunities excellent with a large number of small and large companies wanting information and technical assistance. A consistent supply of high quality grain is the major constraint limiting value-added processing.

Agronomy/Physiology

Rotation with cowpea in Mali increased pearl millet grain yield by 19, 17, 31, 27, and 30% in 1991, 1992, 1993, 1994, and 1995, respectively, while application of 40 kg/ha N fertilizer increased grain yield 8, 20, 16, 35, and 6%. All cropping system plots had lower pH, N, K, and Mg levels than the fallow after 4 years, suggesting that all continuous, rotational, and intercrop systems studied were mining the nutrients.

Increasing the production level in Mali as well as in Niger (manure, fertilizer, higher plant population) increased grain yield of all pearl millet cultivars, suggesting that differential production practices are not required. However, in both locations, cultivar grain yield differences were large among cultivars, indicating the importance of cultivar selection.

Several sorghums reportedly derived by seed radiation and selected at the Institute of Polytechnic Rural de Katibougou showed potential to be stress tolerant and agronomically acceptable for some regions of Mali. It also appears that several of these mutant sorghums are superior for N responsiveness at specific locations.

Early and intermediate maturity advanced breeding lines were evaluated for seedling heat and drought tolerance in soil bin charcoal pits during the 1995 off-season at the Cinzana Station. There were significant differences among lines in 15 day survival. Several lines were more tolerant than Bagoba, but not statistically different from the local check Gnegnefing.

In the soil toxicity-sorghum study plot at Cinzana, Babadia Fara and Lakahiri produced the best plant stands. Most other entries died by the fourth count. Symptoms were very severe in 1995 making ratings difficult.

Economics

Lack of farm credit for sorghum and millet is a major constraint to adoption of new technologies, whereas cotton and maize do receive favorable credit. There is more potential for adoption of new technologies in the drier zone where sorghum and millet do not compete with cotton and maize.

Mutual Benefits

All research results reported should benefit Mali, as well as surrounding countries where similar production constraints occur. Information on sources of improved food quality and food type sorghums should be useful in improving overall quality of U.S. sorghum grain. Several Malian breeding lines show excellent grain yield potential, leaf disease resistance, and excellent grain quality in Puerto Rico and South Texas.

Institution Building

INTSORMIL provided various field and laboratory research equipment including computers, printers, head thresher, pollinating bags, and lab analyses to the IER collaborate program Training in computer use was provided by G.C. Peterson. Subscription to ASA and CSSA were provided for researchers at Cinzana, Mopti, and Sotuba.

Several Malian students at INTSORMIL institutions should make important contributions upon their return to Mali. Mr. A. Sow in soils (TropSoils) at TAMU, Mr. A. Traore in agronomy at Nebraska, Mr. M. Diourte in pathology at KSU, and Mrs. N. Diarisso in entomology at TAMU should all return to Mali soon and strengthen the IER research program. Mde. Salimata Sidibe will soon return with an M.S. in food technology from North Carolina A&T. The soil research component in IER has already been strengthened with the return of Dr. M. Doumbia (M.S. and Ph.D.-TAMU, Soil Management CRSP) who is now an IER researcher and Director of the Soil Laboratory.

New students in training include Minamba Bagayoko to U. of Hohenheim, Germany for Ph.D. on millet in West Africa, and Niabe Teme, complete B.Sc. and M.S. at Texas Tech. Dr. A.Touré accepted a two year Post Doc Fellowship in sorghum biotechnology at Texas A&M. Adama Coulibaly (M.S.-KSU) will assume the responsibilities of Minamba Bagayoko in millet agronomy.

The contribution of INTSORMIL trained Dr. Moussa Traore (Ph.D.-Nebraska), former physiologist and Mali Country Coordinator now the Permanent Secretary to Minister of Agriculture, has been huge in the reorganization and current operation of IER. The contribution of Dr. Oumar Niangado, Director of General of IER, has also been significant. He is a former INTSORMIL collaborator and millet breeder, and has been instrumental from the beginning in INTSORMILs working in Mali. Dr. Aboubacor Touré, Ph.D. from TAMU in breeding, is currently a sorghum breeder, INTSORMIL Country Coordinator, a member of the INTSORMIL Technical Committee (TC), and has served as Head of the Mali national sorghum program.

INTSORMIL travelers to Mali during the year included: Drs. D.T. Rosenow and G.C. Peterson, sorghum breeders; Dr. L.W. Rooney, food scientist: Dr. G.L. Teetes, entomologist; Dr. R.A. Frederiksen, pathologist, all from Texas A&M; Drs. J.D. Maranville and S.C. Mason, agronomists from Nebraska; Dr. J.F. Leslie, pathologist from Kansas State; and J.H. Sanders, economist, from Purdue. Dr. Aboubacar Touré traveled to the U.S. in July to attend the INTSORMIL TC meeting and confer with U.S. PIs.

Networking

The research accomplishments in Mali are immediately and directly transferable to most countries in West Africa. Work on sorghum and millet food technology applies to Africa and many areas of the world. Head bugs are common to West Africa while drought and grain mold are world-wide problems. Exchange of elite germplasm with useful traits is an excellent means of networking among breeders.

Efforts are underway to utilize existing networks to extend technology to the region in both sorghum and millet. Steve Mason and Frank Gilstrap have participated in the ROCAFREMI meetings developing linkages with the millet network. Darrell Rosenow visited briefly with the WCASRN (sorghum network) steering committee in May, 1996 and two members will be participating in the September, 1996 P.I. Conference. There has been a long history of collaboration with ICRISAT in Mali, and collaboration is excellent with Drs. D.S. Murty, J.C. Chantereau, and A. Ratnadass. ICRISAT continues to be useful in networking in the areas of entomology, pathology, and breeding.

Within Mali, there is a pre-extension organization to do on-farm trials, and then the extension personnel do more detailed evaluation and demonstration of new technologies on-farm. Minamba Bagayoko coordinates extension on-farm trials in the Mopti region. Gebisa Ejeta has initiated a plan with World Vision which distributed some improved *Striga* resistant sorghum through on-farm trials in Mali in 1995. World Vision plans to distribute the new white-seeded, tan-plant sorghum cultivar, N'Tenimissa, for a large number of on-farm sites in 1996. More use should be made of some of the NGOs and PVOs working in Mali.

Research Accomplishments

INTSORMIL has been in Mali informally since November of 1979 with a formal MOU signed with IER in 1984. The program has interacted with ICRISAT-WASIP, Trop-Soils, IER, and Ciba-Geigy. USAID-Mali has supported the program with moral and financial support. The most significant accomplishment has been a major improvement in the capability of IER to conduct a sorghum/millet research in Mali. IER is now recognized as having one of the best overall sorghum/millet research programs in Sub-Saharan Africa. Accomplishments for the life of the project have been detailed in previous annual reports with only a few highlighted below:

- INTSORMIL trainees are now in key governmental and research positions in Mali.
- The adverse effect of head bugs on the grain/food quality of sorghum across the guinea type sorghum growing area of West Africa was first recognized and documented in Mali.
- Head bugs and grain molds combine to cause devastating loss in grain yield and quality especially of introduced types.
- Malisor 84-7 was identified to possess excellent genetic resistance to head bugs. Resistance can be genetically transferred to its progeny, but its inheritance is quantitative and primarily recessive.
- An easy, efficient method of screening for head bug resistance using bagged vs. non-bagged heads has been developed and can be used to evaluate a large number of entries with little effort.
- New white-seeded, tan-plant, tan-glume guinea-type breeding cultivars have been developed and tested on-farm where they have performed well. They have good potential for use in developing new high quality, value added food products. They possess excellent guinea traits and yield potential.
- *Striga* resistance using lab screening to *S. asiatica* in the U.S. works under field conditions to *S. hermonthica* in Mali.
- Genetic tolerance to low pH related soil toxicity problems has been demonstrated, and tolerant varieties identified (Bagoba, Babadia Fara, and Gadiaba).

- Crop rotation of pearl millet (or sorghum) with cowpea (or peanut) enhanced grain yield of pearl millet (or grain sorghum) = 25% (17 to 30% Range), and cowpea (or peanut) = 5% (0 to 16% Range).

- Intercropping pearl millet (or sorghum) with cowpea (or peanut) increased land use efficiency by 14% (9 to 37% Range).

- Without fertilizer application, all tested cropping systems (including legume rotations) mine the soil of nutrients.

- Application of N fertilizer and P fertilizer increases pearl millet (and sorghum) grain yields. [Example: 40 kg/ha N increased pearl millet grain yield at Cinzana by 17% (6 to 35% Range)].

- Nitrogen use efficiency (NUE) of improved sorghum cultivars have been better than local cultivars at higher N rates, while local cultivars had better NUE at zero and very low N rates.

- The combination of cowpea and millet flour (1-3) significantly improved the nutritional status of young children. This technology has been transferred to villages, especially in the Cinzana area.

- Parboiling can convert sorghum and millet into acceptable shelf-stable products.

- Mileg, a weaning food using primarily millet flour, has been developed by private enterprise and marketed in stores in the Bamako area. The product was developed using technology developed in the IER Cereal Technology Laboratory.

- The lack of a consistent supply of high quality sorghum and millet grain is the major constraint limiting value-added grain processing.

- Lack of farm credit for millet and sorghum, compared to cotton and maize, discourages adoption by farmers of improved millet and sorghum technology, especially in the Sudano-Guinean (higher rainfall) zone.

Niger

John D. Axtell and Ouendeba Botorou
Purdue University and INRAN/Niger

Coordinators

Abdoulaye Gouro, INRAN Director General
Ouendeba Botorou, INRAN Scientific Director and Niger Country Coordinator
Issaka Mahamane, INRAN/InterCRSP Coordinator
John Axtell, U.S. Coordinator, Purdue University

Collaborative Program

This is an interdisciplinary, multi-institutional collaborative research program which involves INRAN and U.S./INTSORMIL institutions.

A major InterCRSP activity was initiated in 1995 with USAID/Washington support in coordination with the Niger USAID Mission. INTSORMIL activities included a seed production project of the new sorghum hybrid NAD-1 at Lhossa and *Striga* research using INTSORMIL/INRAN tested *Striga* resistant varieties at the Konni station. Cropping systems research was initiated with Tropsoils and the Peanut CRSP at Hamdallaye and a new site, Gaya, near Bengou.

ICRISAT is an active collaborator on the seed production of a new INRAN sorghum hybrid designated NAD-1. Participants include Drs. Karl Harmsen, Anand Kumar, S.C. Gupta, and D.S. Murty. ICRISAT is providing three ha of irrigated land for the production of NAD-1 in 1996 to supplement seed production at other INRAN locations.

A Seed Workshop has been approved for Fall 1997 in Niger which will include seed production specialists from developing countries as well as seed experts from the developed world. There is urgent need throughout Africa for a seed workshop which is the major limiting factor constraining the adoption of new technologies in Africa according to studies by ICRISAT (D. Rohrbach) and by USAID/Africa Bureau.

There are several interdisciplinary activities involved in this program. These include sorghum and millet breeding, agronomy, pathology, physiology, food quality and economics. U.S. INTSORMIL Principal Investigators develop research plans and budgets with INRAN collaborators on an annual basis. Each plan is then translated into French and submitted to Dr. Ouendeba Botorou, Scientific Director, for his approval.

Sorghum/Millet Constraints Researched

Production and Utilization Constraints

Drought, insect pests, long smut and *Striga* are the major constraints in Niger. Extremely high soil temperature leads to difficult problems in crop establishment. Sand blasting of young seedlings is also a complicating factor. Plant breeding for tolerance to these major constraints is one of the most feasible solutions. New cultivars must be acceptable for tuwo preparation. For example, the variety L-30 has been the highest yielding sorghum variety in the Sahelian trials for the past 10 years, but is not accepted by farmers because of poor food grain quality. A number of useful collaborative research activities have been developed in Niger between INTSORMIL principal investigators and INRAN scientists.

Research Methods

The collaborative research program in Niger includes sorghum and millet breeding, agronomy, pathology, physiology, food quality and economics. Research methods appropriate for each of these disciplines are used for this research program.

Research Progress

Sorghum Breeding - I. Kapran,
J. Axtell and G. Ejeta

INRAN's sorghum breeding team includes Dr. Moussa Adamou, Mr. Issoufou Kapran, Mr. Soumana Souley, Mr. Magagi Abdou, and Dr. Noubou Kondo. They receive additional assistance from other INRAN staff at various stations and substations where trials are being conducted. Presently, a World Bank project is the major source of funding for the sorghum improvement activities at INRAN. Based on the general orientation of the sorghum breeding program in Niger, this team has a dynamic exchange with INTSORMIL PIs, mostly the Purdue/INTSORMIL sorghum group. Constraints facing sorghum production in Niger include drought, poor soils, insect pests (especially midge and headbugs), disease including long smut, and *Striga*. It is also very important that new improved materials

be acceptable for local food preparations. In 1995, both on-station and on-farm activities were conducted.

With the supports of InterCRSP, a major step was taken in the production of hybrid seed (NAD-1). Dr. L.R. House was contracted by the INTSORMIL InterCRSP program to help evaluate the progress of the hybrid breeding program and based on his long term experience, suggest solutions for the realization of the full potential of NAD-1 in Niger. He made two trips to Niger with Issoufou Kapran, and visited farmers, INRAN and extension staff; he also was able to see NAD-1 as well as seed production plots, under station and farmer management. Confident that NAD-1 had the potential of launching a private seed industry in Niger, a project was written that would train private entrepreneurs to take up the hybrid production from INRAN to a smooth transition. INRAN would increase its capacity of saturating the existing demand for NAD-1 seed while interested individuals would be contacted to grow small "experimental" seed production plots with the technical backing of INRAN staff. Five farmers in the village of Gidan-Iddar have tried to produce hybrid seed on small plots, with varying success; they were brought to the Konni station and realized there were differences between their and INRAN's management of the production plots. At this point the INRAN seed production has progressed substantially although considerable bird damage reduced the five tons of seed projected to less than one in the 1995/96 off-season. With a reduced version of the long term project, INRAN in collaboration with ICRISAT/SAHELIAN CENTER was able to obtain $22,000 funding toward the enhanced production and marketing of NAD-1 seed in 1996.

