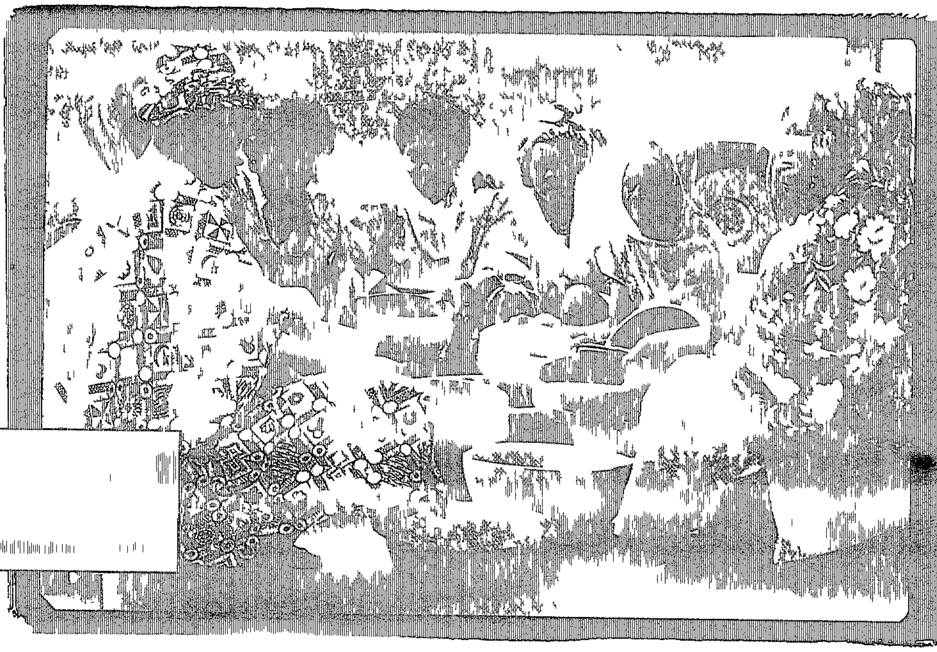
1998 Annual Report

INTSORMIL

Sorghum/Millet Collaborative Research Support Program (CRSP)

INTSORMIL
Sorghum/Millet International Research



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Cover Photographs

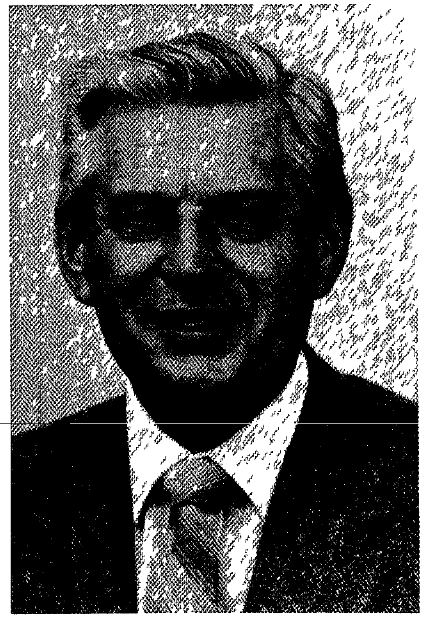
Front cover

Food scientists in Mali have tested value-added processing of cereals grown locally with women such as these in a village near Cinzana The work is important because the cereals grown in Mali are difficult to process through conventional means and the quality of the traditional, ultimate products is poor With improved processing comes better quality food and increased profits for local farmers The research pays off in the United States, too, as the genes identified through International Sorghum/Millet CRSP collaboration with Malian scientists also are being used to improve sorghum here Photo courtesy of Dr Lloyd Rooney, Texas A&M University, College Station, TX

Back cover

International Sorghum/Millet CRSP pearl millet breeders, such as this one at the University of Nebraska, are producing an early-maturing, drought-tolerant alternative grain crop option Pearl millet grain hybrids, now being tested by 20 farmers in six states, can give yields of 50-70 bushels per acre, sometimes as high as 100 bushels per acre, in warm, low-rainfall or short-season areas in the United States Two American seed companies are producing four acres of hybrid seed of these early grain hybrids Genetic material in these U S hybrids was obtained from CRSP researchers' work in Asia and Africa Food-quality pearl millet grain is of interest to the U S because of its premium feed grain value and export potential to countries where pearl millet is consumed in such forms as flat bread, porridge, a popcorn-like food, opaque beer and weaning food Photo courtesy of Professor David Andrews, University of Nebraska, Lincoln, NE

Professor William D "Bill" Stegmeier



The 1998 INTSORMIL Annual Report is dedicated to the memory of William D "Bill" Stegmeier in remembrance of his contribution to INTSORMIL and pearl millet research

William D "Bill" Stegmeier, Associate Professor Emeritus of Agronomy at Kansas State University, and a key member of the INTSORMIL millet research team, passed away July 25, 1998 at the age of 66 Bill was a valued member of the INTSORMIL CRSP beginning in 1978 and worked with researchers both in the United States and in other countries to improve pearl millet production Important contributions he made include the following

- Conversion of tall, late-maturing, tropically-adapted pearl millets to dwarf, early-maturing, high-yielding grain-type hybrids adapted to the mid-latitudes of the U S
- Development of experimental hybrids from landrace materials from the USDA Plant Introduction Station, two improved cultivars from Uganda, and dwarf forage-type, cytoplasmic-genic male sterile lines from the USDA Georgia program
- Discovery by the late 1970s that 'iniadi" landrace materials — as represented by PI 185642 and Serere 3A — had good genetic combining ability for improved grain yield
- Collaborative research, as an INTSORMIL scientist with scientists of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), resulting in several thousand population selections, germplasm and elite inbred lines being exchanged between the two programs — an indirect result of the work of Bill and others
- In 1996, two lines Bill bred from PI 185642 were used as female parents of pearl millet hybrids that are grown on nearly five million acres in India — representing one-half of the total area planted to millet hybrids in that country
- Improvement of grain yields of pearl millet, resulting in grain yield potentials of the best Hays experimental hybrids now 5 350 to 7,130 pounds per acre, a two-fold genetic enhancement over pearl millet grain yields in Hays in the 1970s
- Development of hundreds of adapted breeding lines, that are being preserved by Kansas State University, as they represent a unique pool of genetic variability for the future breeding of both grain and forage pearl millets

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1998 Annual Report

Fighting Hunger with Research . . . A Team Effort

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

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INTSORMIL INSTITUTIONS

University of Illinois at Urbana - Champaign
Kansas State University
Mississippi State University
University of Nebraska - Lincoln
Purdue University
Texas A&M University

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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 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 is one of nine CRSPs currently in operation

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between U S university scientists and scientists of the National Agricultural Research Systems, IARCs, PVOs and other CRSPs INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet 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 agriculture in the U S and Less Developed Countries (LDCs)*** Collaborating scientists in NARS developing countries and the U S jointly plan and execute research that mutually benefits all participating countries, including the United States

INTSORMIL takes a regional approach to sorghum and millet research in the agroecological zones of western, southern, and eastern Africa, and in Central America INTSORMIL resources focus on these prime sites in these five regions supporting 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 six universities currently active in the INTSORMIL CRSP are the University of Illinois, 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, and, in their area of adaptation, sorghum and millet cannot be sustainably substituted by other cereals The development of food sorghums and feed sorghums with improved properties such as increased digestibility and reduced tannin content has contributed to sorghum becoming a major feed grain in the U S and 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 food products that can effectively compete with wheat and rice products Pearl millet also has great potential for processing into high-value food products which can be sold in villages and cities markets, competing 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 serves, population growth rates continue to exceed rates of increase of cereal 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

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 promotes educational outcomes in collaborating host countries The outcomes include strengthening agricultural research institutions, developing collaborative research networks, promoting and linking to technology transfer and dissemination infrastructure, 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 After earning their graduate degrees, host country scientists become***

peer 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, and development of sustainable technologies to conserve biodiversity and natural resources INTSORMIL's emphasis on conserving biodiversity and natural resources enhances society's quality of life and enlarges the range of agricultural and environmental choices in developing countries and in the United States 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 the ecogeographical regional sites has been strengthened by using U S and NARS multidisciplinary research teams focused on common objectives and unified plans INTSORMIL scientists provide global leadership in biotechnology research on sorghum and millets The outputs 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 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 research sites within the region 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 product 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 analyses for prioritization of research, 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 and millet for food Research products transferred to the farm will seek to spur rural economic growth and provide direct economic benefits to consumers INTSORMIL economists and food scientists assess consumption shifts and socioeconomic policies for reducing effects of price collapses, and address methods to more efficiently process 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 INTSORMIL 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, presenting a win-win situation for international agricultural development

Administration and Management

The Management Entity (ME) for the Sorghum/Millet CRSP is at the University of Nebraska - Lincoln (UNL) 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 A portion of the project funds, managed by the ME and U S participating institutions, flow to regional programs 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 ME employed Dr Thomas Crawford of Sioux Falls, South Dakota as the Associate Director for INTSORMIL effective July 1, 1997

- The Board of Directors established a new policy statement regarding publishing of the Annual Report Effective July 1, 1998 all annual reports are due by August 1 and Regional/Country program reports are due by August 15 All projects will be penalized 5% of their budgets if not submitted on time and an additional 10% beginning September 1 and each month there after until the report has been received by the ME

- Dr Carl Nelson, an agricultural economist at the University of Illinois, was awarded a subgrant through the end of the current grant to do research on sorghum,millet marketing/economics (Project UIUC-205)

- The 1998-99 Technical Committee (TC) was elected The TC members are Dr Stephen Mason, Chair, University of Nebraska, Dr Bruce Hamaker, Vice Chair, Purdue University, Dr Henry Pitre, Secretary, Mississippi State University, Dr Gary Peterson, Texas A&M University, Dr John Axtell, Purdue University, Dr Darrell Rosenow, Texas A&M University, Dr Sidi Bekaye Coulibaly, IER/Mali, and Dr Medson Chisi, Mt Makulu Research Station, Zambia