Millet Breeding - O. Botorou

In Niger, the two types of pearl millet grown are the early (75-100 days) and the late (120-150 days) maturing millets. Research (by IRAT and INRAN) has put emphasis mainly on the early type. The late maturing millet called Somno or Maiwa received little emphasis. During the 1992 Regional Research Committee meeting, farmers and extension services showed a strong interest in the development of high yielding late maturing millet in the southern part of the country where Maiwa is grown. The global objectives of the collaborative activities is to develop late-maturing pearl millet cultivars for sustainable production in the good rainfall zones, particularly the south-western part of Niger where agriculture has a good potential.

The research activities started in 1992 on Maiwa millet in collaboration with INTSORMIL and focus has been put on 1) prospection, collection and evaluation of late maturing millet cultivars used in Niger; 2) development of productive late maturing cultivars from local ecotypes collected during the 1992 raining season, and 3) seed production of the best varieties to satisfy the needs of breeders and extension services and farmers

Mutuality of Research Benefits

Extensive use of drought tolerant materials from Sahelian countries, including Niger, have been used extensively by the private and public sectors in the US.

Institution Building

Research Supplies and Support

When INTSORMIL first began collaborative research relationships with INRAN there were relatively few highly trained Ph.D. level scientists in their organization. Over the past 16 years this situation has changed dramatically within INRAN. INRAN has matured and grown significantly as a research organization over the past 20 years. INTSORMIL has played some part through training and through collaborative research efforts in the institutional development of INRAN. INTSORMIL scientists have also grown during this period in terms of their collaborative research capabilities in sorghum and millet research and technology. The collaborative research relationship now is an effective system for delivering excellent research and for the application of this research for the benefit of farmers in Niger and in the US. INRAN now has excellent leadership, excellent scientific direction and excellent scientists, either fully trained or in the final stages of their Ph.D. training programs. They now have a critical mass of excellence in research capability for the agricultural sciences. When one looks at progress in institutional developments over a longer time frame, it is easy to be optimistic about the future of INRAN/INTSORMIL collaborative research. A total of six Nigeriens have received Ph.Ds and six have received M.S. degrees under this program.

In support of this program the field supplies and the following equipment were purchased: rotating couscous-agglomerator sifter, centrifuge rotor, ONERSOL solar dryer, tecator digestion model DS40, combined decorticator and mill for small grain processing, Eclipse seed cleaner, and SP3 sprayers.

The Niger InterCRSP has provided funding for the purchase of a couscous processing unit that is currently being installed in the Cereal Quality Laboratory (LQC) at INRAN. The unit consists of a flour agglomerator (rouleur), a combined grain decorticator and flour mill, a solar dryer, a couscous steamer, and a plastic sealer for packaging. Adam Aboubacar, Ph.D. candidate, will first travel to France and train at CIRAD on the use of the rouleur before continuing to Niger to start the operation. The rouleur, the most important piece of equipment in the preparation of couscous, was fabricated at CIRAD. One use of the unit will be for research to determine and improve processing techniques that can be used to produce good quality couscous from millet and sorghum and mixture with peanut and other legumes. The unit will also be used as a demonstration and testing tool to local entrepreneurs who are interested in commercial production of couscous.

The acquisition of this unit will greatly increase the LQC capabilities to do applied research in cereal processing and cereal products development. This will open the door for more collaboration between the LQC and local food industries and entrepreneurs and is expected to benefit both parties. For example, the milling equipment can be used for research in the commercial production of sorghum and millet flours, grits, and composite flours based on sorghum/millet and wheat or legumes. Flours are used in the preparation of thin and thick porridges, whereas grits are used to make steamed products like couscous. Like couscous, industrially produced flour and grits made from sorghum and millet are rarely available in rural or urban markets. Research in this area will be of interest to Moulins du Sahel, a mill located in Niamey who has plans to commercialize sorghum and millet flours and composite flours in the near future. A biscuit company (SNPA) in Niamey is also interested in replacing maize flour by millet or sorghum flour in the manufacture of biscuits. SNPA is currently incorporating 20% imported maize flour into wheat flour to produce biscuits.

Training of Host Country Researchers

Abdoulaye Tahirou, Ag Economist, received his Masters degree at Purdue University, returned to Niger in October 1995, and is now associated with DECOR/INRAN.

He, along with Mohamadou Abdoulaye, are conducting studies based on identification of socioeconomic constraints which can reduce adoption of new technologies by farmers. In addition, data are collected on farmers' reaction on new sorghum varieties in order to give feedback to breeders. The activities include on-farm trials and surveys Konni, a major sorghum producing region of Niger (Konni). The activities are conducted as part of the INRAN farming system research program.

In collaboration with InterCRSP, a diagnostic survey is being conducted in the region of Tanda. The objective is to describe the farming system of the area and identify agricultural constraints and potentials of farmers. This study will give information on farmers' crop mixes, resources (labor, land, husbandry, other sources of income) , farming practices etc.

This year, eleven farmers in seven villages in the Konni region were surveyed. All these farmers have experience with new sorghum varieties. They have been involved in on-farm trials of SEPON 82 and/or NAD-1 for at least three years. Farmers were asked about their opinion on these varieties and their farming practices. It was found that 11 sorghum varieties including SEPON 82 and NAD-1 were sown in 1995 by these farmers. Ten farmers used inorganic fertilizer on sorghum plots. The INRAN research station and the on-farm trials and demonstrations played a major role in giving information to farmers about new sorghum varieties. For SEPON 82, farmers appreciate the taste (100%), the size of the panicle (81%), the yield (90%) and the stalk quality for fodder (81%). All the farmers interviewed did not like the tillering of both varieties. For NAD-1, farmers like the higher yield (91%), the size of the panicle (90%) and the grain (100%), the color (90%), the taste and the quality of the stalk for fodder (90%).

Host Country and U.S. Scientists Visits

Only limited visits of S/M scientists were allowed to visit U.S. institutions because of strained relations between the two governments; however, several U.S. scientists visited Niger under the InterCRSP program, including Lee House and Issoufou Kapran. Dr. House made two trips as an expert on hybrid seed production in developing countries based on his 35 years experience with the Rockefeller Foundation and ICRISAT.

Issoufou Kapran traveled on a Rockefeller Foundation African Internship to conduct his Ph.D. field research.

Networking

Lee House, consultant, and Issoufou Kapran visited the ONAHA project where seed of rice for the total hectares of rice in the country is produced. Jean Jacques Schalbroek, Chief of the Project Semencier (c/o Ambassade de Belgique. B.P. 10 192 Niamey) indicated that farmers produce about five tons of seed per ha and sell it for around CFA 280 per kg. Farmers would be interested in growing sorghum if the price was competitive (CFA 100/kg for grain). ONAHA, a private seed operation, agreed to produce NAD-1 on 0.1 ha. They have a seed store and seed cleaner to support the operation and are careful about seeds from diseased plants so seed quality is a consideration.

Dr. Ouendeba Botorou has been selected as the new coordinator for the ROCAFREMI Network in West Africa. Frank Gilstrap continues to have an active role in millet entomology, and Bruce Hamaker collaborates with this Network on the millet cereal quality in West Africa.

INTSORMIL/Niger is extensively involved in InterCRSP activities in West Africa through the IPM/CRSP. Activities include intercropping on the watershed management project, cereal quality collaboration with the Peanut CRSP and the INRAN Cereals Quality laboratory, and hybrid seed production between INRAN and ICRISAT.

INRAN as a national Institute collaborates with other national institutes in sharing germplasm and research results. These include ROCAFREMI, IN.E.R.A. in Burkina Faso, IER in Mali and ARC in Sudan. Increasing collaboration with the ICRISAT Sahelian Center in Niamey will expedite transfer of research results across the Sahelian zone.

An InterCRSP project in Niger was funded for 1995-96 involving three active CRSPs in Niger: INTSORMIL, TropSoils and Peanut. These CRSPs developed collaborative

research programs focused on application of research results from the past 10 years on impacting at four sites in Niger: The TropSoils site at Hamdallaye, a new site at Bengou, seed production site at Lhossa and irrigation site at Konni.

A Natural Resource Management InterCRSP workshop for West Africa was held in September 1995 to develop an extensive CRSP activity for West Africa.

Research Accomplishments

Cereal Quality - Moussa Oumarou,
Adam Aboubacar and Bruce Hamaker

The Niger InterCRSP will be providing substantial financial support for the Cereals laboratory. Several important pieces of equipment will be purchased for the preparation of couscous and for grain milling. In addition, the Niger program funded travel for Adam Aboubacar and Bruce Hamaker to visit a cereal quality laboratory in Benin. Adam also traveled to Senegal to meet with scientists at the Institute of Food Technology who developed small scale couscous processing equipment. It is planned that Adam will assist in the installation of this equipment and in training the Cereals Quality Laboratory scientists when the new equipment arrives in Niamey.

During the past year, the Cereal Quality Laboratory (LQC) efforts of increasing the use of locally grown crops in commercial products have continued. Sensory studies on composite flour bread showed that bread containing 20% sorghum flour or 30% millet flour was acceptable by Nigerien consumers. The LQC is now trying to popularize the use of sorghum/millet flour in bread making through government extension services. The LQC has now started to work with a local biscuit company on wheat/sorghum/millet composite flours for making biscuits. The LQC is also working cn producing nutritive weaning foods based on cowpea and sorghum/millet flours. It was found that the low level of cowpea utilization in Nigerien dishes was due to the presence of high level of flatulence causing oligosaccharides in some cowpea foods. In an attempt to identify processing methods that reduce flatulence in cowpea foods, the LQC has recorded several traditional methods of cowpea processing during the last year. Processing techniques shown to decrease the amount of flatulence causing oligosaccharides will be used to produce cheap weaning foods for infants in rural areas as well as urban poor.

During the fall of 1995, Mr. Saley Kaka, nutritionist, and Ms. Ramatou Seydou, chemist, both of the INRAN Cereal Quality Laboratory spent two months in the Cereal Labs at Purdue University. Mr. Kaka worked on the physical and chemical properties of sorghum/wheat composite flours for making bread. He learned some techniques such as the measurement of dough properties using the mixograph and the determination of cooking properties of the flours using the Brabender Amylograph. Ms. Ramatou's work focused on the determination of processing factors that reduce flatulence in cowpea/sorghum-based weaning foods. She used paper chromatography techniques to determine the amount of flatulence causing oligosaccharides in several traditionally processed cowpea products.

Pathology - Issoufou Kollo and R.A. Frederiksen

Pearl Millet-Downy Mildew and Nematodes: Apron® plus has been tested on pearl millet for the last two years and was found to increase yield by 20% on the average. Seedling vigor and stand establishment were also greatly improved. Although the fungicide controls downy mildew (*Sclerospora graminicola*) effectively, the responses can be observed even in the absence of any disease. Since Apron® plus is a mixture containing a systemic nematicide we investigated the presence of nematodes on pearl millet. We found three species of nematodes (*Criconemella* spp, *Tylenchorhynchus* spp and *Helichotylenchus* spp) present on pearl millet in Niger. We postulated that association between these nematodes and soil borne fungi (*Fusarium* spp, *Curvularia* spp and *Helminthosporium* spp) may be important in Niger.

Pearl Millet - Striga hermonthica: The herbicide Dicamba controlled *Striga hermonthica* effectively. The results obtained in 1995 indicate that Dicamba should be applied at the rate of 0.2-0.3 kg a i/ha between 28 and 35 days after planting. Also, from experiments with plants in pots, we have found that eem seed at the rate of 0.5 kg/pot gave 100% *Striga* control; but in a field trial, neem leaf debris applied at the rate of 5 t/ha failed to control *Striga*. This year we lost the following experiments because of drought (screening pearl millet for *Striga* resistance, effect of rotation with ground nut and sesame on the emergence of *Striga hermonthica* with pearl millet, correlation between the *Striga* seed density in the soil, the emergence of *Striga* and yield of pearl millet, as affected by the pattern of rainfall and other soil factors.)

Sorghum - Grain Mold and Nematodes: In sorghum, our work was concentrated on finding the species responsible for grain mold. Three species have been isolated (*Fusarium* spp, *Curvularia* spp and *Helminthosporium* spp). Because of drought we have not been able to assess the relative importance of each fungus in the development of grain mold. The effect of fungi on seed germination and seedling vigor was studied. Fungi reduced the percent germination, radicle and epicotyl length significantly. Secondary root formation is also greatly reduced by the fungi. Our work was extended to nematodes on sorghum. We found that in the Konni area which is the sorghum growing area of Niger, nematode populations are very high. Four species of nematodes were found on sorghum (*Criconemella* spp, *Pratylenchus* spp, *Helichotylenchus* spp and *Tylenchorhynchus* spp). A Nematicide and fungicide test was conducted in pots, using soil from infested areas. With the application of furadan at 1g/pot the growth rate of sorghum seedlings doubled. This suggests that the nematode population has reached a threatening level in the area of Konni. We also lost

some trials on sorghum; for instance, *Striga* emergence was too poor in Konni and occurred only after the maturation of the sorghum. Due to the rain deficit in Bengou we could not evaluate the grain mold nursery.

Entomology - Hamé Kadi Kadi and Frank Gilstrap

The research program is organized as a collaborative effort between INRAN, INTSORMIL and ICRISAT/ISC. The research activities on the **Evaluation of Mortality in Populations of Millet Head Miner (MHM).** *Heliocheilus (=Raghuva) albipunctella* **(de Joannis)** is a joint program funded by Texas A&M/INTSORMIL Entomology and executed on the field by INRAN/Entomology with the ICRISAT/ISC Entomology program technical support. Prior to the start of the cropping season, the entomologists from the three institutions discussed the workplace that was executed on the field. The principle objective was to begin developing a baseline of understanding the mortality of MHM and determine the impact and contribution to total mortality of MHM natural enemies.

During Year 17, substantial funds from Texas A&M/Entomology (TAM 125-B) were transferred in order to support the field work related to research activities on MHM at Maradi. Some of the funds were also used to purchase laboratory equipment and supplies.

The collaboration with ICRISAT/ISC is in Niamey. Through the entomology program of this institution we received some scientific research materials (fine screen mesh cages, wire frames, and rearing cages). These materials were used for cage exclusion experimental design and observations in the field, and for laboratory insect rearing. The entomologist from ISC visited our 1995 experimental field in Maradi, and provide input on improving our experimentation. We also had a field trip in farmer fields around Madarounfa located about 35 km south of Maradi. There, discussions were held with several farmers on their understanding of the MHM problems and how to manage it.

Agronomy - Seyni Sirifi and Jerry Maranville

Research activities in 1995 began with a study on sorghum seeding rate and nitrogen fertilization. The research trial protocol for this study were developed jointly with Jerry Maranville. The study on seeding rate compares five different varieties using different seeding rates. The purpose is to make available to producers from Niger appropriate methods to grow sorghum in order to increase sorghum production. The study on nitrogen fertilization has the same objective. It studies the effect of increasing the quantity of urea applied to the same varieties used in the seeding rate study. All the cultural operations for the 1995 agricultural season were funded by INTSORMIL. To strengthen our activities, we plan to conduct research activities in collaboration with the InterCRSP project and ICRISAT beginning with the 1996/1997 season.

In addition to the improved varieties of sorghum already adopted, other varieties such as SEPON 82, SRN 39 and NAD 1 are at the pre-extension stage. Agronomic studies on these new varieties are being conducted.

Sorghum Breeding - Issoufou Kapran, John Axtell and Gebisa Ejeta

A major activity involving NAD-1 at the farmer level was an extensive yield trial comparing the hybrid to one of our best local landraces, Mota Maradi (MM). Trials were conducted in an area extending from Konni to Zinder eastward, and as far north as Dakoro. The objectives were to check the extent of NAD-1 superiority over locals under as diverse conditions as possible with farmer management, and assess its area of best performance. A preliminary yield analysis shows that overall NAD-1 yielded an average 1.6 t/ha compared to 1.1 t/ha for MM. This is about 50% better yield for the hybrid, like we observed before. This is especially important because 1995 was not a good year. The data also shows that better yields were obtained around Konni in the middle of the sorghum belt than at Dakoro, mostly a grazing area. Overall the information obtained from this trial is very positive and supports the strengthening of our breeding program. This test will continue in the 1996 season.

Our collaborative work on-station included observation nurseries with new A/B lines, high lysino lines, two new hybrids trials (to assess the adaptation of new R and B lines), all coming from Purdue University; there was also a hybrid trial from Nebraska. Generally these trials failed due to very late planting, but we observed that ABON34 still expressed a vigorous growth in the sandy droughty soil of Maradi; also among the Nebraska hybrids, entry 19 (9A x 94PV678) was agronomically interesting. A hybrid trial planted at eight INRAN stations was designed to compare our new hybrid (ABON34 x MR 732) to NAD-1, to evaluate whether such a combination between two tan plants may solve some of the weathering and disease problems of NAD-1. Only the female parents are different in the two hybrids, and e habe observed that TX623A may be the source of discoloration of NAD-1 grain in the areas of heavier rainfall, and a severe early senescence of the plants seen often at Konni. For this first year, our results show that the new hybrids is on average later maturing (78 vs. 73 days to half-bloom) and lower yielding (3.0 t/ha vs. 3.6 t/ha) than NAD-1. Both were better yielding than the checks, MM (2.7 t/ha) and Mota Galmi (MG, 2.2 t/ha), which were however earlier maturing (62 days to half-bloom). Visual observations made during the season indicate that the new hybrid is clearly better for leaf disease and headbugs than NAD-1 at Bengou in southern Niger. This will be repeated in 1996, but it is apparent that the new hybrid has a potential in at least the better managed farms.

A major thrust this year was the development of seed production capabilities of the sorghum hybrid in Niger, NAD-1. Dr. Lee House made two trips to Niger and advised

INRAN about his experience in India and Sudan as they relate to seed production.

It is clear that hybrid sorghum would provide an opportunity for a "Green Revolution" in Africa. The advantage of hybrids under stress conditions because of the genetic advantages of homeostasis is very clear in Niger under rainfed conditions. It is also clear that the lack of infrastructure for seed production will be a major problem which must be confronted in the near future. A seed production workshop sponsored by INTSORMIL in the Fall of 1997 will provide a major opportunity for education of researchers and policy makers of the well-documented advantages of sorghum hybrids in Niger.

Lee House will be an invaluable asset throughout this experiment working closely with Issoufou Kapran and INRAN. The ICRISAT Sahelian Center is proving to be a valuable partner in this endeavor and we look forward to close cooperation in the future.

Southern Africa (Botswana, Namibia, Zambia, Zimbabwe)

D. J. Andrews
University of Nebraska

Collaborators

Mr. David J. Andrews, Regional Coordinator, Sorghum/Pearl Millet Breeder, University of Nebraska, Lincoln, NE
Dr. Gary Odvody, Plant Pathologist, Texas A&M, Corpus Christi, TX
Dr. Lloyd Rooney, Food Quality, Texas A&M, College Station, TX
Dr. Chris Manthe, Host Country Coordinator, Entomologist, Department of Agricultural Research, Gaborone, Botswana
Mr. Peter Setimela, Sorghum Breeder, Department of Agricultural Research, Gaborone, Botswana
Mr. W. R. Lechner, Chief Ag Officer, Ministry of Agriculture, Water and Rural Development, Oshakati, Namibia
Mr. S. A. Ipinge, Ministry of Agriculture, Water and Rural Development, Tsumeb, Namibia
Mr. M. Chisi, Sorghum Breeder, Chilanga, Zambia
Ms. Trust Beta, Food Utilization Lecturer, Mt. Pleasant, Harare, Zimbabwe
Dr. Tunde Obilana, Sorghum Breeder, Bulawayo, Zimbabwe
Dr. Emmanuel Monyo, Pearl Millet Breeder, Bulawayo, Zimbabwe

Collaborative Program

Organization

This support project is new and 1995-1996 is an interim year, prior to the projected new 5 year phase.

Financial Inputs

Currently the project is funded by INTSORMIL with cooperation in kind by NARS. A Memorandum of Understanding is being developed with SACCAR to facilitate coordination of research throughout the region and expenditure of funds to NARS.

Collaboration with Other Organizations

Research on pearl millet and sorghum breeding is organized with NARS in collaboration with ICRISAT regional center at Matopos, Zimbabwe, which ensures complimentarity to existing ICRISAT and NARS programs.

The Planning Process

Research projects in breeding and pathology were based on ongoing linkages. Research on food quality was established during the year. The future program will be shaped by priorities decided by SADC NARS, and the availability of matching INTSORMIL resource persons.

Sorghum and Pearl Millet Constraints Researched

Production and Utilization Constraints

Sorghum and pearl millet are major food crops in the Southern African (SADC) region. Sorghum is also used to make opaque beer. Sorghum is the major cereal in Botswana and parts of Zambia, and pearl millet is the major cereal in Namibia. Most of the usual constraints associated with low resource agriculture are present. These include low yield potential, infertile soils, variable moisture availability, numerous pests and diseases, and poor market facilities. There are established grain quality attributes which must be maintained or improved in new varieties.

Research Methods

Breeding. Sorghum varieties and seed parents are developed from chosen segregating populations *in situ* in Botswana, with assistance from the regional sorghum breeder at ICRISAT/SMIP Zimbabwe. Pearl millet breeding involves a testing program in Namibia to identify male fertility restorer lines, leading to topcross hybrids using the successful variety, Okashana-1. This also involves back-up assistance from the regional millet breeder at ICRISAT/SMIP, Zimbabwe.

Pathology. Sorghum disease nurseries (virus and sorghum downy mildew), other sorghum nurseries, selected sorghum lines and advanced generation breeding germplasm were evaluated at two sites in Botswana (Sebele and Pandatmatenga) to identify sorghums with improved drought tolerance, and resistance to sugarcane aphids and

disease. The DAR plant pathologists, entomologist, and sorghum breeder assisted in identification and selection of those cultivars for incorporation into their sorghum improvement program which have the best overall adaptation and pest resistance for Botswana. Sorghum disease nurseries primarily of lines and advanced generation germplasm were evaluated at two sites each in Zambia and Zimbabwe to identify those having the best resistance to one or more foliar diseases (anthracnose, leaf blight, and sooty stripe) and the best adaptation to the region.

Food Quality. An important regional use of sorghum for food in the SADC region is the preparation of Sadza. Small and large scale commercial milling of sorghum is spreading. Grain and flour properties that contribute to acceptable Sadza need to be defined. The project with the University of Zimbabwe will be to examine the dry milling properties of sorghum and pearl millet. Important parameters are decortication percentage and flour characteristics, including consistency for making acceptable Sadza.

Examples of Findings

First hybrid yield tests with sorghum seed parents developed in Botswana were conducted. Cytoplasmic male sterile pearl millet lines sent to Namibia expressed their sterility perfectly and the first test crosses from Okashana-1 and MK population S_1s were made.

Several lines and other INTSORMIL sorghum germplasm, some evaluated for the first time in Botswana, showed excellent adaptation to the Sebele area and some had good resistance to sugarcane aphid. Though normally a major factor, drought stress was not significant during the current season. The importance of avoiding high susceptibility to leaf blight and sooty stripe was evident in the two Zimbabwe nurseries where leaf death and yield reduction were evident primarily on the material most vulnerable to the predominant foliar pathogen at each location (leaf blight at Henderson Station and sooty stripe at Panmure station).

Mutuality of Research Benefits

The productivity of both sorghum and pearl millet will ultimately be improved both in SADC countries and the USA through joint research. Germplasm flow is useful in both directions. Basic research from the USA can often be adapted for use in developing countries, where yield potential, along with adaptation need to be increased. U. S. pathologists and entomologists can become familiar with diseases and insects not yet present in the USA, or find new resistances to existing pests. Nutritional components of food quality researched in collaborative projects are often synonymous with aspects of livestock feed values.

Institution Building

Research Supplies and Support

Breeding projects in Botswana were supplied with a computer to support field program work, analysis of results and communication. Similar computers were supplied to the pathology program in Botswana, and the breeding program in Zambia. Sorghum and millet selfing bags were supplied both to Botswana and Namibia to permit more comprehensive hybrid breeding operations. Travel and subsistence funds were reserved to enable four SADC scientists to attend the International Conference on Genetic Improvement of Sorghum and Pearl Millet in Lubbock, September 1996. To support the food quality research in Zimbabwe, a decorticator, laboratory balances, oven, sieves and other equipment was purchased.

Training of Host Country Researchers

Numerous scientists in the SADC region have been trained by INTSORMIL. Of those directly connected with this project, Dr. C. Manthe is now cereals coordinator in Botswana and active in sorghum pathology. Mr. M. Mogorosi is the millet breeder and trials officer in northwestern Botswana.

Baikabile Matilo (M.S. Texas A&M) is a plant pathologist at the Sebele station with research activities involving nematodes on several crops and the pathogen Macrophomina phaseolina on several crops, especially cowpeas and beans, where it causes a disease called ashy stem blight. In Zambia, Dr. Medson Chisi (M.S. Texas A&M and Ph.D. Kansas State) is now a sorghum breeder and the team leader for the sorghum program in Zambia.

Ten students in the SADC region have been trained in food technology. In general the students were complimentary of their training but disappointed in that they were in most cases not integrated into the National programs upon their return from studies. Nearly all of the students are working in the region in some aspect of food science and technology. Several have joined the food industry where they are making important contributions.

Host Country and U.S. Scientists Visits

Lloyd Rooney participated in the SADC workshop on food technology of sorghum and millets, Harare, Zimbabwe, (January 29-30, 1996) and visited food research centers at the University of Pretoria, South Africa.

Gary Odvody traveled to the SADC region from March 22nd through April 13 reviewing research progress on collaborative disease projects and nurseries in Botswana, Zambia, and Zimbabwe. He also visited with plant pathologist Dr. Neal McLaren and other scientists at the Grain Crops Institute in Potschefstroom to gather information about ergot of sorghum and explore potential research collaboration.

Dr. Odvody sponsored travel of Dr. Bhola Nath Verma (Zambia sorghum breeder) to Corpus Christi, Texas for one week to view South Texas sorghum nurseries and interact with most of the Texas A&M sorghum improvement team.

David Andrews visited Botswana and ICRISAT/SMIP project staff at Matopos, Zimbabwe in November 1995 to coordinate the planning of breeding research projects in Botswana and Namibia. A second visit was made in March/April to work with NARS personnel in these projects in Botswana and Namibia and with SMIP staff in Zimbabwe. Since South Africa is now a member of SADC, a visit was made to the Grain Crops Institute, Potchefstroom and Pannar, a commercial seed company at Klerksdorp to assess the possibilities of collaboration.

Human Resource Strategy

This will be planned at a meeting with SACCAR and ICRISAT/SMIP in September 1996. Mr. Peter Setimela, the sorghum breeder in Botswana, will start a Ph.D. at UNL in the summer of 1996.