- The Technical Committee and the Board of Directors approved the Five Year In-Depth EEP review schedule commencing in September 1998, and finishing in August 1999

- Dr Walter DeMilliano, Novartis Seeds, Amsterdam, Holland was approved by the BIFAD and USAID to succeed Dr Merle Shepard on the EEP Dr DeMilliano will represent the crop protection disciplines and will serve a five-year term

- Dr Richard Hahn has been nominated by INTSORMIL to succeed Dr Joseph Hulse on the EEP Dr Hahn will represent the processing/utilization discipline and will serve a five-year term

- INTSORMIL entered into a Memorandum of Agreement with the Instituto Nicaraguense De Technologia Agropecuaria (INTA) of Managua, Nicaragua on May 8 1998

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

  * Publication 97-1 INTSORMIL Policy and Operating Procedures
  * Publication 97-2 U S CRSP P I s (All CRSPs)
  * Publication 97-3 "Inside INTSORMIL Newsletter"
  * Publication 97-4 INTSORMIL CRSP Directory
  * Publication 97-5 Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet
  * Publication 98-1 1997 Annual Report
  * Publication 98-2 1997 Annual Report Executive Summary
  * Publication 98-3 "Inside INTSORMIL Newsletter"

- To increase recognition of INTSORMIL research among the general public, Congress and USAID, the INTSORMIL ME established an information site on the world wide web at http //www ianr unl edu/intsormil/ and an informational site for all Collaborative Research Support Programs at http //www ianr unl edu/crsps/ In addition, the ME responded to the news media with information about INTSORMIL that was published by the Association Liaison Office, that represents 2,200 institutions of higher learning in the U S Other articles were published in the popular press highlighting INTSORMIL research

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 economics, 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 1997-98, there were 55 students from 23 different countries enrolled in advanced degree programs that were advised by one or more INTSORMIL principal investigators This was a decrease of two students from the previous year Approximately 78% 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 17% of all INTSORMIL graduate students were women

The number of students receiving 100% funding by INTSORMIL in 1997-98 totaled 23 An additional 15 students received partial funding from INTSORMIL The remaining 17 students were funded from other sources but are working on INTSORMIL projects These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding pathology, entomology, food quality, and economics The number of students receiving 100% funding from INTSORMIL dropped from a high of 71 in 1986 to a low of 17 in 1993-94, then increased to 21 in 1995-96 and is now up to 23 in 1997-98 The reduction in total students being trained from INTSORMIL funds is, in part, due to train ing taking place under other funding sources, but an even more significant factor is that budget flexibility for support ing 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 1997-98

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, ROCARS, ASARECA, 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 multilocation testing of breeding materials), promote germplasm and information exchange, and facilitate impact evaluation of new technologies
- Develops regional research networks, 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, WCASRN, WCAMRN, ROCAFREMI, EARSAM of ICRISAT, ICRISAT/Mexico, CIAT and CLAIS of Central and South America for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditures of research dollars There also has been excellent collaboration with each of these programs in cosponsoring 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 (Reseau 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 collaboration with ROCAFREMI in West Africa has much potential in allowing INTSORMIL utilization scientists to collaborate regionally ROCAFREMI is a good mechanism for promoting millet processing over a wider geographic extent than has been seen before in West Africa 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 resistance 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, East,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 × K1567), for this country The female line Tx623 was used due to its wide adaptation, high yield potential and drought resistance Hageen Dura-1 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 ATx623 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 × Tortillero) and Sureño [(SC423 × 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, that have been distributed 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 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 filling 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 × 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^{-1} on-station, ten times the average yield of the farmer in Niger (273). In 1993, the farm level plots showed the average farmer yield for the Konni and Jirataoua region was 2365 kg ha^{-1} for NAD-1. In 1994, NAD-1 yielded an estimated 1725 kg ha^{-1} (Say), 3500 kg ha^{-1} (Jirataoua), 3800 kg ha^{-1} (Cerasa), and 4600 kg ha^{-1} (Konni) for an overall farmer yield of more than 3000 kg ha^{-1}. This is compared to the national average of 273 kg ha^{-1}. 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^{-1} compared to 1.1 t ha^{-1} 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 develop superior hybrids from their research. INRAN has made a substantial contribution in producing NAD-1 seed on an interim basis. INRAN/INTSORMIL is encouraging private farmers/organizations (farmer cooperatives) to take up seed production. The numbers of interested parties is rapidly expanding across the southern part of Niger. Private seed production (1997-98) now significantly exceeds that of INRAN. Training has become an important component of assisting those interested in hybrid seed production. This training aspect should be expanded to provide hands on experience, seminars, small workshops on special topics for a range of concerned individuals/organizations, i.e., bankers, NGOs, government officials, as well as seed producers. INRAN is effectively assuming lead responsibility for the production and availability of foundation seed. At the present time demand for seed of NAD-1 exceeds supply and since 1995 NAD-1 seed has sold for 700-800 CFA/kg which is 4-8 times the price of grain.

While new sorghum hybrids are being developed by INRAN/INTSORMIL collaboration, pearl millet hybrid researchers continue to improve pearl millet hybrids. INTSORMIL scientists at IER/Mali and from the United States are collaborating with scientists at the ICRISAT Sahelian Center in the hybrid pearl millet programs.

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 has been 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 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 A major accomplishment in 1997-98 has been the development of a rapid screening assay for the high protein digestibility trait This has been a joint effort of INTSORMIL and the Texas Grain Sorghum Board

There is considerable interest in Niger and neighboring countries about the potential of commercializing couscous, a processed food, made from sorghum and millet flour The INRAN/INTSORMIL couscous project has advanced substantially The process for making couscous has been optimized as a result of collaborative INTSORMIL research, this optimization of the process is a critical step in achieving a consistent, high-quality couscous product Consumer acceptibility tests show that the couscous made from the INRAN/INTSORMIL unit was highly acceptable Market testing will be taking place during 1998-1999

A *Striga* resistant variety, SRN-39, was identified as promising and released for production in Sudan SRN-39 and other possible sources of resistance to *Striga* are now 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 those *Striga* resistant food quality sorghums were tested on field stations or in farmers fields, or both, in the following countries Ghana, Senegal, Mali, Niger, Sudan Rwanda, Mozambique, and Eritrea Based upon field results of this germplasm and a mix of cultural practices that alleviate the *Striga* problem, an integrated *Striga* control project combining host plant resistance, fertilizers, and cultural practices was initiated in 1997 for on-farm testing in Northern Ethiopia as a joint project between INTSORMIL, Global 2000 and the Ethiopian Agricultural Research Organization Discussions have also been held with other NARS in the Horn of Africa Region regarding the possibility of conducting the same project on a regional basis

During the 1997-98 program year, INTSORMIL collaborated with the sorghum program of IER/Mali and ROCARS to grow, increase and characterize the Mali sorghum collection This endeavor collected all sorghum accessions of Mali origin from the U S , ICRISAT, CIRAD, and Mali The project was very successful From this it was recommended that in the future, more emphasis should be placed on breeding for drought resistance, especially in northern Mali, and that work should be cooperative with drought breeding efforts in Niger

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 × 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 In 1998, the food processing unit of IER/Sotuba Station, Bamako Mali has contracted with one village to produce 10 tons of the N'tenimissa grain which will be sold to the GAM, the major biscuit manufacturer in Mali They will use that grain to blend at a 20/80 ration with wheat for biscuit production This is a major step for increased use of sorghum in food industry utilization and value-added product development for sorghum The PVO, World Vision, distributed N'tenimissa to 20 on farm trials in 1997/98 In Northern Mali, CARE is cooperating with IER and testing new sorghum cultivars at about 20 sites INTSORMIL has introduced N'tenimissa to the Bean/Cowpea CRSP/INTSORMIL/Worldvision West Africa NRM Inter-CRSP Project which covers sites in Niger, Mali, Ghana, Chad and Senegal

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, 1993, 1994, and 1995 respectively, while application of 40 kg ha^{-1} 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 removing mineral nutrients from the soil at rates faster than they were being replenished 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^{-1} N and 40 kg ha^{-1} N, respectively, in monoculture and 64% and 66% for 20 kg ha^{-1} N and 40 kg ha^{-1} N, respectively, in millet-cowpea rotation Crop rotation (millet-cowpea) alone without N increased millet grain yield by 74% The legume effect appears to be worth 30 to 40 kg N/ha This information, developed by collaborative INTSORMIL research of Malian and American scientists, 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^{-1} 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^{-1} better than the other cultivars Increasing the fertilizer rate to the highest level (15 t ha^{-1} manure plus 100 kg ha^{-1} N) increased grain yield from 1246 to 2475 kg ha^{-1} and stover yield from 3178 to 5067 kg ha^{-1} 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 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 larval and adult populations of head bugs vary naturally from year to year 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 traits Cultivars with previously identified specific and general resistance to the three major foliar diseases (leaf blight, anthracnose, and sooty stripe) maintained their resistance under variable disease pressure in nurseries across the SADC region Some entries in these nurseries are being utilized in sorghum improvement programs in Zambia and Zimbabwe Progress was made on several ergot objectives including additional information on the efficacy of triazole fungicides to control sorghum ergot in seed production fields and the necessity of integrating chemicals with other controls like pollen management Investigations for alternate hosts for sorghum ergot continued to indicate that *Sorghum* spp are the only important hosts in nature

Work continues on identification of the most important disease constraints and for design of disease control strategies in Central America 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 principal sorghum production area 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 are 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, and in 1996 they began their graduate degree research at the ICRISAT Sahelian Center Their research objectives and results will build on findings for millet head miner (MHM) biological control reported by INTSORMIL scientists in 1994 and 1995 Annual Report Results from these students' research will be used to construct a stage-specific life table of the MHM, thus providing an understanding of factors that regulate the abundance of MHM These results also can be used to develop an improved plan for managing MHM on pearl millet in West Africa Ultimately, these data will support developing a "Millet Head Miner Warning System" model to forecast the probability of MHM outbreak in a given area so that appropriate measures can be implemented to control the pest before it damages pearl millet 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

In Honduras, insect pest control developed for one species or a complex of pest species of sorghum involves the integration of specific management tactics, possibly 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 (three army worm species) and a grass looper insect Soil inhabiting insect pests contributing to seed and seedling losses in southern Honduras were identified as wireworms, white grubs, and rootworms Slash-and-burn fields were infested with greater populations of these insects than slash-and-mulch fields, with insects attracted to luxuriant plant growth in burned fields Neotropical cornstalk borer attacked sorghum in monoculture at greater infestatation levels than sorghum intercropped with maize Planting sorghum with hybrid maize reduced stalk borer infestations and damage to sorghum compared with sorghum planted with a native maize These investigations have provided the information for design of integrated insect pest management programs for designated crop production areas Recommendations for planting dates, weed control and insecticide applications to manage lepidopterous defoliators have been developed

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 was 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 In 1998 the food processing unit of IER/Souba Station, Bamako, Mali has contracted with one village to produce 10 tons of the N'tenimissa grain which will be sold to the GAM, the major biscuit manufacturer in Mali They will use that grain to blend sorghum at a 20/80 ratio with wheat for biscuit production This is a major step for increased use of sorghum in food industry utilization and value-added product development for sorghum

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 The INRAN/INTSORMIL couscous project has advanced substantially The process for making couscous has been optimized which is a critical step in achieving a consistent, high quality couscous product Consumer acceptibility tests show that the couscous made from the INRAN/INTSORMIL unit was highly acceptable Market testing will be taking place during 1998-1999

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 Gene mapping has shown that genes conferring resistance to different greenbug biotypes are slightly different, but probably control the same resistance process Molecular biology is contributing to understanding of the inheritance of resistance to greenbug Results from molecular mapping are used in marker-assisted selection studies for greenbug resistance and post-flowering drought resistance Good progress is being made for greenbug resistance Parental lines with biotype I- and K-resistance are anticipated to qualify for release

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 Resistance of sorghum to midge 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 were released to other breeders during the fall of 1996 These were 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

During 1997-98, 62 parental lines of sorghum and 7 of grain pearl millet were released by the Nebraska INTSORMIL collaborating breeder Progress is being made with studies on germination and seedling cold and heat tolerance in sorghum

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 (N) 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 CO^2 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 CO^2 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 Twenty farmers in Nebraska South Dakota, Oklahoma, Colorado, Iowa and Illinois are trying test plots of pearl millet for the first time in 1998

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 de signed with LDC laboratory conditions in mind It has been shown that the causal agent of bacterial leaf streak is seed-borne 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 pro vides 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 sav ings 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

Throughout 1997-98 INTSORMIL continued to function as one of the primary sources for sorghum ergot information as the pathogen spread across Texas, Oklahoma, Kansas and into Nebraska INTSORMIL was one of the organizers of a U S ergot conference held in late June, 1998 in Corpus Christi, Texas Across south Texas sorghum ergot overwintered in an active disease phase predominantly on feral sorghum in abandoned fields and along roadsides or other areas but also on johnson grass Triazole fungicides continued to provide the best control of ergot on sorghum plants in the field but the necessity for good coverage and contact of the head has raised concerns over efficacy of aerial applications

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 INTSORMIL scientists 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-210A
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Summary

Identification of *Fusarium* species is difficult and even experts often have difficulties distinguishing the subtle differences in morphology that can be significant in identification The *Fusarium* species from sorghum and millet are among the most treacherous of this lot as the number of strains available for examination is not large, and relatively few researchers in the *Fusarium* community have paid serious attention to these predominantly third world pathogens Until approximately 15 years ago, most of the *Fusarium* species from sorghum and millet were assigned to the *Liseola* section of the genus, and usually to the *F moniliforme* species This lumping of isolates allowed for easy field identification but propagated the illusion that these strains all belonged to the same species, and shared, by implication, economically important traits such as pathogenicity, host range and the ability to synthesize various mycotoxins As more attention has been gradually focused on these pathogens, it has become apparent that they are quite different from one another and from strains isolated from other hosts that were assigned to the same species We have recently described a new species of *Fusarium*, *F thapsinum*, that appears to be the most common *Fusarium* species from sorghum These strains differ from the traditional *F moniliforme* strains in reproductive isolation, frequency of sexual reproduction, electrophoretic karyotype, isozyme profile, hygromycin sensitivity, and the spectrum of mycotoxins synthesized, even though the two species are morphologically quite similar We have positively identified strains of this species from maize, sorghum, peanut and bananas from Egypt, Uganda, Mali, Tanzania, South Africa, the Philippines, Thailand, Uruguay, and at least nine states from the United States - Arkansas Georgia, Illinois, Kansas, Mississippi, Missouri, Ohio and Texas

Objectives, Production and Utilization Constraints

Objectives

- Increase collection of *Fusarium* samples from sorghum and millet, and identify the species recovered
- 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
- Determine mycotoxigenic potential of *Fusarium* spp from 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 Correct identification of the fungi colonizing and causing disease is essential for the design of breeding and control measures Without a thorough understanding of the pathogen's genetic diversity and population dynamics, effective control measures are difficult to design and resistant lines may have unexpectedly brief lives

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

Strain Collection

Strains were collected from plant seeds and stems, and from soil Material was placed on plates of a peptone-PCNB medium that is selective for *Fusarium* spp Plates were incubated at 25° C, and colonies selected after growth for 10-14 days Individual cultures were purified by isolating a microconidium from each colony using a micromanipulator, and allowing a colony to form from this spore Strains are preserved for long-term storage in 15 85 glycerol water and frozen at -70°C

Microscopic Observations

Observations of asexual spores were made at a magnification of 1000x Cultures were grown on carnation leaf agar for 1-2 weeks at 25°C under a mixture of cool-white and near U V fluorescent light Sexual spores were from nearly mature perithecia that had been growing on carrot agar for 2-4 weeks under similar conditions

Sexual Crosses and Mating Population Identification

Standard tester strains were used as one of the parents in all of the crosses Crosses were made on carrot agar following standard protocols developed at Kansas State University Initially, field isolates were used as males with the standard tester as the female parent Fertile crosses produced perithecia that exuded a cirrhus of ascospores Female fertility was determined by reversing the roles of the strains in the initial cross and using the field isolate as the female parent and the standard tester strain as the male parent

Effective Population Number

Effective population number was determined based on the relative number of male-only and self-sterile hermaphrodites in the population Equations we had developed previously for fungal populations were used for the analysis

Hygromycin Resistance

Resistance was measured at 70, 140 and 300 ppm in minimal medium after three days growth at 25°C on agar plates Resistance was scored as sensitive (growth radius < 1 mm), intermediate (1 < growth radius < 2 5 mm), and resistant (growth radius > 2 5 mm)

Isozyme Banding Pattern

Cultures were grown on minimal medium overlaid with cellophane strips for 5-7 days The cellophane and adhering mycelium were flash frozen in liquid nitrogen and then ground to a fine powder in a mortar and pestle Protein extraction followed standard protocols Protein extracts were run on starch gels, with exact conditions depending upon the starch lot and the isozymes being resolved Gels were stained according to standard protocols for five different isozymes fumarase (e c 4 2 1 2), esterase (e c 5 3 1 9), glucose phosphate isomerase (e c 5 3 1 9), NADP-dependent isocitrate dehydrogenase (e c 1 1 1 42), and triose phosphate isomerase (e c 5 3 1 1)

Electrophoretic Karyotype

Conidia were collected from 2 to 3 day old liquid cultures by filtration, washed in sterile water, and allowed to germinate for 10-16 hours in potato dextrose broth Germinated spores were harvested by centrifugation, washed twice in protoplasting buffer, and then treated with Novozym 234 and β-mercaptoethanol for two hours to overnight at 32°C Spheroplasts were separated from cellular debris by filtration through two layers of cheesecloth and a 44 µm mesh nylon screen Spheroplasts were concentrated by gentle centrifugation, washed twice with buffer, and resuspended at 2 x 10^6 cells/ml, mixed with an equal volume of barely molten (37°C) 1 4% low melting point agarose, and then poured into plugs Spheroplasts were lysed in situ and chromosomes were separated on 0 5% agarose gels, using a contour-clamped homogeneous electric field (CHEF) apparatus Gels were run with one hour switching times for two weeks, with changes of electrode buffer midway through the run Chromosomes were visualized by staining the gel in ethidium bromide and then illuminating the gel with U V light Sizes were estimated by comparison to chromosomes from *Saccharomyces cerevisiae* and *Neurospora crassa*

rDNA ITS Restriction Fragments

DNA was extracted from colonies grown in liquid shake flask culture for 2-3 days Cells were harvested by filtration, ground to a powder in liquid nitrogen, extracted twice with phenol chloroform, once with chloroform, treated with RNAse for 30 minutes, and then precipitated with two volumes of 95% ethanol at room temperature overnight The resulting pellet was dried, resuspended in TE, and the amount of nucleic acid determined by spectrophotometer readings The rDNA region was amplified by PCR using the ITS4 and ITS5 primer sequences The PCR protocol was 94°C - 4 min, then 30 cycles of 96°C - 35 sec, 50°C - 55 sec, 72°C - 120 sec, followed by a final elongation at 72°C for 7 min Resulting DNA was cleaned by extraction with phenol chloroform and precipitated again with ethanol The resulting DNA was digested with restriction enzymes according to the manufacturer's protocol and the digests resolved on 5% acrylamide gels Bands were visualized under U V light following staining with ethidium bromide

Chemical Assays for Mycotoxins

Fumonisins B_1, B_2 and B_3 (FB1, FB2 and FB3) were determined using standard reverse-phase High pressure liquid chromatography (HPLC) methods to detect fluorescent *ortho*-phthaldialdehyde derivatives of these compounds