Networking

An efficient sorghum and millet network exists in the SADC region conducted by the ICRISAT/SMIP program. The Memorandum of Understanding with SACCAR will establish INTSORMIL, alongside the SMIP program, with access to the network.

Research Accomplishments

Though this current project is new, INTSORMIL has had collaborative research in the SADC region for several years, but not on a regionally funded basis. Sorghum breeding work in Botswana has resulted in a large part of the current country program being advanced lines and hybrid parents derived from INTSORMIL x Botswana crosses. Thirty-seven Botswana seed parents developed with assistance of the ICRISAT/SMIP program are in hybrid assessment tests. Hybrids are being made on 11 other seed parents.

Pearl millet collaboration in Namibia is in its first year. Parent lines were introduced from Nebraska and the first test crosses made in the A_4 topcross hybrid program.

Several sorghums derived from crosses with SC326-6 continued to show good regional adaptation and good general foliar disease resistance in Zimbabwe and Zambia. Some of those lines and others with good adaptation and foliar disease resistance are being used extensively in the sorghum improvement program in Zambia. Several sorghum lines and other germplasm evaluated at the Sebele Station in 1996 had good adaptation and sugarcane aphid resistance. They will undergo further evaluation under more typical stress conditions in the Southern and Pandamatenga areas of Botswana with the latter having more disease pressure for sorghum downy mildew and a virus disease. However, some sorghums, including a variety recently released in Botswana, also showed a higher vulnerability to virus infection and associated necrosis at Sebele than did most other sorghums. Several virus samples from sorghum and millet in Zambia and Botswana were collected for analysis by Dr. Stan Jensen at the University of Nebraska.

A research project on grain milling was organized with Ms. Trust Beta of the University of Zimbabwe, in collaboration from the National Agricultural Research Service in Zimbabwe, and ICRISAT/SADC SMIP at Matopos, Zimbabwe. Support from private industry appears possible.

Horn of Africa

Gebisa Ejeta
Purdue University

Coordinators

Gebisa Ejeta, U.S. Country Coordinator, Department of Agronomy, Purdue University, West Lafayette, IN 47907
Katy Ibrahim, Administrative Assistant, International Programs in Agriculture, Purdue University, West Lafayette, IN 47907
El Hilu Omer, Sudan Coordinator, Gezira Research Station, Wad Medani, Sudan

Collaborative Program

The Horn of Africa is a new INTSORMIL initiative proposed to regionalize collaborative research efforts in Eastern Africa. INTSORMIL has had a productive collaboration with the Agricultural Research Corporation (ARC) in Sudan. Our collaboration has resulted in an array of technical developments that have impacted on sorghum agriculture in Sudan. Sudanese scientists have been trained in INTSORMIL institutions. U.S. scientists have traveled extensively in Sudan and worked alongside their Sudanese counterparts. Joint workshops and conferences were organized and attended. Results of joint research efforts are published and distributed widely. Extensive raw and improved germplasm have been identified, assembled, and catalogued for the benefit of U.S. and Sudanese agriculture. The Horn of Africa initiative is, therefore, an attempt by INTSORMIL to share many of these developments with NARS in the Eastern Africa region through an organized and functional network.

Organization

While the Horn of Africa project is a new initiative, the Sudan country program has continued to function in the existing mode of organization:

The INTSORMIL/U.S. principal investigators develop their scope of work jointly with ARC scientists. These workplans are reviewed and approved by Dr. Osman Ageeb, ARC Director General; Dr. El Hilu Omer, ARC/INTSORMIL coordinator and Dr. Gebisa Ejeta, Sudan Country Coordinator, and become part of the INTSORMIL Memorandum of Agreement.

Each workplan has its own funding. Funds are forwarded directly from Purdue University or the INTSORMIL Management Entity at the University of Nebraska, and are then disbursed in Sudan to each ARC scientist to carry out this research program.

Dr. Ejeta and Katy Ibrahim coordinate the management of this program with U.S. principal investigators at Texas A&M, Nebraska, Mississippi State, and Purdue Universities.

Since direct communication with ARC/Sudan is basically nonexistent, the USAID Mission has provided excellent logistical support to relay communications to the ARC at Wad Medani and El Obeid research stations.

Research Disciplines

Cooperative Sorghum Breeding and Genetic Evaluation- Osman I. Obeid Ibrahim, ARC; Gebisa Ejeta, Darrell Rosenow, INTSORMIL.

Cooperative Millet Breeding - El Haj Abu El Gasim, ARC; David Andrews, INTSORMIL.

Agronomy and Water Management Program - S.M. Farah, Hassan Osman, ARC.

Plant Pathology Program - El Hilu Omer, ARC; Richard Frederiksen, INTSORMIL.

Striga and Weed Control - A.G.T. Babiker, ARC; Larry Butler and Gebisa Ejeta, INTSORMIL.

Entomology Program - N. Sharaf Eldin, ARC; Henry Pitre, INTSORMIL.

Food Quality Program - Paul Bureng, ARC; Bruce Hamaker, INTSORMIL.

Economic Program - Hamid Faki, Abdel Moneim Taha, ARC; John Sanders, INTSORMIL.

Collaboration with Other Organizations

The INTSORMIL/Sudan country program continues to collaborate with the following host country and U.S. organizations:

Agricultural Research Corporation (ARC)
Gezira Research Station (GRS)
Kadugli Research Station (KRS)

Food Research Centre (FRC), Shambat
Sudan National Seed Administration (NSA)
El Obeid Research Station
USAID/Khartoum
University of Nebraska-Lincoln
Texas A&M University
Mississippi State University
Purdue University

Sorghum/Millet Constraints Researched

Production and Utilization Constraints

The potential for expansion of sorghum in the rainfed areas of Sudan is enormous; however, the major constraints limiting expansion are inadequate soil moisture, inadequate soil nutrients, and shortage of labor. Other factors that reduce sorghum yields in Sudan include insect pests, plant diseases, and *Striga*. High yielding cultivars with good grain quality, suitable for mechanical harvesting, are also requirements for future expansion of sorghum in the rainfed central clay plain regions of Sudan.

Breeding efforts currently under way in Sudan to incorporate drought tolerance with higher-than-average yield potential in sorghum are limited by the lack of a rapid field screening procedure and lack of knowledge on sources of sorghum germplasm with useful traits. The insect pests known to attack sorghum, especially in the rainfed areas of Sudan, include stem borers, American bollworm, and central shoot fly. The major fungal diseases that affect sorghum production in Sudan include charcoal rot, anthracnose, long smut and a variety of grain molds. *Striga*, a parasitic weed of sorghum, constitutes a major constraint to sorghum production in Sudan. There is very little sorghum germplasm with resistance to *Striga* and the mechanism that renders resistance to *Striga* is not well understood. Knowledge about the inheritance of this trait is also lacking. The lack of absolute definitions and good screening methods for food quality to some extent also limit the utilization of high yielding sorghum varieties and hybrids in Sudan. Work on all of these aspects is needed to improve sorghum production and utilization in Sudan.

Almost all of the pearl millet grown in Sudan is used for home consumption by farmers in Western Sudan. The exception is a small but growing activity of millet cultivation in the mechanized rainfed regions where millet is produced on fields where sorghum yields have fallen too low. In Western Sudan, the crop/bush fallow system of production has traditionally been used to provide enough nutrients and possibly some moisture for a period of crop years (5-10 years fallow/2-4 years cropping). Crops are often grown in an intercropping system with millet to maximize production. Over the last 20 years, rainfall has declined, thus reducing the soil recovery rate during fallow. Fallow periods have also decreased due to higher human and animal pressure on plant cover, further aggravating the loss of moisture, nutrients and soil structure. As a result, there has been further reduction in millet yields.

Accordingly, the primary constraints to millet production in Western Sudan are lack of moisture and soil nutrients, and poor husbandry. Crop losses to insect pests (Raghuva), diseases, and *Striga* are also important factors limiting millet production.

Research Methods

Research conducted by participating PIs at the Agricultural Research Corporation, Sudan is primarily applied research. Research scientists are closely in tune with crop production, protection, and utilization constraints encountered by farmers in the various agricultural schemes in the country. Research constraints are assessed and prioritized on a regular basis, often annually and in collaboration with production scheme managers. Field facilities at ARC stations and particularly at the Gezira Research Station are excellent. Machinery and equipment often have been adequate and appropriate. Technical support has always been good. Laboratory facilities are modest and efforts have always been made to summarize research results to share information, informally and formally, with production agencies and their extension services. In general, a good research infrastructure, manned by an excellent cadre of manpower focused on sorghum and millet research, exists in the Sudan.

Research Progress

In Year 17, we report on research findings from two collaborative projects in ARC in the areas of Cereal Quality/Food Chemistry and Chemical Control of *Striga*.

Evaluation of Sorghum Cultivars
for Kisra Processing and Utilization
Bureng, Paul L., Food Research Centre, Shambat

Introduction

Sorghum (*Sorghum bicolor L. Moench*) is the main crop in Sudan. Most Sudanese derive their energy from sorghum products such as Kisra (baked thin sheets), Asida (thick porridge), Madida (thin porridge) and Abre (flakes).

Kisra is prepared from fermented sorghum/millet/maize batter on a hot rectangular or circular iron plate. This product is widely consumed in Sudan as fresh or dried for long storage and journeys. The old method of processing good quality Kisra was by adding Madida prepared from fermented batter or using cassava flour. When wheat grain or flour was widely introduced in the country, it took over as the main additive. Since wheat is either ground together with sorghum or added as flour to sorghum flour, it became the best additive for texture improvement as well as being convenient.

Four factors are important for Kisra acceptability: Texture (puffy, supple, elastic, smooth, etc.), color, taste and flavor. Social taboos also play an important part in sorghum consumption habits. The red and brown sorghum varieties are popular in rural farming communities, but the white and cream are highly acceptable to the high income urban dwellers.

The traditional method of dehulling sorghum by mortar and pestle has been effectively replaced by modern dehulling devices. But the milling of sorghum has remained traditional using mechanical stone mills. The transfer of milling technology of sorghum is very slow and poor. This is due to lack of developing small scale milling devices or commercial scale mills. This is also attributed to lack of scientific innovations and interest. The only modern mills in Sudan were developed by Schule of Germany in 1976 and supplied by UNDP/FAO to the Food Research Center for the project on composite flour.

The dehulling process based on abrasive principle has been successfully tested on sorghum and millet. The dehulling units integrated to the modern mills as well as stone/hammer mills in Sudan have improved flour quality and prolonged the shelf-life. This has positive (quality improvement) and negative (Kisra tends to be dry and crumbly) effects on Kisra. Adding more wheat flour (5-20%) improves suppleness.

The appropriate technology concept being adopted at the Food Research Centre (FRC) is based on a "Product Development" strategy for the national food industry. The main objectives for the research program on "Sorghum and Millet Processing and Utilization" agreed upon between FRC and the Gezira Research Station (GRS) breeders were: to identify and test various processing technologies that can improve the palatability of sorghum; to identify grain characteristics which influence processing performance; to select varieties suitable for processing; and to establish the economic feasibility of sorghum processing enterprise.

The objective of this study is to assess physical and chemical characteristics on grain and their influence on Kisra processing and acceptability.

Materials and Methods

Seven sorghum cultivars HD-1, F.W. Ahmed, 87/OSH-5283, 89/OSF_5-2451, 89/OSF_5-3582, ICSV-207 and ICSV-230 were received from sorghum breeders at the Gezira Research Station (GRS) from the 1994/1995 crop season. Dabar was used as a control sample. The grain was aerated, sieved, washed and sun-dried, then milled to flour through 0.4 mm screen Cyclotec 1093, sample mill, Tecator. Physical-chemical methods of analysis are the AACC (1984) Standard Methods. Fat acidity was determined according to AACC Toluene Method 02-01A. The grain hardness was assessed by dehulling the grain in TADD (Tangential Abrasive Dehulling Device Model 4E-220, manufactured June 1988, Venables Machine Works Ltd, Saskatoon, Sask, Canada) for three minutes (20 g. per hole).

Kisra processing stages were carried out as shown in the following diagram. The wholemeal sorghum was weighed into a 1000 ml. beaker and a 20% starter (old batter ferment) was added to the flour followed by water in a ratio of 1:1.5 (flour to water). The batter was properly mixed and placed at room temperature to ferment for six hr. The batter is considered ready for baking when it tastes acidic (traditional method) at pH 4±0.5. The batter is now added to improve the texture. In this study, additives were not included. The batter consistency was adjusted with water and small quantity of batter, 50-100 ml, was quickly poured and spread on hot flat plate (temperature 120-220°C) and Kisra sheets removed within 15 - 25 seconds.

Methods of Assessing Kisra Quality

Kisra quality was determined by physical and chemical methods. The best method for testing Kisra quality is the subjective method, the organoleptic test. The qualities considered were: Texture (thickness, suppleness, elasticity, stickiness); taste and flavor; batter spreadability on hot plate; and color.

Results and Discussion

Kernel weight is a measure to indicate the density of the grain and the flour recovery during milling. ICSV cultivars are small grains. The rest of cultivars are considered medium size (24-27g/100 kernel wt.) as shown in Table 1.

Table 1. Physico - chemical analysis of sorghum cultivars from GRS Breeders 1994-95.