Moniliformin levels were initially determined by separation using reverse phase HPLC, and monitoring UV adsorption at 229 nm In samples in which little or no moniliformin was detected, extracts were evaluated by paired ion chromatography in which the column eluent was monitored at wavelengths between 200 and 350 nm by using diode array UV detection

Fusaric acid (5-butylpicolinic acid) was extracted from corn meal cultures with a 1 1 mixture of methanol 1% aqueous KH_2PO_4 (pH 3 0), and then centrifuged to remove debris The pH of the supernatant was adjusted to 3 0 and then extracted with methylene chloride (three times), 5% aqueous $NaHCO_3$ (two times), and then again with methylene chloride (two times) The methylene chloride was removed under vacuum at 40°C on a rotary evaporator Extracts were analyzed by HPLC The presence of fusaric acid was confirmed using gas chromatography-mass spectrometry (GC-MS) of the trimethylsilyl ester

Research Findings

Background on Fusarium species in Sorghum and Millet

Fusarium spp are associated with sorghum throughout its life cycle from seed to senescence These fungi also are associated with the diseases seedling blight, root and stalk rot, pokkah boeng, grain mold, and storage diseases and mycotoxicoses *Fusarium* spp can live in sorghum plants with no obvious disease symptoms, and the absence of symptoms should not be equated with the absence of these fungi The mode of spread and entry into the plant varies and may include seed-borne, wind-borne, and soil-borne routes Indeed growing sorghum to maturity without it becoming associated with one, or more, *Fusarium* strains is most unlikely

Identification of the *Fusarium* spp present can be quite important since different species are associated with different diseases and are capable of synthesizing different sets of mycotoxins Unfortunately, the differentiation and identification of these species is not an easy task This task is further complicated by the limited to nonexistent formal descriptions of *Fusarium* spp commonly recovered from sorghum and millet in Africa, where sorghum and millet are native Some species are more important than others, and a thumbnail sketch of the most significant is given below (Tables 1 and 2) Alterations and additions to this list are to be expected since research in *Fusarium* identification methods and taxonomy remains very active The separation of *F moniliforme* from *F thapsinum* described below is but a single example of the significant changes that can be expected in the taxonomy of the fungi that are associated with sorghum and millet during the coming years

The traditional method for distinguishing *Fusarium* spp is based on morphology, especially that of spores, of cultured strains Culture conditions play an important role in determining morphology and it is easy to make mistakes Spore morphology alone is insufficient to distinguish all of the biologically significant entities More recently, crossing with standard tester strains, isozyme polymorphisms, and various protocols that rely on DNA sequence polymorphisms have been used to distinguish strains in much more detail Since plants may be infected simultaneously by more than one species of *Fusarium*, it is important to start cultures to be identified from a single conidium before proceeding with any of the identification protocols

Microscopic Examination of Cultures

Morphology of colonies growing on defined media, e g , PDA, carrot agar, or carnation leaf agar, and their associated structures, are usually the primary tools used for identifying a *Fusarium* isolate to species Representative photographs of various structures are shown in Figures 1- 9 Figures 1-3 represent the sexual stage and are identified by the name of the sexual (perfect) state, *Gibberella thapsina* Figures 4-9 represent the two strains, F-04093 and F-04094, that were crossed to give the sexual stage depicted in Figures 1-3 and are identified by the name of the asexual (imperfect) stage *Fusarium thapsinum*

Sexual Crosses and Mating Population Identification

Fusarium moniliforme and *F thapsinum* were first recognized as distinct entities on the basis of their reproductive

Table 1 Characters Dıstınguıshıng *Fusarıum thapsınum* from *Fusarıum monılıforme*

Character	*F thapsınum*	*F monılıforme*
Host preference	Sorghum	Maıze
Yellow pıgment	Yes	No
Fıeld straın female fertılıty	< 10%	> 50%
Ascospore dımensıons (μm)		
Length	12 22	12 23
Wıdth	4 8	4 6
Mycotoxın productıon		
Fusarıc acıd	Yes	Yes
Fumonısıns	No	Yes
Monılıformın	Yes	No
Hygromycın sensıtıvıty (70 ppm)	Sensıtıve	Resıstant
Growth rate on PDA (mm/day)	3 5 5	4 6
Electrophoretıc karyotype (Megabases)	45 5	46 1
Chromosome 2	6 0	6 5
Chromosome 4	4 0	4 1
Chromosome 6	3 5	3 6
Chromosome 8	2 5	2 6
Chromosome 11	2 1	2 0
Chromosome 12	0 8	0 7
Isozyme bandıng patter		
Fumarase	γ	α
Esterase	β	γ or δ
Glucose phosphate ısomerase	α	α or β
Isocıtrate dehydrogenase (NADP)	α or β	β
Trıose phosphate ısomerase	α	β
rDNA ITS restrıctıon fragments (bp)		
*Mbo*I	174 143 110 60 50 44	305 110 60 50 46
*Sma*I	570	363 199

ısolatıon Fertıle straıns of *F monılıforme* are well known and have been descrıbed for some tıme Straıns that formed the basıs for the descrıptıon of *F thapsınum* were first ıden tıfied on the basıs of theır yellow pıgment and theır ınabılıty to cross wıth the standard testers of *F monılıforme* A subset of these straıns were then ıntercrossed wıth one another ın all possıble paırwıse combınatıons untıl a fertıle cross was ıdentıfied Inıtıally, female-fertıle straıns of only one matıng type were ıdentıfied Two serıes of laboratory backcrosses were requıred to obtaın the female fertıle tester straıns that now anchor the descrıptıon of thıs specıes In these backcrosses, female sterılıty was always sıgnıficantly more frequent than female fertılıty Thus ıt ıs possıble that most field straıns of *F thapsınum* only rarely pass through the sexual portıon of the lıfe cycle and that field populatıons are composed of one or a few domınant clonal lıneages

Effectıve Populatıon Number

The effectıve populatıon number ıs the sıze of the populatıon relatıve to a randomly-matıng populatıon In a populatıon genetıcs context, effectıve populatıon number ıs usually used ın the evaluatıon of field populatıons because matıng ıs often not at random, and because not all members of a populatıon leave equal numbers of progeny The major constraınts on effectıve populatıon sıze ın filamentous ascomycetes are the relatıve frequencıes of the matıng type alleles and the number of self-sterıle hermaphrodıtes ın the populatıon Maxımum effectıve populatıon sızes ın these fungı occur when the matıng type alleles are present ın a 1 1 ratıo, and when all of the straıns are self-sterıle hermaphrodıtes In both *F monılıforme* and *F thapsınum*, matıng type ıs present at slıghtly skewed frequencıes, and results ın a loss ın populatıon sıze of 10% and 2%, respectıvely The number of self-sterıle hermaphrodıtes ın the populatıon ıs approxımately 50% of the count for *F monılıforme* and 10% of the count for *F thapsınum* The lack of hermaphrodıtes means that the effectıve populatıons numbers are some what reduced for *F monılıforme*, an addıtıonal 12% of the count, and quıte severely reduced for *F thapsınum*, an addıtıonal 68% of the count Populatıons of *F monılıforme* from sorghum ın Tanzanıa are sımılar to those from the larger populatıon sampled ın the Unıted States The *F thapsınum* straıns from Tanzanıa were much more fertıle, however, and loss of hermaphrodıtes there reduced the effectıve populatıon number by only 47% ınstead of 68%

The relatıve lack of female fertıle straıns and relatıvely low effectıve populatıon numbers ıs consıstent wıth the hy-

Table 2 Alphabetical listing of *Fusarium* species commonly associated with sorghum

Species	Sexual stage	Other names	Mycotoxins produced	Comments
Fusarium equiseti	*Giberella intricans*	None	Fusarochromanone moniliformin trichothecenes zearalenone	Associated with root and stalk rots Distributed throughout all sorghum growing areas
Fusarium graminearum	*Gibberella zeae*	None	Fusaproliferin fusarins trichothecenes (nivalenol and deoxynivalenol) zearalenone	Is the only *Fusarium* commonly associated with sorghum that is homothallic Often referred to as *F graminearum* group II to distinguish it from the heterothallic *F graminearum* group I that causes a dryland foot rot of wheat in Australia and the United States Associated with seedling blight stalk and root rot grain mold and storage molds and mycotoxicoses Pigs are particularly sensitive to sorghum feed contaminated with this fungus Grain contaminated with *F graminearum* used for malt can result in gushing in beer due to the presence of deoxynivalenol More common in cooler and wetter sorghum growing areas
Fusarium napiforme	None known	None	Fumonisins fusaric acid moniliformin	Newly described species commonly associated with sorghum previously probably misidentified as either *F moniliforme* or *F oxysporum* Distribution limits are not yet known
Fusarium nygamai	*Gibberella nygamai*	*Gibberella fujikuroi* Mating Population G	Fumonisins fusaric acid moniliformin	Newly described species (may be a species complex) commonly associated with sorghum and millet previously probably misidentified as either *F moniliforme* or *F oxysporum* Distribution limits are not yet known but widespread in Africa and Australia
Fusarium oxysporum	None known	Numerous usually related to the host infected	Cyclic peptides fusaric acid moniliformin naphthazarin sambutoxin	A very common and widely dispersed soil fungus Probably a species complex and not a single species Reported to colonize sorghum root and stalk tissue but pathogenic association with sorghum has not been proven Distributed throughout all sorghum growing areas
Fusarium proliferatum	*Gibberella fujikuroi* Mating Population D	None	Cyclic peptides fumonisins fusaproliferin fusaric acid fusarins moniliformin	Often misidentified as *F moniliforme* and occasionally as *F subglutinans* therefore the damage attributed to this organism is probably underestimated Associated with seedling blight, pokkah boeng grain mold stalk and root rot and storage diseases and mycotoxicoses Clear identifications are possible using isozymes or crosses with standard tester strains Distributed throughout all sorghum growing areas
Fusarium semitectum	None known	*Fusarium pallido roseum*	Moniliformin sambutoxin	Has not been the subject of as intensive study as many of the other *Fusarium* spp listed here Associated with grain mold and root and stalk rots Distributed throughout all sorghum growing areas
Fusarium solani	*Nectria haematococca*	Numerous often related to the host infected	Fusaric acid napththazarin	A very common soil fungus A species complex containing multiple biological species that are usually identified as mating populations of *N haematococca* Reported to colonize sorghum root and stalk tissue but pathogenic association with sorghum has not been proven Distributed throughout all sorghum growing areas
Fusarium subglutinans	*Gibberella fujikuroi* Mating Populations B & E	Fusarium sacchari Gibberella subglutinans	Cyclic peptides fusaproliferin fusaric acid moniliformin	Often misidentified as *F moniliforme* Is a species complex containing at least three and probably more different biological species Traditionally named as the causal agent of pokkah boeng but recent work suggests that *F proliferatum* is the correct name for the causal agent of that disease Associated with root and stalk rots Clear identifications are possible using isozymes or crosses with standard tester strains Probably distributed throughout all sorghum growing areas
Fusarium tricinctum	*Gibberella indica*	None	Fusarins cyclic peptides	Reported to colonize sorghum root and stalk tissue but pathogenic association with sorghum has not been proven

pothesis that populations of *F thapsinum* are relatively clonal under field conditions and that selection for resistance to local clones may be an effective strategy for breeding for resistance to this pathogen

Hygromycin Resistance

Hygromycin resistance was tested at three different levels, 70, 140 and 300 ppm, using 28 *F moniliforme* strains and 20 *F thapsinum* strains Transformed strains, for which this drug is used as a selectable marker, are usually resistant to 100 ppm of this drug The *F moniliforme* strains were much more resistant to this compound than were the *F thapsinum* strains Of the 28 *F moniliforme* strains tested, 27 were resistant to 70 ppm, and seven were partially resistant at the 140 ppm level In contrast, 19-20 strains of *F thapsinum* were sensitive to 70 ppm of this drug and 12-20 were sensitive to 35 ppm Thus, hygromycin resistance can be used as a simple preliminary screen to distinguish *F moniliforme* and *F thapsinum*, but the occasional overlaps in sensitivity probably are sufficient to prevent this screen from being used as the sole test Certainly strains that are

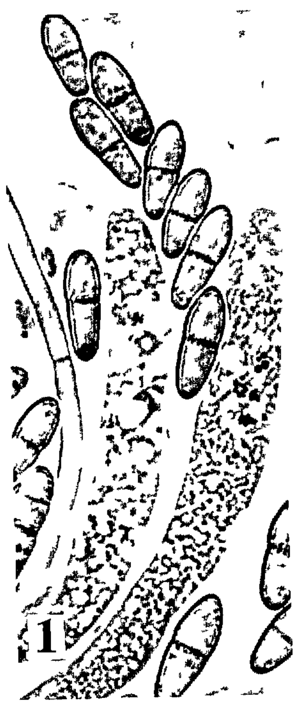

Figure 1 Immature asci and ascospores of *Gibberella thapsina* from the interior of a perithecium (sexual fruiting body) (×1000) Mycologia 89 643-652

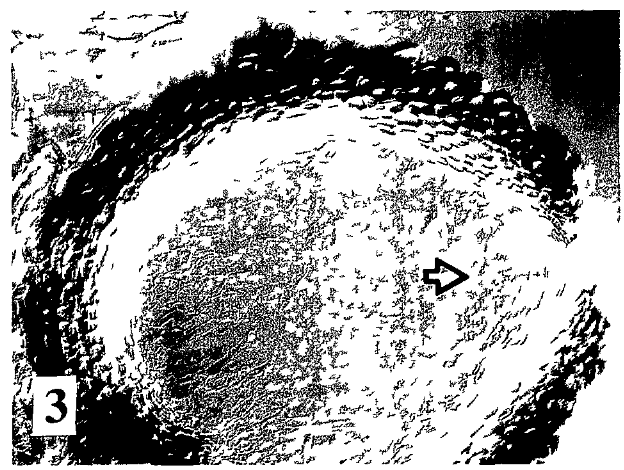

Figure 3 Median longitudinal section through a perithecium mounted in 100% lactic acid Ostiolar opening through the apex is indicated by an arrow (×250) Mycologia 89 643-652

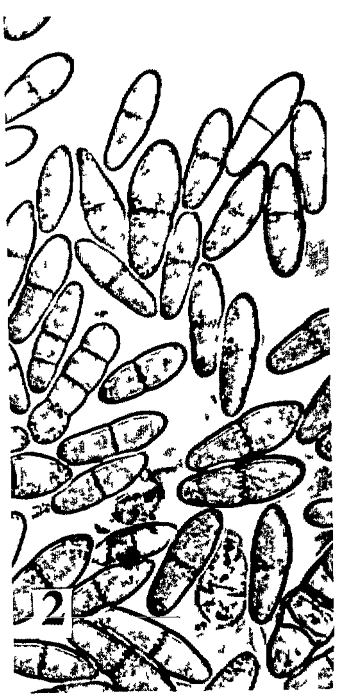

Figure 2 Extruded ascospores of *G thapsina* from a perithecial spore cirrhus (×1000) Mycologia 89 643-652

Figure 4 *Fusarium thapsinum* strain F-04093 macroconidia (×1000) Mycologia 89 643-652

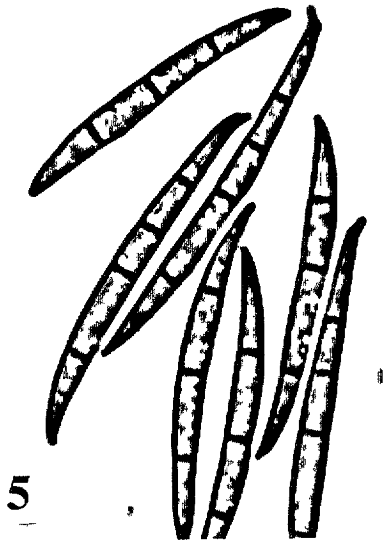

Figure 5 ***Fusarium thapsinum*** **strain F-04094 macroconidia (×1000) Mycologia 89 643-652**

Figure 7 ***Fusarium thapsinum*** **strain F-04094 microconidia (×1000) Mycologia 89 643-652**

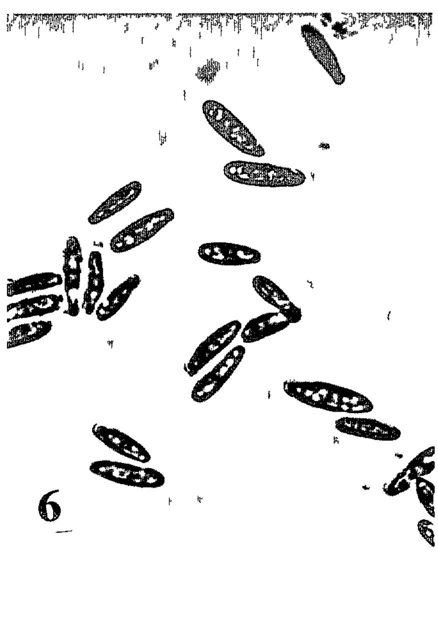

Figure 6 ***Fusarium thapsinum*** **strain F-04093 microconidia (×1000) Mycologia 89 643-652**

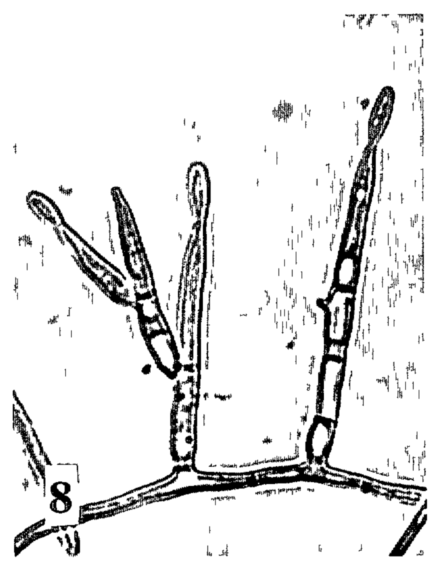

Figure 8 ***Fusarium thapsinum*** **strain F-04093 monophialidic spore-bearing hyphae (×1000) Mycologia 89 643-652**

Figure 9 ***Fusarium thapsinum*** **strain F-04094 monophialidic spore-bearing hyphae (×1000) Mycologia 89 643-652**

sensitive to 35 ppm hygromycin could be identified as *F thapsinum* however, and those resistant at the 140 ppm level could be identified as *F moniliforme*

Isozyme Banding Pattern

Isozyme banding is presently the fastest and most economical way to distinguish *F moniliforme* from *F thapsinum* The most informative enzyme for this distinction is triose phosphate isomerase *Fusarium moniliforme* has a unique band for this enzyme, and the gel to resolve the two species can be run in an afternoon If it is important to distinguish *F thapsinum* from other closely related species, e g , *F subglutinans* and *F proliferatum*, then other isozymes should be used and the gel usually runs overnight rather than in a single afternoon The isozyme banding patterns for both species are remarkably stable and show little to no variation even when strains from different continents are analyzed