Cultivars	Moisture	1000 kernel wt (g)	Dehulled grain recovery %	Ash (Minerals) %	Protein (NX6.25) %	pH	Total Acidity as Lactic %	Fat Acidity mgKOH/100g
HD-1	8.5	26.4	61.2	1.57	11.3	6.60	0.56	26.1
F.W. Ahmed	8.9	25.4	77.8	1.72	11.2	6.25	0.61	88.9*
87/OSH-5283	8.9	23.8	83.5	1.59	12.8	6.35	0.42	26.3
89/OSF_5-2451	8.8	26.5	55.3.	1.84	9.6	6.25	0.63	25.9
89/OSF_5-3582	8.2	24.0	65.5	1.63	11.4	6.05	0.49	49.2
ICSV-207	8.8	20.8	84.0	1.39	11.0	6.25	0.49	58.5*
ICSV/230	8.5	20.2	77.0	1.40	11.7	6.40	0.49	26.2
Dabar	8.2	22.4	76.4	1.56	11.5	6.33	0.47	26.5

* Above recommended limit of 50mg KOH/100g.

Dehulled grain recovery percentage has been established as an important measure of grain hardness (ICRISAT, 1992). The comparison of dehulling properties of new hybrid sorghum cultivars for three minutes in TADD showed wide degree of hardness from very hard to soft varieties (Table 1). The hardness of sorghum grain showed direct influence on Kisra quality. The hard grains produced poor Kisra quality as judged by the panelists. The cultivars that produced good Kisra quality were the medium hard (70-80% recovery), medium soft (60-70% recovery) and soft (50-60% recovery) grains.

Protein content is normal except in cultivar 89/OSF$_5$-2451 that had low protein of 9.6%. This is a soft cultivar that gave good Kisra quality. Fat acidity above 50 mg KOH/100g was found to lower the general acceptability of Kisra products due to rancid flavor. This was found true for sorghum flour of cultivars, F.W. Ahmed and ICSV-207. Fat acidity and total acidity in sorghum are important factors requiring further investigation to establish the limit of deterioration and effect on product quality.

Organoleptic Evaluation of Kisra Using Hedonic Test Method

Hot plate spread was observed at the baking stage. Four cultivars performed extremely well producing smooth full spread Kisra sheets on hot plate. Feterita Wad Ahmed (F.W. Ahmed), Dabar (control), 89/OSF$_5$ - 2451 and HD-1. The poor spread with balling and foaming characteristics was found in ICSV-207. Hot plate spread was found to be an important indicator for Kisra quality measure. It indicates whether a waxy batter or sticky characteristics may be found in the Kisra product (FRC, 1995).

The panelist score for Kisra quality of seven sorghum cultivars expected for release to farmers in 1995/96 season plus the control (Dabar) are shown in Table 2a. Dabar is a popular variety with medium hard and white grain that gives good Kisra quality.

The Hedonic test (10 - point category scale) was conducted to determine consumers degree of acceptability for Kisra products from eight sorghum cultivars. The analysis of variance (ANOVA) was computed as reported in Watts et al. (1989). The calculated F test for varieties or cultivars showed significant ($p \leq 0.05$) difference among the mean hedonic scores for the eight cultivars. Similarly the panelist F test showed significant panelist effect (Table 2b). Therefore, the ANOVA indicated that there were significant differences among the cultivars. To determine which cultivar samples differed significantly from each other, a multiple comparison test, Duncan's New Multiple Range Test was applied (Watts et al, 1989). The results obtained showed that there is no significant difference among the control sample and three new sorghum cultivars, 89/OSF$_5$-2451, 89/OSF$_5$-3582 and HD-1 (Table 2c). The three best cultivars showed no significant difference with ICSV-230. The poor Kisra

Table 2a. Kisra scores for Hedonic Test (Panelist scores for acceptability).

Panelist	HD-1	F.W. Ahmed	87/OSH-5283	87/OSF$_5$-2451	89/OSF$_5$-3582	ICSV-207	ICSV-230	Dabar (control)	Panelist (total)	(Mean)
1	6	5	7	8	6	6	6	7	51	6.375
2	7	5	4	8	8	3	4	6	45	5.625
3	6	3	5	7	8	5	5	8	47	5.875
4	6	6	4	10	8	4	8	10	56	7.000
5	7	8	7	8	7	5	7	10	59	7.375
6	8	6	6	6	6	8	8	8	56	7.000
7	5	2	4	5	7	4	7	5	39	4.875
8	6	5	5	5	5	2	5	5	38	4.750
9	6	5	7	8	6	8	5	9	54	6.750
10	8	7	6	9	10	1	6	9	56	7.000
Total	65	52	55	74	71	46	61	77	501	
Mean	6.5	5.2	5.5	7.4	7.1	4.6	6.1	7.7		

Table 2b. ANOVA Table for the Hedonic Test (Kisra Quality From Sorghum Cultivars)

Source of variation	df	SS	MS	Calculated	Tabular P<.05
Total (T)	79	277.5			
Treatment (Tr)	7	86.2	12.31	6.064	2.1665
Panelist (P)	9	63.1	7.01	3.453	2.0401
Error (E)	63	128.2	2.03		

There is significant difference in the varieties (treatment) as well as the panelists shown under the calculated (MS (Tr)/MS (E), Ms (P)/MS(E)) and Tabular F ratio (P<.05) from df (Tr)/df (E) and df(P)/df(E).

Table 2c. Sorghum Cultivars Significant Test on Treatment Means Duncans' Test

Cultivars	Treatments
Dabar (Control)	7.7 a
89/OSF5 - 2451	7.4 ab
89/OSF5 - 3582	7.1 ab
HD-1	6.5 abc
ICSV - 230	6.1 bc
87/OSH - 5283	5.5 cd
F.W. Ahmed	5.2 cd
ICSV - 207	4.6 d

The significant difference among the means are presented by using letters. Means followed by different letters were significantly different at the 5% level of probability.

quality from cultivar ICSV-207 has no significant difference with two cultivars 87/OSH-5283 and F.W. Ahmed (Table 2c) that were rated satisfactory.

The results of this study have indicated that an early link between the breeders and food scientists in a research program is important. Breeders tend to plan in isolation from processors and consumers. Therefore, at the time of transfer of technology, we meet with constraints that could have been avoided at the initial stage of planning. There is no specific program on regional or international level that addresses the processing of sorghum or millet. Advances in sorghum processing for utilization in the linked research systems is usually given less attention. Therefore it is imperative to address the constraints faced in the transfer of technology of developed products and those in the pipeline.

Chemical Control of *Striga* - A.G.T. Babiker and M.T. El Mana, Gezira Research Station

Four field experiments were conducted under irrigation at the Gezira Research Station to study the potential of several control measures in combating the root parasitic weed *Striga* hermonthica on sorghum. The method covered in this investigation include herbicides, fertilizers and sorghum varieties. Sorghum was planted in July in a *Striga* sick plot on ridges 80cm apart at a within row spacing of 15 cm. The seedlings were thinned to two plants/hole 15 days after emergence. All herbicide treatments, unless mentioned otherwise, were applied as soil directed sprays four weeks after crop sowing. *Striga* counts were made periodically. Crop stand, number of sorghum heads, straw yield and *Striga* air-dry weight were determined at harvest. The individual experiments are described below.

Effects of Garlone on *Striga* on Sorghum

Sorghum (cv. Gadam El Hamam) was used in this experiment. Urea at 0, 20, 40 and 60 kg was applied at sowing. Garlone at 0, 0.15, 0.2 and 0.3 kg/fed was superimposed on the urea treatments. Urea at 20 kg/fed increased *Striga* emergence, however, it did not influence air-dry weight at harvest. Increasing urea to 40 and 60 kg/fed increased both *Striga* emergence and dry weight. Garlone at 0.15 kg effected moderate control of the parasite early in the season, but did not curtail late season infestation. The herbicide at 0.2 and 0.3 kg gave excellent and lasting control of *Striga*. Urea applied prior to Garlone increased herbicidal efficacy. The product, even at the lowest rate when applied subsequent to urea, effected satisfactory to excellent control throughout the growing season.

The untreated plots sustained the lowest crop stand. Urea increased crop stand by 31 to 51%. The corresponding increments for Garlone, when not preceded by urea, were 14-33%. Garlone, applied subsequent to urea, increased crop stand by 33-88%. The observed increments were, however, not consistent with either urea or herbicide rate. Untreated sorghum yielded the least number of heads. Urea alone increased heading by 204-224%. The corresponding increments attained from Garlone treatments were 86-177%. Plots treated with urea at 20 to 40, alone or in combination with Garlone at 0.15 kg, yielded comparable number of heads. Garlone at 0.2 and 0.3 kg applied subsequent to urea at 40 and 60 kg/fed increased heading considerably. Unchecked *Striga* parasitism resulted in a considerable reduction in straw yield. Urea or Garlone treatments increased yield significantly. However, the observed yield increments were inconsistent with urea or herbicide rate. Garlone applied subsequent to urea, invariably, out yielded the corresponding separate urea and Garlone treatments.

Effect of Application Time on Herbicidal efficacy of Garlone on *Striga* on Sorghum

Three sorghum varieties Gadam El Hamam (G/H), Korakolo and Abu Sabien were employed in this experiment. The herbicide Garlone at 0.25 kg was applied at 2,4,6 and 8 weeks after sowing.

Early season *Striga* emergence was more intense on Korakolo and Abu Sabien (31 and 32 plants/m^2) than on Gadam El Hamam (19 plants/m^2). However, late in the season *Striga* population density declined. The displayed decline was negligible (11%) on Gadam El Hamam and considerable (45-90%) on Korakolo and Abu Sabien. Garlone treatments made at two, four, and six weeks effected excellent (82-100%) initial control of the parasite on all varieties. Early season control of *Striga* by Garlone applied at eight weeks, was good (74%) on Gadam El Hamam, satisfactory (65%) on Abu Sabien and poor (31%) on Korakolo. At 15 to 18 weeks after planting Garlone treatments made at two weeks effected poor control of *Striga* (0-42%) on all varieties. Herbicide treatments made at four to eight weeks maintained good to excellent control (69-95%) on Gadam El Hamam and Korakolo. However, on Abu Sabien Garlone applied at four weeks displayed poor activity (0% control). Garlone treatments made at six and eight weeks effected good to excellent control on all varieties. *Striga* dry weight at harvest was maximum (27-32.4 g/m^2) on plots sown to Gadam El Hamam and Korakolo and minimum (8.9 g/m^2) on those planted to Abu Sabien. Garlone treatment made at two weeks reduced *Striga* dry weight on Gadam El Hamam and Korakolo by 57 and 65%, respectively. However, on Abu Sabien a considerable increase (39%), relative to the untreated control, was displayed. Garlone treatments made at four to eight weeks reduced *Striga* dry weight on all varieties. *Striga* dry weight was invariably, the lowest in plots treated at six weeks. The maximum reduction (97%) was attained in plots sown to Gadam El Hamam.

Unrestricted *Striga* parasitism reduced the stand of all varieties. Stand reduction was highest in Abu Sabien and lowest in Gadam El Hamam. Garlone treatments made at two weeks, considerably improved stand of korakolo and Abu Sabien but not that of Gadam El Hamam. The herbicide treatment made at four weeks considerably increased the

stand of all varieties. The highest crop stand (43,300 plants/fed) was attained by Korakolo. One percent basis stand increments, over the respective untreated controls, were 52, 124 and 138% for Gadam El Hamam, Korakolo and Abu Sabien, respectively. Garlone treatments made at six and eight weeks were less effective. Treatments made at six weeks increased crop stand by 35, 63 and 17% for Gadam El Hamam, Korakolo and Abu Sabien, respectively. The corresponding stand increments effected by Garlone applied at 8 weeks were 5.8, 24 and 28.5%. *Striga*, invariably, reduced crop height. Among the untreated controls Gadam El Hamam and Abu Sabien gave the tallest and shortest plants, respectively. Garlone treatments made at two weeks decreased height of Gadam El Hamam by 17%. However, a substantial increase in height (95-117%) was displayed by Korakolo and Abu Sabien. Garlone treatments made at four weeks increased plant height in all varieties. Treatments made at six weeks effectively increased height of Gadam El Hamam and Korakolo (11-64%), but not that of Abu Sabien. Garlone treatments made at eight weeks caused a comparatively slight increase in height of Korakolo and Abu Sabien and a slight reduction in that of Gadam El Hamam. Unrestricted *Striga* parasitism reduced straw yield of all varieties. In among the untreated controls Korakolo and Gadam El Hamam gave the lowest and highest yields, respectively. In among all treatments plots sprayed with Garlone at two and four weeks gave the highest straw yield. Yield increments varied from about nine-fold with Korakolo to about three-fold with Abu Sabien. Treatment made at six and eight weeks were less effective. Yield increments varied from negligible with Abu Sabien to between one and six-fold with Gadam El Hamam and Korakolo.

Effects of MCPA and 2, 4-D on Striga on Sorghum

Sorghum (cv. Gadam El Hamam, G/H) was used in this experiment. Urea at 0, 20 and 40 kg a.i./fed. was applied at sowing. MCPA and 2, 4-D at 0.42 and 0.32 kg/fed. each, were superimposed on the urea treatments.

Striga emergence was early and more intense in plots treated with urea alone at 20 and 40 kg. However, late in the season (17 weeks or more) *Striga* emergence was about equal in the fertilized and unfertilized plots. MCPA and 2, 4-D, irrespective of rate or the preceding urea treatment, effected satisfactory (70%) control of the parasite at 10 weeks. However, at 17 and 21 weeks a differential decline in activity occurred. 2,4-D alone and when preceded by urea at 20kg resulted in poor control. However, 2, 4-D treatments made subsequent to urea at 40 kg displayed satisfactory activity (70% control). MCPA alone effected poor control and a surge in *Striga* emergence occurred at 21 weeks. MCPA treatments made subsequent to urea at 20 or 40 kg maintained moderate control of the parasite for 17 weeks. At 21 weeks a further decline in herbicidal activity was displayed. *Striga* air-dry weight at harvest from plots treated with 2, 4-D at 0.32, MCPA at 0.32 and 0.42 or urea at 20 and 40 kg was not different from that obtained of the untreated plots. However, 2, 4-D at the high rate of 2,4-D and MCPA treatments made subsequent to urea resulted in drastic reductions in *Striga* dry weight.