Electrophoretic Karyotype

Electrophoretic karyotypes were determined for both *F moniliforme* and *F thapsinum* Both of these strains have 12 chromosomes numbered from 1, as the largest, to 12, as the smallest In *F moniliforme*, chromosome 12 is dispensable, and this presumably is the case in *F thapsinum* as well These dispensable chromosomes have been found to carry genes that confer pathogenicity in other species of *Fusarium*, e g *F oxysporum* and *F solani*, but *F moniliforme* strains that lack all or part of chromosome 12 retain their pathogenicity in limited greenhouse tests The genome sizes of the two species are very similar as are the individual chromosome sizes In a brief survey of the genome organization of *F moniliforme* and *F thapsinum*, it appears likely that most of the genes carried on a particular chromosome in *F moniliforme* also are carried on the chromosome with the same number in *F thapsinum*

rDNA ITS Restriction Fragments

The rDNA region was amplified from 28 *F moniliforme* strains and 21 strains of *F thapsinum* The resulting DNAs were cut with seven restriction enzymes - *Bgl*I, *Cla*I, *EcoRI*, *Hinc*II, *Mbo*I, *Sma*I, and *Sph*I Differences between *F moniliforme* and *F thapsinum* were seen only with *Mbo*I and *Sma*I

Mycotoxins Produced

Fusaric acid was one of the first fungal metabolites implicated directly in plant pathogenesis It is mildly toxic to mice and affects brain and pineal neurotransmitters and metabolites in mammals Fusaric acid's major importance however, may be in its synergistic interactions with other naturally occurring mycotoxins such as fumonisins, moniliformin, fusarins, beauvericin and fusaproliferins All tested strains of both *F thapsinum* and *F moniliforme* produce fusaric acid We expect that most *Fusarium* strains from sorghum probably synthesize fusaric acid, and fusaric acid has been nearly universally detected in the relatively few sorghum grain samples that have been analyzed for it However, the average level and incidence of this compound in grain used for food and feed remains unknown, and so its impact on human and animal health has never been accurately estimated

Fumonisins are important toxins that have recently been shown to induce equine leukoencephalomalacia and pulmonary edema in swine, and correlated with esophageal cancer in humans Fumonisins have been shown to induce plant disease symptoms when applied directly to plants, but there is as yet no solid evidence that strains that produce higher levels of fumonisin are more aggressive than are their non-producing counterparts The fumonisins are produced by *F moniliforme*, but not by *F thapsinum*

Moniliformin is an unusual compound with a cyclobutane ring at its core This compound is toxic to poultry but has no, as yet, detectable effects on other domesticated animals or humans Moniliformin is made at quite high levels by *F thapsinum*, but at only very low levels, if at all, by *F moniliforme* Thus, the species for which the compound is named apparently is incapable of synthesizing it In addition to these three toxins, both *F moniliforme* and *F thapsinum* synthesize compounds that can lead to duckling toxicity, but that have yet to be identified

Networking Activities

Editorial and committee service (1997)

Editor of *Applied and Environmental Microbiology*

Associate Editor and Editorial Board of *Mycologia*

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

Editor and organizer of the Genetics session of the Paul E Nelson Memorial Symposium

Participant in USDA-National Research Initiative, Biologically Based Pest Management Panel

Research Investigator Exchange

Dr Leslie participated in the INTSORMIL traveling workshop in Ethiopia and Eritrea, September 19 - October 1, 1997

Dr Leslie made the following scientific exchange visits (1997) Kenya - August 6-10, Uganda - August 10-20, Hungary - August 27 - September 5, Czech Republic - September 6-10, Egypt - October 3 - 14, and, South Africa - December 2-16

Seminar, Workshop and Invited Meeting Presentations

Department of Botany, University of Georgia, Athens, Georgia - 4/97

Faculty of Agriculture and Forestry, Makerere University, Kampala, Uganda - 8/97

Germplasm and Research Information Exchange

Germplasm Conservation and Use

During 1997 standard *Fusarium* cultures were provided to

* M P Latorse, Rhône-Poulenc Agro Lyon France
* Dr L Hornok, Agricultural Biotechnology Center, Institute for Plant Sciences, Godollo, Hungary
* Dr W Gams, Centraalbureau voor Schimmelcultures, Baarn, The Netherlands
* Dr J T Cowsert, Limagrain Genetics Research, Champaign, Illinois
* Dr C Waalwijk, DLO Institute for Plant Protection, Wageningen, The Netherlands
* Dr H I Nirenberg, Biologische Bundesantsalt für Land- und Forstwirtschaft, Berlin, Germany
* Dr R C Ploetz, Tropical Research & Education Center, University of Florida, Homestead, Florida
* Dr W F O Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa
* Dr S C Jong, American Type Culture Collection, Rockville, Maryland
* Dr M P Wach, Sylvan, Inc , Kittanning, Pennsylvania
* Dr D C Kenison, Ivy Laboratories, Inc , Overland Park, Kansas
* Dr L W Burgess, University of Sydney, Sydney, New South Wales, Australia
* Dr Charles Bacon, USDA Russell Research Center, Athens, GA
* Drs A Logrieco & A Moretti, Istituto Tossine e Micotossine da Parassiti Vegetali, Bari, Italy
* Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, KS
* Dr J S Smith, Department of Animal Sciences & Industry, Kansas State University, Manhattan, KS
* Drs R W Bowden, L E Claflin & D J Jardine, Department of Plant Pathology, Kansas State University, Manhattan, KS
* Dr B Bakan, INRA, Nantes, France
* Dr S Gnanamanickam, University of Madras, Madras, India
* Dr R W Schneider, Plant Pathology Department, Louisiana State University, Baton Rouge, Louisiana
* Dr E L Nigh, Department of Plant Pathology University of Arizona, Tucson Arizona
* Dr B Heremans, Riksstation voor Plantenziekten, Merelbeke, Belgium
* Dr M Diourte, IER, Bamako, Mali
* Dr S Chulze, Universidad Nacional de Rio Cuarto, Rio Cuarto, Argentina

* Drs M Wingfield and B Wingfield, University of the Orange Free State, Bloemfontein, South Africa

Other collaborating scientists

* 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 M Flieger & S Pazoutova, Institute of Microbiology, Czech Academy of Sciences, Prague, Czech Republic

* Drs M Wingfield and B Wingfield, University of Pretoria, Pretoria, South Africa

* Drs A E Desjardins & R D Plattner, USDA National Center for Agricultural Utilization Research, Peoria, IL

* Dr Charles W Bacon, USDA Russell Research Center, Athens, GA

* Dr G Odvody, Texas Agricultural Experiment Station, Corpus Christi, TX

* Dr K K Klein, Mankato State University, Mankato, MN

Publications and Presentations (1997)

Journal Articles

Klittich C J R J F Leslie P E Nelson and W F O Marasas 1997 *Fusarium thapsinum* (*Gibberella thapsina*) A new species in section *Liseola* from sorghum Mycologia 89 643 652

Leslie J F and C T Yamashiro 1997 Effects of the *tol* mutation on allelic interactions at *het* loci in *Neurospora* crassa Genome 40 834 840

Mansuetus A S B G N Odvody R A Frederiksen and J F Leslie 1997 Biological species of *Gibberella fujikuroi* (*Fusarium* section *Liseola*) recovered from sorghum in Tanzania Mycological Research 101 815 820

Agroecology and Bıotechnology of Fungal Pathogens of Sorghum and Mıllet from the Greater Horn of Afrıca

Proȷect KSU-210B
Larry E Claflın
Kansas State Unıversıty

Prıncıpal Investıgator

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Dr Darrell Rosenow, Texas A&M Agrıcultural Experıment Statıon, RR 3, Box 219, Lubbock, TX 79401
Dr G A Odvody, Texas A&M Research and Extensıon Center, Route 2, Box 589, Corpus Chrıstı, TX 78406
Dr Jose Calderon, Unıversıty de San Carlos de Guatemala, Guatemala Cıty
Dr Neal McLaren, ARC-Graın Crops Instıtute, Potchefstroom, Republıc of South Afrıca

Summary

Survıval of ergot conıdıa rapıdly declıned under Kansas condıtıons as vıable conıdıa were not detected ın Aprıl from ınfected panıcles Sımılar trends were observed ın Mexıco as populatıons declıned nearly 50% from March to Aprıl

The polymerase chaın reactıon (PCR) was developed for ascertaınıng the presence of cells of *Xanthomonas campestrıs* pv *holcıcola* (causal agent of bacterıal leaf streak dısease of sorghum) ın sorghum seeds Bacterıal cells were only detected from the external tıssue of seeds but results were unrelıable due to the lımıted number of cells present Extracts from ınternal tıssues of seeds were negatıve for *X c* PV *holcıcola* by PCR and recovery on medıa

Obȷectıves, Productıon and Utılızatıon Constraınts

Obȷectıves

- Determıne the survıvabılıty of macro- and mıcroconıdıa of *Clavıceps afrıcana*, causal agent of ergot dısease of sorghum, on varıous surfaces ın the U S Mexıco, and Guatemala
- Determıne the overseasonıng survıval of macro- and mıcroconıdıa of *C afrıcana* ın the U S
- Contınue to screen for genetıc varıabılıty of sorghum germplasm to covered kernel smut and ergot dıseases ın the U S , Kenya, and Egypt
- Screen varıous genera of plants ıncludıng *Sorghum* sp , *Andropogon Cenchus* etc , to ascertaın potentıal alternate hosts of *Clavıceps afrıcana* ın the U S , Kenya, and Egypt

Constraınts

Ergot was only a problem ın graın sorghum ın Afrıca and Asıa prıor to 1996 when the dısease was first detected ın Brazıl and Argentına In 1997, the dısease spread to Colombıa, Honduras, Mexıco, numerous ıslands ın the Carıbbean, and, very recently, ın Central and South Texas Thıs poses profound ımplıcatıons for the sorghum ındustry ın North Amerıca Losses due to ergot may be attrıbutable to actual reductıon ın graın yıelds, loss of export markets of seed and feed graıns to those countrıes where ergot has not been reported, and loss of germplasm and or hybrıd seed ıncreases ın wınter nurserıes where ergot was detected and quarantıne regulatıons prohıbıt return of the graın ınto the U S Graın sorghum ıs used as a human food ın numerous countrıes and may be the only food staple avaılable ın those areas where drought ıs a common occurrence and ergot contamınatıon of such graın could result ın extensıve hunger It ıs unknown ıf the macro- mıcroconıdıa or sclerotıa wıll survıve between sorghum croppıng seasons ın temperate areas

Covered kernel smut ıs one of the more ımportant dıseases of graın sorghum ın LDCs The dısease ıs easıly controlled by chemıcal seed treatments but these chemıcals may not be avaılable or the cost may be prohıbıtıve for purchase by farmers Incorporatıon of resıstant or ımmune germplasm ınto acceptable cultıvars would partıally allevıate concerns about covered kernel smut

Xanthomonas campestris PV *holcicola*, is the causal agent of bacterial leaf streak disease of grain sorghum and has been reported from many countries Losses vary but are generally considered minimal as excellent genetic resistance has been incorporated into inbreds, hybrids and cultivars The principal concern of *X c* PV *holcicola* is exchange of germplasm, imports and exports of grain sorghum due to quarantine regulations of various countries

Rapid and accurate identification of *X c* PV *holcicola* is important to commercial seed companies, import, and export agencies The success of regulatory agencies in issuing phytosanitary certificates and sorghum breeding programs to determine genetic variability of germplasm depends primarily on the availability of reliable methods for detection of pathogens in plant tissue Serious problems have been encountered when a causal microorganism is on a quarantine list of a regulatory agency Problems such as an incorrect diagnosis, failure to provide a phytosanitary certificate with the export shipment and/or a devious attempt to reduce the cost of a commodity by stating that the causal pathogen was found in the shipment are all causes for concern In addition, regulatory personnel may not have sufficient expertise or training to accurately diagnose the target organism and/or the laboratory facilities may be inadequate An incorrect diagnosis by a regulatory agency will mandate that the burden of proof rests with the exporter

Diagnosis of plant pathogenic bacteria is commonly based on biochemical, physiological, and pathogenicity tests which are time-consuming, laborious and often ambiguous and subjective *Xanthomonas campestris* consists of at least 125 pathovars that are differentiated by their ability to cause diseases on host plants Moreover, saprophytic *X campestris* strains exist on or in plants and plant debris in association with pathogenic pathovars of *X campestris* *X c* PV *holcicola* cannot be differentiated from other pathovars of *X campestris* by use of physiological and biochemical tests Serological techniques based on currently available polyclonal antibodies are of dubious merit because of cross-reactions that occur with numerous pathovars

Research Approach and Project Output

Research Methods

The polymerase chain reaction (PCR) for diagnosis rapidly gained acceptance when *Thermus aquaticus* (Taq), a polymerase enzyme was reported This technique provides a rather simple and ingenious method to exponentially amplify specific DNA sequences by *in vitro* DNA synthesis PCR specificity is from the synthetic oligonucleotide primers which base-pair to and define each end of the target sequence to be amplified PCR-based detection and identification methods were described for other plant pathogens The technique offers numerous advantages such as it is not necessary to have the causal agents in a pure culture for diagnosis by PCR, the method has excellent sensitivity with the theoretical potential to detect a single target molecule in a complex mixture without using reactive probes and is rapid and versatile As with serological probes, narrow and broad selections are possible, facilitating the detection of a single pathogen or many members of a group of related pathogens, depending on the primers that have been chosen Reagents with narrow or broad specificities can be developed at a reasonable cost The expense generated by the synthesis of hundreds of different primers for PCR would be equal to only a few monoclonal antibodies The rep-PCR technique is based on the amplification of DNA with oligonucleotide primers from three families of unrelated repetitive DNA sequences corresponding to repetitive extragenic palindromic (REP), enterobacterial repetitive intergenic consensus (ERIC), and BOX elements

Ergot

Conidial spores produced by the ergot fungus are reported to be very fragile with a short life An extremely high incidence of ergot was reported in grain sorghum over a several week period in February (1997) on numerous islands within the Caribbean This is likely attributable to an airborne spore-shower This may occur under climatic conditions of moderate temperatures and favorable levels of relative humidity, coupled with a tropical disturbance or a prevailing wind to disseminate the spores over wide geographical areas A major concern in the U S is the prevailing southerly winds during the growing season for grain sorghum, especially since ergot has been reported in Central and South Texas

Durability of ergot conidia will be determined by evaluating longevity of spores under natural field conditions The survival rate will also be determined on the surface of various materials such as cotton to imitate clothing, leather to mimic shoes, and metal and rubber to simulate machinery used in producing grain sorghum Monel metal disks were cleaned with several changes of acetone, washed in several changes of sterile distilled water and dried A portion of the disks were painted yellow, green and red to determine if pigments in paint used in painting agricultural implements were toxic to ergot conidia Other disks were from rubber, tarpaulin, paper from corn seed bags, and leather Panicles exhibiting honeydew symptoms were collected and stored at room temp Individual ergot-infected florets were removed and placed in a beaker containing a solution of 10 mM phosphate buffered saline (PBS) The final concentration consisted of 6 6 X 10^7 cells/ml of microconidia and 1 1 X 10^7 cells/ml of macroconidia Disks were infested by placing 250µl of the suspension on each disk and then dried overnight in a laminar flow hood Disks were placed in perforated paper bags for storage in an unheated building

Sampling

Disks were removed at monthly intervals from the storage facility and placed in six-well tissue culture flat bottom plastic plates Four ml of PBS was added to each well Plates were then placed on a Thermolyne rotator/shaker at a setting of 150 rpm for 45-60 min Plates were removed and 250 µl from each well was added to a hemocytometer Counts were determined primarily with the 10X objective, however the 40X objective was used to determine microconidia At least 10 fields were counted in the Hemocytometer

Volunteer plants

Various species of *Panicum Cenchrus Sorghum and Andropogon* have been reported as susceptible to *C africana* Seeds of these plants will be obtained from the plant introduction centers and planted In addition, various *Sorghum* sp such as *aethiopicum almum japonicum miliaceum plumosum saccharatum sudanense versicolor verticilliflorum and virgatum* will be evaluated under greenhouse conditions as some are potentially serious weeds if escapes occur Koch's postulates will be used as to identify those susceptible

Development of a PCR technique for X c PV holcicola

Source and maintenance of bacterial cultures — Twenty-eight strains of *Xanthomonas campestris* PV *holcicola* seventeen strains of different pathovars of *Xanthomonas* and four strains of *Pseudomonas* from various areas of the world were used All bacterial strains were preserved in silica gel at -80°C or lyophilized for long-term storage After removal from silica gel or lyophil tubes, cultures were added to nutrient broth, placed on a rotary shaker, and after 1-2 hrs were streaked on yeast extract dextrose-calcium carbonate medium (YDCA) to confirm purity and for growth on *X phaseoli* medium (MXP), a semiselective medium for Xanthomonads Working cultures were maintained on silica gel at 4°C

DNA extraction and PCR assay using rep-PCR — For DNA extraction, a single colony was selected from plates after 48 hours of incubation at 28°C Genomic DNA from each strain was extracted by a modification of the procedure of Murray and Thompson or by the lysozyme-sodium dodecyl sulfate lysis method as modified by Leach *et al* Genomic DNAs from the bacterial strains selected were quantified by spectrofluorimetry with a model TKO-100 minifluorometer (Hoefer Scientific Instruments, San Francisco) and adjusted to 50 ng/µl Genomic DNA concentrations from seed samples were estimated in an agarose gel by comparing to reference serial dilutions of *X c* pv *holcicola*

REP, ERIC, and BOX element (BOX1A) oligonucleotide primers were synthesized by Oligo's Etc (Wilsonville, OR) The sequences of the primers were as follows ERIC (ERIC1R, [5'-ATGTAAGCTCCTGGGGATTCAC-3'], ERIC2R, [5'-A GTAAGTGACTGGGGTGAGCG-3']), REP (REP1R-I, [5'-IIII-CGICGICATCIGGC3'], and REP2-I, [5'-ICGICTTATCIGGCCTAC-3']), BOX, (BOXA1R [5'-CTACGGCAA GGCGACGCTGACG-3'])

PCR amplifications were performed in an automated thermal cycler (Perkin - Elmer DNA Thermal Cycler, Foster City, CA or MJ Research, Inc , Watertown, MA) Initial denaturation was at 94°C for one min followed by 35 cycles of ERIC and REP primers that annealed at 52°C for one min for the ERIC primer and at 44°C for one min with the REP primer and extended at 65°C for eight min The final extension cycle was at 65°C for 15 min followed by a final incubation at 4°C A 12 5 µl portion of each amplification reaction was separated at 4°C on a gel mixture of 0 75% agarose and 0 75% Synergel (Diversified Biotech, Inc , Boston, MA) in 0 75X TAE (4mM Tris-acetate, 2 mM EDTA) or 0 5X TBE buffer The gel was stained with ethidium bromide and photographed on an UV transilluminator Throughout the study, PCR amplifications with DNA from randomly selected strains were repeated two or three times for confirmation of banding patterns

Data analysis — Fingerprint patterns generated by each strain were compared visually and grouped according to unique fingerprints based on rep-PCR amplification alone Each unique banding pattern generated by the rep-PCR primer ERIC, was regarded as a haplotype Only amplification products that were present throughout each of three repetitions for at least one isolate were scored

Reproducibility of DNA fingerprints — Fingerprint profiles generated from independent DNA preparations extracted from single-colony cultures and a protocol involving the direct use of whole cells collected directly from solid and liquid media were tested to determine reproducibility For the solid media assay, two strains of *X c* pv *holcicola* (4429XCH, 4413XCH) and one strain of a different pathovar, *X c* pv *malvacearum* (KSU4485), were streaked on nutrient yeast-dextrose Bacterial cells were collected by passing a 1 µl disposable inoculating loop through the colonies and then inserted into the PCR mixture and vigorously stirred until the cells were suspended Each bacterial strain was grown overnight in 8 ml of nutrient broth media and 3 µl of the suspension was added directly to the PCR mixture