Untreated sorghum or plots treated with urea at 20 kg displayed a stunted growth. In comparison to the untreated crop urea at 40 kg, 2,4-D, MCPA and the herbicide/urea combinations increased sorghum height by 17 to 69%. Untreated *Striga* parasitism considerably reduced sorghum heading. Urea increased sorghum heading by about 50 to 60%. Plots treated with 2,4-D and MCPA sustained more heads than the urea treated plots. The number of heads displayed a further increase in plots treated with the urea/herbicide combinations. Among the individual treatments, maximum heading was attained from plots sprayed with herbicides subsequent to urea treatments. Straw yield was considerably reduced by *Striga*. Urea at 20 and 40 kg increased straw yield by 49 and 96%, respectively. Yield increments effected by MCPA and 2,4-D ranged between 73 and 123%. A further increase in straw yield was realized when the herbicide treatments were made subsequent to urea. Higher yields were, invariably, obtained from plots treated with the low herbicide from plots treated with the herbicides at low rates subsequent to urea at 40 kg.

Effects of 2, 4-D on Striga on sorghum

Three sorghum varieties, Gadam El Hamam (G/H), Korakolo and Safra were employed in this experiment. The berbicide 2, 4-D at 0.42 kg/fed was applied as a single dose at four weeks or as a split dose at four, and six or four and eight weeks after planting, respectively.

Early in the season *Striga* emergence was intense on Safra and moderate on Korakolo and (G/H). Initial control of the parasite by 2,4-D, single or split dose, was excellent (79-83%) on G/H, moderate to satisfactory (62-75%) on Safra and poor to moderate (31-64%) on Korakolo. Late in the season *Striga* population density, in all plots, displayed a sharp decline. 2,4-D as a single dose effected 33-36% control. Split application at four and six weeks resulted in 50-64% control. Split 2, 4-D treatment made at four and eight weeks gave 71-83% control. *Striga* air-dry weight at harvest varied with crop variety and herbicide treatment. On G/H and Safra 2,4-D, irrespective of application method, effected significant reduction (44-89%). However, on Korakolo a significant reduction was only achieved in plots sprayed with 2,4-D as a split treatment at four and eight weeks. *Striga* reduced straw yield of all varieties with the highest reduction displayed by G/H. Straw yield was considerably improved by 2,4-D, irrespective of application method. Split applications were more effective on Korakolo and Safra, but were about equally effective as a single dose of G/H.

Institution Building

Research Equipment Purchased

During Year 17, research supplies and equipment were purchased for the Agricultural Research Corporation in Sudan to support on-going collaborative efforts and for the Institute of Agricultural Research (IAR), Ethiopia to initiate a new collaborative venture as part of the new Greater Horn of Africa initiative for INTSORMIL.

The following research supplies and equipment were purchased for ARC, Sudan: Microwave oven, pruning knives, computer and related software, sorghum and millet pollinating bags, and SP3 sprayers.

Items purchased for the IAR, Ethiopia include: HP LaserJet 4 Plus, HP ScanJet 4C, HP ScanJet 4S, Dot Matrix printer, international smart UPS, facsimile, photocopier, computer with related software, slide projector, Mettler precision balance, Hygrothermograph, Pentex camera, overhead projector, vacuum cleaner, Cannon camera, seed envelopes, glass bags for crossing, poly bottles, pollinating bags, triangular seed sample pans, air conditioners, voltage regulators, table top hand sealer, altimeter, cloth bags, power converters, microscope and accessories, and a spectrophotometer.

Host Country Researchers Trained

Two Sudanese students, Yahia Ibrahim and Abdalla Mohammed are currently pursuing their Ph.D. programs, both working under the supervision of Dr. Gebisa Ejeta. Yahia Ibrahim is supported by INTSORMIL under PRF-107, whereas Abdalla Mohammed is supported by the Rockefeller Foundation under a grant provided for *Striga* research.

In the past, a number of students from Sudan and the other Horn of Africa countries have been trained in INTSORMIL institutions. The initiative to establish a network in the Horn of Africa region that is currently underway, involves many of our former graduates who now hold key positions in their national research programs.

Host Country Scientist Visits

Yahia Ibrahim, a Ph.D. student at Purdue University returned to Sudan to conduct field studies on *Striga*. Yahia spent the 1995 crop season at Wad Medani where he evaluated a population of recombinant inbred sorghum lines for field *Striga* resistance. He also interacted with ARC sorghum and millet scientists during his stay in Sudan.

Dr. Abdel Gabar Babiker was sponsored by INTSORMIL to attend the Sixth Parasitic Weed Conference held at Cordoba, Spain in April 1996. He presented a paper entitled "Chemical Control of *Striga hermonthica* in sorghum" which was co-authored with his collaborators, Gebisa Ejeta and Larry Butler.

Networking

INTSORMILs Involvement in Establishing a Sorghum and Millet Research Network in the Greater Horn of Africa

Commodity based regional research networks have been operating in Africa with support provided by several donor agencies. Primary support for sorghum and millet networks have been provided, until recently, by USAID through SAFGRAD. The Eastern Africa Regional Sorghum and Millet (EARSAM) network was founded in 1986 and managed by SAFGRAD through ICRISAT until USAID funding terminated in 1993. During its operations, the EARSAM network served as a forum to bring sorghum and millet scientists in the region to work together on research issues that transcend political boundaries. Under the auspices of EARSAM, regional priorities were set, lead centers (countries) were identified for regional priority projects, and results from such research projects were reported and shared at biannual regional meetings. Monitoring tours were organized to familiarize NARS scientists with the array of challenges and research opportunities in the region.

Since the end of SAFGRAD funding for commodity networks, regional collaboration continued with alternative funding in Western and Southern Africa, but not in Eastern Africa. Consequently, senior sorghum and millet research scientists in Eastern Africa, with encouragement and support from ICRISAT, gathered in Nairobi on October 8-9, 1993 to evaluate and discuss the importance of a regional network and to assess ways and means for generating long-term support for such a regional collaborative venture. The scientists unanimously agreed to form a new network for continued interaction and cooperation in the region. The new network is expected to draw from experiences gained from the years of operation under EARSAM and build upon the results achieved so far particularly in the areas of varietal development and exchange of scientific and programmatic information. The scientists in the region also agreed to have the new sorghum and millet network operate under the umbrella of a newly formed regional organization, the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA).

The formation of ASARECA has been a rather informal initiative. Directors of research from a number of African countries, having witnessed the benefit occurred from regional ventures such as the SADC program, agreed to form a similar but less formal program in the region. As the name implies they wanted to make ASARECA an association of national programs in the eastern and central Africa region. ASARECA includes all of the countries in the Greater Horn of Africa (Ethiopia, Sudan, Eritrea, Kenya, Somalia, except Djibouti) and some Central African countries (Rwanda, Zaire, Burundi, Uganda) plus Madagascar. Djibouti has been recalcitrant about joining ASARECA, presumably because it has been the headquarters for IGADD (another regional development project) and the formation of this new

association may have been perceived as a threat to the more formal (read political) IGADD.

The International Centers operating in East Africa have had input in defining the early form and scope of ASARECA. USAID has also been among the early endorsers of this program having pledged significant resources to jump-start the organization. One of the concepts that the Centers' staff in the region has promoted is the creation and operation of networks under ASARECA. Dr. G. Ejeta learned about this in June 1995 when he was in Nairobi on assignment working with World Vision. About the same time, (INTSORMIL) was trying to salvage our operation in Sudan which has suffered a setback as a result of travel restrictions between the U.S. and Sudan. The travel restrictions brought about operational havoc in an otherwise excellent and productive collaborative relationship. The Sudan Country Coordinator had proposed to INTSORMIL, as early as 1994, a plan to sign MOUs with neighboring countries in Eastern Africa so that the project could be run as a regional sorghum and millet network research program. The size and scope of the network envisioned were much smaller and more specific, however. Dr. Ejeta, therefore, proposed to ICRISAT personnel in Kenya about jointly sponsoring a workshop in Uganda (headquarters for ASARECA) to discuss the formation of a regional sorghum and millet network in which both ICRISAT and INTSORMIL will be participants and where they may provide technical backup and support. At the time, ICRISAT already had approval and consent from both ASARECA and NARS leaders and a tentative date for the workshop, but had not generated sufficient funds to go ahead. Both ICRISAT and ASARECA welcomed INTSORMIL as a co-sponsor and the workshop was held in Kampala in November 1995. INTSORMIL participated both in the development of the agenda for the meeting as well as in the conduct of the workshop.

The workshop was a success in many regards. It reaffirmed the need for a network in the region to strengthen ties among NARS, to promote free and timely exchange of information and germplasm, to develop collaborative research projects on priority production and utilization constraints of regional importance, and to share experiences on effective transfer of technologies to farm communities. The workshop also provided for a better understanding of the aspirations of each national sorghum and millet improvement programs in the region as well as the modes of operations of both ICRISAT and INTSORMIL. In addition to country reports, members of ICRISAT and INTSORMIL also made presentations. Participants from INTSORMIL included Dave Andrews, Larry Butler, Richard Frederiksen, John Leslie, and Gebisa Ejeta. INTSORMIL presentations focused on how collaborative ventures are initiated and implemented between INTSORMIL institutions and NARS using specific examples in sorghum and millet breeding, plant pathology, utilization, and biotechnology. **Many of the features the INTSORMIL CRSP provides, such as graduate training, staff exchange, a joint research agenda, a mentoring program for newly trained staff, equitable sharing of limited resources, and the opportunity for technical backup by some of the best sorghum and millet research programs in the world were very appealing to the NARS scientists in the ASARECA region.** Leaders of many of the NARS expressed a desire to sign an MOU with INTSORMIL. Unfortunately, limitations of resources does not permit signing of MOU with every NARS. However, we have since signed MOUs with Ethiopia, Kenya, and Eritrea following discussions initiated during the workshop in November. This will give INTSORMIL an excellent nucleus in which to operate an effective regional research network in the Greater Horn of Africa. The USAID Missions in Ethiopia and Eritrea have identified crop research and production as targets for development initiatives. Leaders of the Eritrean program are particularly excited about the opportunity for working with CRSPs because as a new nation, they have identified human capital development as a priority and they see U.S. universities providing graduate education opportunities.

As part of the agenda developed for the workshop, NARS scientists in the ASARECA region developed a draft proposal to solicit funding for revitalization and operation of a sorghum and millet research network in the ASARECA region. Both INTSORMIL and ICRISAT expect to be key participants in such a network in the Greater Horn of Africa. Proceedings of the workshop, including the proposal drafted by NARS scientists in the region, are currently under preparation for publication at Purdue University.

We certainly hope that donor funding for support of sorghum and millet network in eastern Africa will be forthcoming. A network in the region will greatly enhance interaction and dissemination of research results among NARS. It will also facilitate INTSORMIL's efforts in the Greater Horn of Africa. With or without additional funding, however, INTSORMIL activities in the Horn, by necessity, will be based on regional networking among, at the minimum, NARS with which we already have signed Memoranda of Understanding. The details of how such a small regional network would function will be further developed in cooperation with scientists from participating NARS.

Training

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 international development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the year covered by this report, 57 students from 18 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 77% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

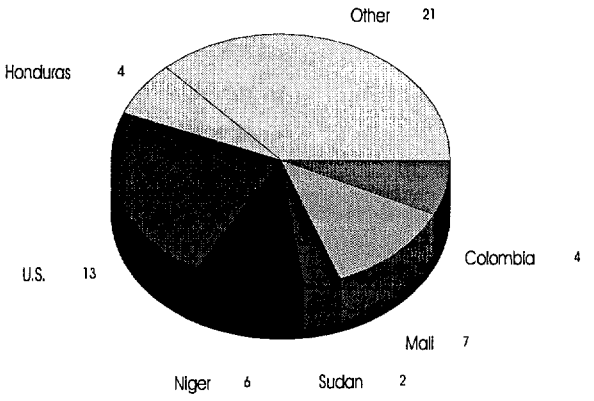

Figure 1. Training analysis - country breakdown.

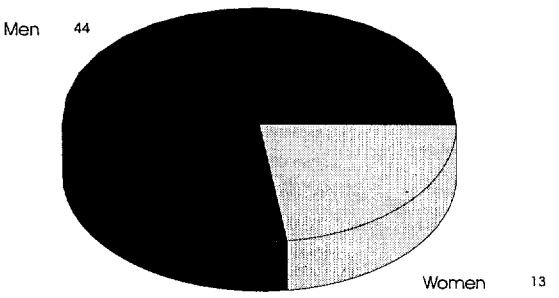

Figure 2. Training analysis - gender breakdown.

INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 1996, 23% of all INTSORMIL graduate participants were female. Twenty-One of the total 57 students received full INTSORMIL scholarships. An additional 16 students received partial INTSORMIL funding and the remaining 20 students were funded from other sources as shown in Figure 3.

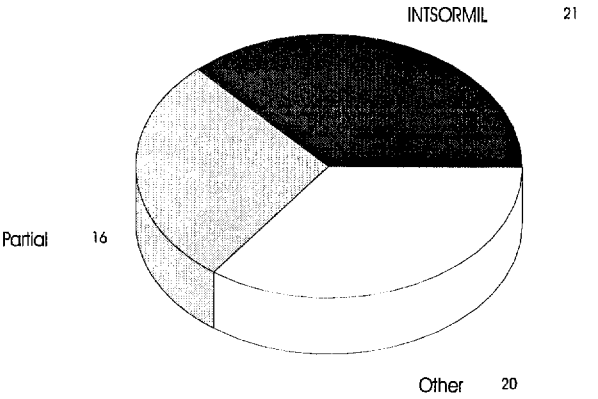

Figure 3. Training analysis - source of funding.

All 57 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding, pathology, entomology, food quality, and economics.

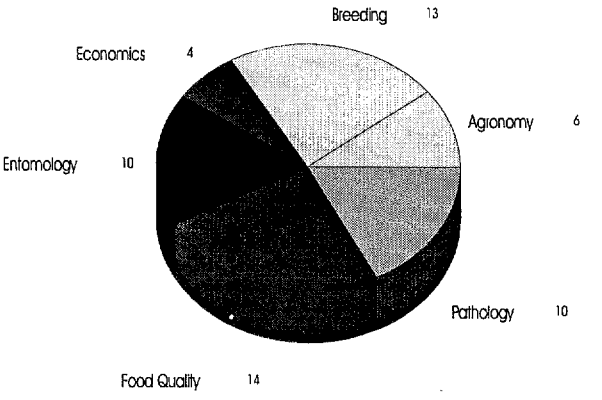

Figure 4. Training analysis - discipline breakdown.

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Total student numbers decreased in 1995-96 as compared to 1994 and 1995. The number of INTSORMIL funded students has decreased gradually over the years. This is related to decreases in program budget and the loss of U. S. Principal Investigators. In 1993-1994 there were 25 U.S. PIs with the program and in 1995-1996 this had decreased down to eighteen.

In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Three visiting host country scientists and four post doctoral scientists were provided the opportunity to upgrade their skills in this fashion during 1995-1996.

The following table is a compilation of all INTSORMIL training activities for the period July 1, 1995 through June 30, 1996.

Year 17 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Gutierrez, Patricio F.	Ecuador	UNL	Agronomy	Clegg	PHD	M	I
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M	O
Traore, Abdoulaye	Mali	UNL	Agronomy	Maranville	PHD	M	I
Maman, Nouri	Niger	UNL	Agronomy	Mason	M.S	M	I
Stockton, Roger	U.S.	UNL	Agronomy	Mason	PHD	M	P
Traore, Samba	Mali	UNL	Agronomy	Mason	PHD	M	O
Carvalho, Carlos H.S.	Brazil	PRF	Breeding	Axtell	PHD	M	P
Kapran, Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	I
Ndulu, Lexingtons	Kenya	PRF	Breeding	Axtell	PHD	M	I
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	PHD	M	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	P
Tuinstra, Mitchell	U.S.	PRF	Breeding	Ejeta	PHD	M	I
Stewart, Klint G.	U.S.	TAM	Breeding	Peterson	MSC	M	O
Katsar, Catherine Susan	U.S.	TAM	Breeding	Peterson/Teetes	PHD	F	P
Crasta, Oswald	India	TTU	Breeding	Rosenow	PHD	M	P
Munera, Alvaro	Colombia	TTU	Breeding	Rosenow	MSC	M	P
Rodriguez, Raul	Mexico	TAM	Breeding	Rosenow/Rooney	PHD	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Jeutong, Fabien	Cameroon	UNL	Breeding	Andrews	PHD	M	O
Coulibaly, Bakary	Mali	PRF	Economics	Sanders	MSC	M	O
Dembele, Issiaka	Mali	PRF	Economics	Sanders	VS[1]	M	O
Kebe, Demba	Mali	PRF	Economics	Sanders	VS[1]	M	O
Lilja, Nina	U.S.	PRF	Economics	Sanders	PHD	F	O
Sidibe, Mamadou	Senegal	PRF	Economics	Sanders	PHD	M	O
Vitale, Jeff	U.S.	PRF	Economics	Sanders	PHD	M	I
Boire, Soualika	Mali	TAM	Entomology	Gilstrap	PHD	M	I
Kadi Kadi, Hame	Niger	TAM	Entomology	Gilstrap	MSC	M	I
Calderon, Pedro	Honduras	MSU	Entomology	Pitre	MSC	M	P
Cordero, Roberto	Honduras	MSU	Entomology	Pitre	MSC	M	I
Vergara, Oscar	Honduras	MSU	Entomology	Pitre	MSC	M	I
Diarisso Yaro, Niamoye	Mali	TAM	Entomology	Teetes/Peterson	PHD	F	O
Jensen, Andrea	U.S.	TAM	Entomology	Teetes	PHD	F	I
Lingren, Scott	U.S.	TAM	Entomology	Teetes	PHD	M	O
Magallenes, Ricardo	Mexico	TAM	Entomology	Teetes	PHD	M	P
Mott, Dale Allen	U.S.	TAM	Entomology	Teetes	MSC	M	O
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker/Axtell	PHD	M	I
Buckner, Becky	U.S.	PRF	Food Quality/Util	Hamaker	PHD	F	O
Itapu, Suresh	India	PRF	Food Quality/Util	Hamaker	PD[2]	M	O
Mamadou, Lewamy	Niger	PRF	Food Quality/Util	Hamaker	MSC	M	O
Oria, Maria P.	Spain	PRF	Food Quality/Util	Hamaker	PHD	F	I
Weaver, Charlotte	U.S.	PRF	Food Quality/Util	Hamaker	MSC	F	O
Zhang, Genyi	China	PRF	Food Quality/Util	Hamaker	MSC	M	I
Acosta, Harold	Colombia	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Asante, Sam	Ghana	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Bueso, Francisco Javier	Honduras	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	I
Floyd, Cherie	U.S.	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Guajardo-Flores, Sara	Mexico	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	I
Kunetz, Christine	U.S.	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Seetharaman, Koushik	India	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Suhendro, Elly	Indonesia	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Diourte, Mamourou	Mali	KSU	Pathology	Claflin	PHD	M	O
Lu, Ming	China	KSU	Pathology	Claflin	PHD	M	O
Muriithi, Linus M.	Kenya	KSU	Pathology	Claflin	PHD	M	O
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	MSC	M	O
Nzioki, Henry S.	Kenya	KSU	Pathology	Claflin	MSC	M	O
Xu, Xiude	China	KSU	Pathology	Claflin	VS[1]	M	O
Amoah, Ben	Ghana	KSU	Pathology	Leslie	PD[2]	M	I

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Arjula, Vaishal	India	KSU	Pathology	Leslie	MSC	F	O
Salleh, Baharuddin	Malaysia	KSU	Pathology	Leslie	PD[2]	M	O
Zeller, Kurt P.	U.S.	KSU	Pathology	Leslie	PD[2]	M	O
Kollo, Issoufou	Niger	TAM	Pathology	Frederiksen	PHD	M	I
Osorio, Jairo	Colombia	TAM	Pathology	Frederiksen	PHD	M	O
Rosewich, Ute L.	Germany	TAM	Pathology	Frederiksen	PHD	F	I
Torres-Montalvo, Jose H.	Mexico	TAM	Pathology	Frederiksen	PHD	M	P

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
O = Other source

[1]VS = Visiting Scientist
[2]PD = Post Doctoral

KSU = Kansas State University
MSU= Mississippi State University
PRF = Purdue University
TAM= Texas A&M University
TTU = Texas Tech University
UNL = University of Nebraska - Lincoln

Appendices

INTSORMIL Buy-Ins through FY 96

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
KSU-106	Kansas Sorghum Board	1985	6 years	17,500	105,000
	Kansas Agric. Exp. Station	1989	3 years	19,000	57,000
	Kansas Agric. Exp. Station	1989	3 years	13,333	40,000
	Kansas Sorghum Board	1991	4 years	15,334	61,338
	Kansas Agric. Exp. Station	1990	3 years	19,000	57,000
	EPA/Univ. of Nebraska	1990	2 years	32,518	65,036
					$ 385,374
KSU-108	Kansas Sorghum Board	1985	9 years	18,482	166,338
	Kansas Corn Commission	1988	3 years	16,845	50,535
	Kansas Sorghum Commission	1989	1 year	7,166	7,166
	Kansas Sorghum Commission	1989	1 year	6,500	6,500
	EPA	1990	3 years	39,523	118,569
	Kansas Agric. Exp. Station	1991	3 years	19,000	57,000
	USDA/ARS	1992	1 year	14,400	14,400
					$ 420,508
KSU-108B	Myco Pharmaceuticals	1993	3 years	30,000	90,000
	Kansas Agric. Exp. Station	1993	3 years	17,500	52,500
	USDA/Pioneer Seed Co.	1994	2 years	75,000	150,000
	USDA/Pioneer Seed Co.	1994	2 years	30,000	60,000
	No. Central Biotechnology Initiative	1994	2 years	65,000	130,000
	USDA/CSRS	1995	2 years	62,000	124,000
					$ 606,500
MSU-104	MIAC/Kenya	1990	2 years	115,725	231,450
	MIAC/Kenya	1992	3.5 years	142,000	497,000
	USAID/MIAC	1992	5 years	35,000	175,000
					$ 903,450
MSU-105	FAO	1992	3 years	2,245	**$ 6,735**
MSU-111	Fedearroz	1990	5 years	10,000	50,000
	El Alcaravan Foundation	1990	2 years	200,000	400,000
	Fenalce	1991	1 year	5,000	5,000
					$ 455,000
PRF-103A	AID/Program Support Grant	1988	2 years	7,500	15,000
	Agric. Exp. Station	1988	2 years	6,000	12,000
	Purdue Agronomy Dept.	1989	2 years	1,000	2,000
	McKnight Foundation	1989	3 years	250,000	750,000
	Corporation for Science & Tech.	1991	1 year	10,000	10,000
	Pioneer Hi-Bred Intern.	1992	3 years	33,900	101,693
	Purdue Agronomy Dept.	1992	1 year	1,000	1,000
	McKnight Foundation	1992	3 years	250,000	750,000
	Midwest Biotechnology Consortium	1993	1 year	32,627	32,627
	Purdue Agronomy Dept.	1994	2 years	1,000	2,000
	Pioneer Hi-Bred	1994	2 years	30,000	60,000
					$ 1,736,320
PRF-103B	USDA Training	1989	3 years	15,000	45,000
	AFGRAD Training	1989	4 years	9,000	36,000
	NAAR Project	1991	1 year	3,000	3,000
					$ 84,000
PRF-104B & 104C	USAID PSG	1989	2 years	7,500	15,000
	Rockefeller Foundation	1989	3 years	23,067	69,200
	USAID/PSTC	1990	4 years	37,450	150,000
	USAID PSG	1991	2 years	10,000	20,000
	Purdue Research Foundation	1991	1 year	2,800	2,800
	Pioneer Seed Co.	1991	3 years	40,000	120,000
	PSTC/USAID	1991	3 years	50,000	150,000
	Pioneer Seed Co.	1991	2 years	30,000	60,000
	NSF	1992	1.5 years	173,333	260,000
	Pioneer Seed Co.	1993	2 years	13,600	27,192
	Dept. of Energy	1993	2 years	56,780	113,560
	Rockefeller Foundation	1993	2 years	45,000	90,000
	USAID/PSTC	1994	2 years	50,000	100,000
	McKnight Foundation	1994	1 year	85,000	85,000
	National Science Foundation	1994	1 year	85,000	85,000
	USDA	1995	1 year	4,275	4,275
	ASA/Sorghum Crop Advisory	1995	1 year	10,000	10,000
					$ 1,362,027

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University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
PRF-105	USAID PSG	1989	4 years	5,000	20,000
	USAID PSG	1989	3 years	5,000	15,000
	World Bank	1989	2.5 years	10,000	25,000
	World Bank/IDA	1989	1 year	4,500	4,500
	USAID/Bean-Cowpea CRSP	1990	1 year	27,000	27,000
	EMBRAPA	1992	1 year	10,000	10,000
	USAID/AFT/ARTS	1992	1 year	20,000	20,000
	USAID/AFT/ARTS	1994	2 years	150,000	300,000
	USDA/SCS	1995	1 year	27,820	27,820
					$ 449,320
PRF-107	Purdue Agronomy Dept.	1988	1 year	1,500	1,500
	State of Indiana	1990	1 year	7,000	7,000
	McKnight Foundation	1990	3 years	20,632	61,896
	USAID PSG	1990	2 years	14,000	28,000
	McKnight Foundation	1990	3 years	22,000	66,000
	Pioneer Seed Co.	1991	2 years	30,000	60,000
	State of Indiana	1991	1 year	1,200	1,200
	Rockefeller Foundation	1992	3 years	33,335	100,000
					$ 325,596
PRF-109	USDA Grant	1990	2 years	60,000	**$ 120,000**
PRF-112	Purdue Agronomy Department	1994	1 year	12,000	12,000
	USDA	1993	3 years	17,000	51,000
	Mahyco Research Foundation	1995	2 years	40,000	80,000
					$ 143,000
TAM Joint	USAID/TAMU	1989	3 years	15,000	45,000
	USAID/TAMU	1991	3 years	15,000	45,000
					$ 90,000
TAM-122	State of Texas Grant	1989	2 years	20,000	40,000
	USAID/TAMU	1990	2 years	10,000	20,000
	USAID/TAMU	1990	3 years	13,000	39,000
	Texas Higher Coordinating Board	1991	2 years	27,000	54,000
	USDA	1991	2 years	7,500	15,000
	USAID/TAMU	1992	2 years	28,000	56,000
					$ 224,000
TAM-123	Texas Grain Sorghum Producers	1990	5 years	50,000	250,000
	USAID/TAMU	1990	1 year	17,000	17,000
	USAID/TAMU	1991	1 year	28,000	28,000
	TAES	1993	2 years	22,500	45,000
	USDA/Sorghum Advisory Committee	1994	1 year	5,000	5,000
					$ 345,000
TAM-124	USDA	1989	3 years	10,000	30,000
	Texas Advanced Research	1989	1 year	75,000	75,000
	TAES/ERA	1989	2 years	32,000	64,000
	Texas Advanced Research	1990	3 years	15,000	45,000
	Rockefeller Foundation	1990	2 years	30,000	60,000
	Texas Advanced Research	1992	2 years	10,000	20,000
	Rockefeller Foundation	1992	2 years	7,000	14,000
	Rockefeller Foundation	1994	3 years	25,000	75,000
	Pioneer Seed Company	1994	2 years	30,000	60,000
	TAES	1994	2 years	50,000	100,000
	Texas Sorghum Board	1995	2 years	22,500	45,000
					$ 588,000
TAM-125	TAMU/PSG	1989	2 years	45,000	90,000
	Industry Grant	1989	2 years	10,000	20,000
	USDA/CRSP	1989	1 year	15,000	15,000
	USDA/APHIS	1989	2 years	15,000	30,000
	USDA/APHIS	1989	1 year	14,000	14,000
	Texas Agric. Exp. Station	1990	2 years	7,000	14,000
	USDA/APHIS	1990	3 years	23,734	71,202
	USDA/CSRS	1990	2 years	59,819	119,638
	TAMU/Program Support Grant	1990	2 years	18,638	37,276
	TAMU/Program Support Grant	1990	2 years	30,000	60,000
	Texas Grain Sorghum Producers	1990	2 years	50,000	100,000
	USDA/APHIS	1991	1 year	13,200	13,200
	TAMU/Program Support Grant	1990	3 years	27,000	81,000
	Texas Grain Sorghum Producers	1993	5 years	25,000	125,000
	TAES Ag Research Station	1994	2 years	10,000	20,000
	Texas Grain Sorghum Prod.	1994	2 years	40,000	80,000
					$ 890,316

University/ Project No.	Buy-In	Year	Life of Buy-In	Annual Amount	Total
TAM125-B	TAES	1993	2 years	29,000	58,000
	USDA/APHIS	1993	4 years	32,500	130,000
	USDA/CSRS-SR	1993	2 years	45,000	90,000
	USDA/APHIS	1993	4 years	15,000	60,000
	USDA/APHIS	1994	2 years	25,000	50,000
	TAES	1994	2 years	5,000	10,000
	USDA/CSRS	1995	1 year	7,000	7,000
					$ 405,000
TAM-126	Texas Center for Energy	1989	1 year	14,500	14,500
	TAMU/Program Support Grant	1989	3 years	10,000	30,000
	Texas Agr. Exp. Station	1989	5 years	50,000	250,000
	TAES/ERA	1990	2 years	25,000	50,000
	HATCH	1990	4 years	35,000	140,000
	Texas Sorghum Producers	1990	1 year	15,000	15,000
	Grain Sorghum Producers	1991	3 years	10,300	30,900
	TAMU/Hatch	1992	5 years	31,184	155,920
	TAES/ERA	1990	2 years	19,000	38,000
	Grain Sorghum Producers	1992	2 years	20,000	40,000
	Texas Grain Sorghum Board	1994	2 years	20,000	40,000
	Pioneer Seed Co.	1994	2 years	30,000	60,000
	TAMU/HATCH	1995	3 years	35,000	105,000
	TAMU/HATCH	1995	5 years	55,000	275,000
	TAMU/Program Support Grant	1995	2 years	17,000	34,000
					$ 1,278,320
TAM-128	TAES	1993	2 years	10,000	**$ 20,000**
TAM-131	USAID/Honduras PL480	1990	1 year	111,395	111,395
	USAID/Honduras PL480	1991	1 year	120,000	120,000
	USAID/Honduras PL480	1992	1 year	88,704	88,704
	USAID/Honduras PL480	1993	1 year	88,704	88,704
	Commercial Seed Co.	1992	1 year	7,000	7,000
	EEC/IICA/PRAIG	1992	3 years	9,260	27,780
	EEC/IICA/PRAIG	1993	3 years	10,975	32,920
					$ 476,503
UNL-113	Rockefeller Foundation	1988	3 years	8,333	25,000
	Ministry of Science (Leave)	1991	1 year	25,000	25,000
	Nebraska Foundation	1994	2 years	15,000	30,000
					$ 80,000
UNL-114	German Acad.Exchange Serv.	1993	2.5 years	11,000	$ 27,500
	FAO/IAR/Ethiopia	1994	.5 year	14,900	14,900
	Zambia/World Bank	1994	1 year	13,000	13,000
					$ 55,400
UNL-115 & 118	Michigan State/Senegal Agric.	1989	3 years	46,700	140,000
	USAID/Dakar	1992	5 years	70,000	350,000
	Nebraska Grain Sorghum Board	1994	1 year	20,900	20,900
	Nebraska Grain Sorghum Board	1993	3 years	15,600	45,500
	Nebraska Grain Sorghum Board	1994	2 years	6,500	13,000
					$ 569,400
UNL-116	Elliott Grant	1986	4 years	17,250	69,000
	USDA/OICD	1989	3 years	14,667	44,000
	Nebraska Sorghum Board	1990	3 years	24,00	72,000
	USAID/OICD	1990	3 years	43,000	129,000
	USAID/OICD	1990	1 year	4,000	4,000
					$ 318,000
UNL-123	USAID/PSTC Grant	1989	3 years	50,000	150,000
	USDA/ARS	1986	5 years	22,669	113,345
	USDA/ARS	1991	5 years	24,356	121,780
					$ 385,125
M.E.	INTSORMIL/Egypt/NARP Nebraska/Kansas St.	1991	3 years	156,727	$ 470,183
	SADC/ICRISAT/INTSORMIL Training	1990	5 years	1,280,400	6,402,039
	AID/CROSS CRSP Activities	1990	1 year	100,000	100,000
	USAID/Botswana/DAR	1990	1 year	35,860	35,860
	USAID/Khartoum/ARC	1990	1 year	80,000	80,000
	Social Science Research Workshop	1991	1 year	31,600	31,600
	Adaptation of Plants to Soil Stress Workshop	1992	1 year	25,000	25,000
	Rockefeller Foundation-Conference	1993	1 year	6,500	6,500
	FAO/IAR Ethiopia Training	1994	1 year	20,000	20,000
	Niger Mission Inter/CRSP Support	1995	1 year	100,000	100,000
					$ 7,271,182
Total Buy-Ins					**$ 19,994,076**

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1996

	Name	Where	When
1.	International Short Course in Host Plant Resistance	College Station, Texas	1979
2.	INTSORMIL PI Conference	Lincoln, Nebraska	1/80
3.	West Africa Farming Systems	West Lafayette, Indiana	5/80
4.	Sorghum Disease Short Course for Latin America	Mexico	3/81
5.	International Symposium on Sorghum Grain Quality	ICRISAT	10/81
6.	International Symposium on Food Quality	Hyderabad, India	10/81
7.	Agrimeteorology of Sorghum and Millet in the Semi-Arid Tropics	ICRISAT	1982
8.	Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82
9.	Sorghum Food Quality Workshop	El Batan, Mexico	4/82
10.	Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82
11.	Plant Pathology	CIMMYT	6/82
12.	Striga Workshop	Raleigh, North Carolina	8/82
13.	INTSORMIL PI Conference	Scottsdale, Arizona	1/83
14.	INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT	4/83
15.	Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83
16.	Stalk and Root Rots	Bellagio, Italy	11/83
17.	Sorghum in the '80s	ICRISAT	1984
18.	Dominican Republic/Sorghum	Santo Domingo	1984
19.	Sorghum Production Systems in Latin America	CIMMYT	1984
20.	INTSORMIL PI Conference	Scottsdale, Arizona	1/84
21.	Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santo Domingo, Dominican Republic	2/84
22.	Evaluating Sorghum for Al Toxicity in Tropical Soils of Latin America	Cali, Colombia	4/84
23.	First Consultative and Review on Sorghum Research in the Philippines	Los Banos, Philippines	6/84
24.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84
25.	International Sorghum Entomology Workshop	College Station, Texas	7/84
26.	INTSORMIL PI Conference	Lubbock, Texas	2/85
27.	Niger Prime Site Workshop	Niamey, Niger	10/85
28.	Sorghum Seed Production Workshop	CIMMYT	10/85
29.	International Millet Conference	ICRISAT	4/86
30.	Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
31.	INTSORMIL PI Conference	Kansas City, Missouri	1/87
32.	2nd Global Conference on Sorghum/Millet Diseases	Harare, Zimbabwe	3/88
33.	6th Annual CLAIS Meeting	San Salvador, El Salvador	12/88
34.	International INTSORMIL Research Conference	Scottsdale, Arizona	1/89
35.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	7/89
36.	ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
37.	Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
38	Improvement and Use of White Grain Sorghums	El Batan Mexico	12/90
39.	Sorghum for the Future Workshop	Cali, Colombia	1/91
40.	INTSORMIL PI Conference	Corpus Christi, Texas	7/91
41.	Social Science Research and the CRSPs	Lexington, KY	6/92
42.	Seminario Internacional Sobre los Cultivos de Sorgo y Maiz sus Principales Plagas y Enfermedades	Colombia	1/93
43.	Workshop on Adaptation of Plants to Soil Stresses	Lincoln, NE	8/93
44.	Latin America Workshop on Sustainable Production Systems for Acid Soils	Villavicencio, Colombia	9/93
45.	Latin America Sorghum Research Scientist Workshop (CLAIS Meeting)	Villavicencio, Colombia	9/93
46.	Disease Analysis through Genetics and Biotechnology: An International Sorghum and Millet Perspective	Bellagio, Italy	11/93

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	All Disease and Insect Nursery
ADRA	Adventist Development and Relief Agency
A.I.D	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARGN	Anthracnose Resistant Germplasm Nursery
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ATIP	Agricultural Technology Improvement Project
BAMB	Botswana Agricultural Marketing Board
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARO	Chief Agricultural Research Officer
CARS	Central Agricultural Research Station, Kenya
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CEDA	Centro de Enseñanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro de Technologia de Agricola, El Salvador
CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands, Mexico
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre International en Recherche Agronomique pour le Dèveloppement
CLAIS	Consejo Latin Americana de Investigadores en Sorgho
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CRSP	Collaborative Research Support Program

CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DAR	Department of Agricultural Research, Botswana
DR	Dominican Republic
DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAP	Escuela Agricola Panamericana, Honduras
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
ECHO	Educational Concerns for Hunger Organization
EEC	European Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
EMBRAPA-CNPMS	EMBRAPA-Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture, Honduras
EPIC	Erosion Productivity Impact Calculator
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
DRA	Division de la Recherche Agronomique, IER Mali
FAO	Food and Agriculture Organization of the United States
FEDEARROZ	Federación Nacional de Arroceros de Colombia
FENALCE	Federacion Nacional de Cultivadores de Cereales
FHIA	Fundacion Hondurena de Investigacion Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
HIAH	Honduran Institute of Anthropology and History
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources, University of Nebraska - Lincoln
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas

ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IHAH	Instituto Hondureno de Antropologia e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agriculture
ILCA	Instituto Interamericano de Cooperación para la Agricultura
INCAP	Instituto de Nutricion de Centro America y Panama
IN.ERA	Institut d'Etudes et de Recherche Agricoles Agricultural Research Institute
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigacions Agricola, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIPA	National Agricultural Research Institute, Peru
INRAN	Institute Nigerien du Recherche Agronomic, Niger
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronomicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Research Institute, Philippines
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISRA	Institute of Agricultural Research, Senegal
ISVN	International Sorghum Virus Nursery
ITA	Institut de Technologie Alimentaire, Senegal
ITAT	International Tropical Adaptation Trials
ITESM	Monterrey Institute of Technology, Mexico
ITVAN	International Tall Variety Adaptation Nursery
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LASIP	Latin American Sorghum Improvement Project, Mexico

LDC	Less Developed Country
LIDA	Low Input Dryland Agriculture
LIFE	League for International Food Education
LUPE	Land Use and Productivity Enhancement
LWMP	Land and Water Management Project
MAFES	Mississippi Agricultural and Forestry Experiment Station
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MIAC	MidAmerica International Agricultural Consortium
MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources, Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras
MSU	Mississippi State University
NAARP	Niger Applied Agricultural Research Project
NARP	National Agricultural Research Project
NARS	National Agricultural Research System
NCRP	Niger Cereals Research Project
NGO	Non-Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory, Fort Collins, CO
NU	University of Nebraska
OAS	Organization of American States
OAU	Organization of African Unity
OICD	Office of International Cooperation and Development
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios
PI	Principal Investigator
PL480	Public Law No. 480
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains in Central America
PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Medical Research Council
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
RADRSN	Regional Advanced Disease Resistance Screening Nursery

RARSN	Regional Anthracnose Resistance Screening Nursery
RFP	Request for Proposals
RIIC	Rural Industry Innovation Centre, Botswana
ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger
RPDRSN	Regional Preliminary Disease Resistance Screening Nursery
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern Africa Development Conference
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SANREM	Sustainable Agriculture and Natural Resource Management CRSP
SAT	Semi-Arid Tropics
SDM	Sorghum Downy Mildew
SDMVN	Sorghum Downy Mildew Virulent Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMIP	Sorghum and Millet Improvement Program
SPARC	Strengthening Research Planning and Research on Commodities Project, Mali
SRCVO	Section of Food Crops Research, Mali
SRN	Secretaria de Recursos Naturales, Honduras
TAES	Texas Agricultural Experiment Station
TAMU	Texas A&M University
TARS	Tropical Agriculture Research Station
TC	Technical Committee
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UANL	Universidad Autonoma de Nuevo Leon, Mexico
UHSN	Uniform Head Smut Nursery
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska - Lincoln
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDA/TARS	United States Department of Agriculture/Tropical Agriculture Research Station
VCG	Vegetative Compatibility Group
WASAT	West African Semi-Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WSARP	Western Sudan Agricultural Research Project