Sensitivity thresholds — The limits of detection (amplification) of *X c* pv *holcicola* genomic DNA by the ERIC primers was evaluated as follows Extracted genomic DNA (strain 4429XCH) was serially diluted to concentrations of 50, 25, 20, 15, 10, 5, 2, 1 ng/µl in filtered, autoclaved, HPLC-grade water Aliquotes (3 µl) from each dilution were added to the rep-PCR mixture and then analyzed by agarose gel electrophoresis

Efficacy of diagnosis of *X c* pv *holcicola* in seed—X c pv *holcicola* (strain 4412XCH) was grown overnight in eight ml of nutrient broth and then centrifuged for two min at 10,000 rpm and resuspended into sterile water for a suspension of approximately 10^8 cfu/ml Sorghum plants at the bloom stage of growth were inoculated by injecting the suspension in the rachis tissue with a needle (26-gauge) and syringae and by infiltration of the uppermost leaves At physiological maturity, panicles were hand-harvested, threshed and the seeds dried at room temp Bacterial genomic DNA from sorghum seeds was extracted according to a simple procedure used to extract bacterial genomic DNA from bean seeds To determine if *X c* pv *holcicola* colonized the outside surface of seeds, four seeds from each inoculation technique were added to 1 5-ml tubes containing 0 5 ml of 0 5 N NaOH and 0 5% (wt/vol) PVP and soaked for two min The tubes were centrifuged at 500 X g for two min and 5 µl of the extract was transferred to a 1 5-ml tube containing 495 µl of 20 mM Tris-HCl, pH 8 0 One 5-µl aliquot was used per individual PCR assay To determine if *X c* pv *holcicola* colonized the internal tissues of seeds, four kernals each from both inoculation techniques were washed in a solution of 0 5 N NaOH and 0 5% (wt/vol) PVP for 2 min and then rinsed twice for five min in sterile PBS buffer Seeds were blotted dry with paper towels, placed in a sterile mortar, and then coarsely crushed with the pestle These seed fragments were transferred to 1 5-ml tubes containing 0 5 ml of 0 5 N NaOH and 0 5% (wt/vol) PVP and thoroughly mixed for 15 sec by vortexing After a brief centrifugation, 5 µl of the supernatant was transferred to a 1 5-ml tube containing 495 µl of 20 mM Tris-HCl, pH 8 0 One 5-µl aliquot was used per individual PCR assay Extracts from autoclaved sorghum seeds were used as negative controls The rep-PCR amplification assays were performed as described above but only with the primer combinations of ERIC1R and BOXA1R and the thermal cycling parameters described for ERIC-PCR

Research Findings

Ergot

Survival of ergot conidia rapidly declined under Kansas conditions at the onset of warmer weather in March (Table 1) Viable conidia were not detected in April and only one conidium was observed to germinate in May Similar trends were observed in Mexico as populations declined nearly 50% from March to April on extracts from all surface materials (data not shown) Surprisingly, ergot macroconidia remained viable on galvanized metal for over six months Galvanized metal contains zinc, a known heavy metal toxic to fungi Survival was very poor on the brown inner paper liners of seed sacks Conidia remained relatively static on rubber and leather

Characterization of *X c* pv *holcicola* by rep-PCR — A unique genomic fingerprint for *X c* pv *holcicola* was generated by BOX, REP and ERIC-PCR Most strains of *X c* PV *holcicola* produced highly similar BOX, REP, and ERIC-PCR banding patterns to the *X c* pv *holcicola* pathotype strain (4429XCH) Differences were limited to the presence or absence of one to three bands Bands were distinct from other *Xanthomonads* and *Pseudomonads* examined (Figure 1) However, some strains recovered from different areas in Kansas had a few common bands to the fingerprint patterns generated from other strains of *X c* pv *holcicola* and distinct from other bacterial species included as controls The absence or presence of extra bands with ERIC-PCR differentiated nine fingerprint types within the 29 strains of *X c* pv *holcicola* that we tested These strains were classified into four distinct genotypes based on those fingerprints) Six common bands to all strains of *X c* pv *holcicola* were observed

Sensitivity thresholds — DNA was extracted from *X c* pv *holcicola* cells as mentioned above and the minimal amount needed as determined by a dilution series to detect the characteristic ERIC1R/BOXA1R-PCR sequence using ERIC-PCR thermal cycling parameters was 10 ng/ml This corresponded to a suspension of approximately 1 3 x 10^6 cfu/ml (data not shown)

A simple DNA extraction method involving a seed soak procedure was used to determine the relative efficiency of rep-PCR Seeds were harvested from plants inoculated either by rachis-injection or leaf-infiltration The seed extracts were tested on agar media plates for recovery of *X c* pv *holcicola* cells Saprophytic contamination created

Table 1 Survivability of *Claviceps sorghi* conidia in Kansas, 1997-98

Month	Water agar Nonviable	Water agar Viable	Water agar % Viable	Water agar + streptomycin Nonviable	Water agar + streptomycin Viable	Water agar + streptomycin % Viable
November	724	364	33 5			
December	325	338	51 0	629	224	52 0
January	791	857	52 0			
February	783	443	36 0	696	224	24 3
March	1060	100	9 4			
April	18	0	0 0			
May	164	1	0 61			

problems in identification of the causal agent Colonies of *X c* pv *holcicola* were only recovered on MXP and YDCA from the external colonized tissue of seeds ERIC1R/BOXA1R-PCR detected *X c* PV *holcicola* from only the external colonized tissue but results were unreliable due to the low number of cells present PCR profiles generally correlated with the typical fingerprint patterns of genomic DNA at concentrations approximately 10 ng/µl Other components such as phenols in seeds may have interfered with the minimal level of bacterial DNA detection Extracts from the external seed coat that tested positive on MXP and YDCA were also positive in the PCR test Extracts from internal tissues of seeds were negative for *X c* pv *holcicola* by PCR and recovery on media

Direct extraction of genomic DNA from recovered *X c* pv *holcicola* cells in colonized seeds was easily made with a solution of NaOH and PVP Elimination of *X c* pv *holcicola* cells that colonized seeds with brief consecutive soaks in NaOH and PBS were very effective for assessing PCR for detection of the causal agent in internal seed tissues None of the strains presented any residual amount of external contamination of *X c* pv *holcicola* cells as was previously detected by PCR

Networking Activities

Research Investigator Exchanges

Numerous contacts were made with International Scientists at the Principal Investigators Conference (June 23-24, 1998) and the International Conference on ergot of Sorghum (June 25-26, 1998) in Corpus Christi, TX

Research Information Exchange

Assistance Given

Reprints of pertinent journal articles, antisera, bacterial cultures, and nitrocellulose paper were furnished to Dr Debbie Frederickson, University of Zimbabwe, for identification of several bacterial pathogens of pearl millet

Bacterial cultures were provided to Dr Norman Schaad, Plant Quarantine Laboratory (USDA), Ft Detrick, MD

Microscope repair parts were purchased and shipped to Mr Girma Tegegne, IAR, Ethiopia

Publications and Presentations

Abstracts

Diourte M and L E Claflin 1997 Characterization of *Fusarium* isolates from Kansas and Mali Phytopathology 87 S24

Diourte M L E Claflin and B A Ramundo 1997 Infection and colonization of sorghum plants by two *Fusarium* species involved in the etiology of Pokka Boeng Phytopathology 87 S24

Journal Articles

Muriithi L M and L E Claflin 1997 Genetic variation of grain sorghum germplasm for resistance to *Pseudomonas andropogonis* Euphytica 98 129 132

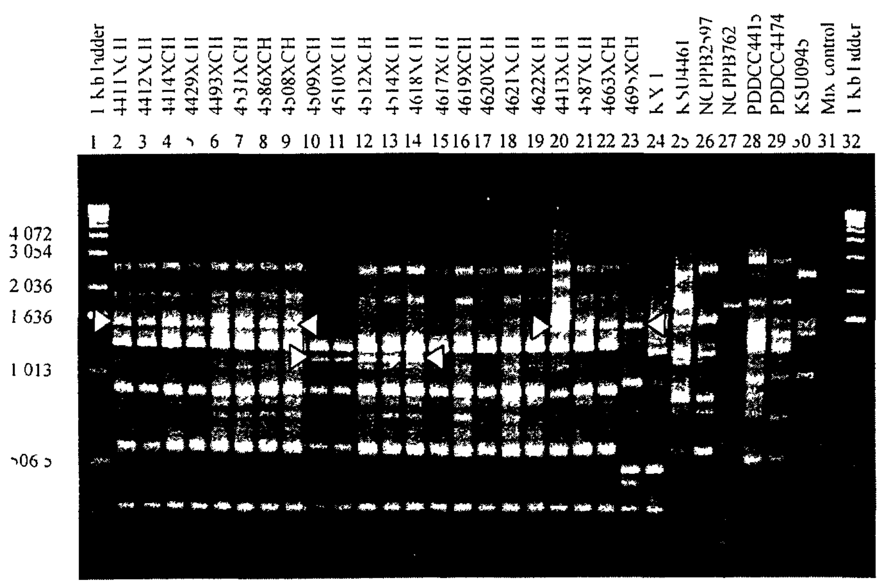

Figure 1 ERIC-PCR fingerprinting patterns from genomic DNA of *X c* pv *holcicola* and other bacterial species used as controls A 10 µl portion of each amplified PCR product was separated at 4°C on a gel mixture of 0 75% agarose and 0 75% Synegerl stained with ethidium bromide The control lane (31) represents the same ERIC-PCR but lacking template DNA

Dissertations and Theses

Nzioki Henry S (Kenya) December 1997 Inheritance of resistance epidemiology and development of isoenzyme and random aplified polymorphic DNA (RAPD) techniques for *Sporisorium sorghi* M S thesis Kansas State University Manhattan 113 p

Diourte Mamarou (Mali) August, 1997 Etiology and epidemiology of Pokka Boeng disease of grain sorghum [*Sorghum bicolor*(L) Moench] in Kansas Ph D diss Kansas State University Manhattan 122 pp

Muriithi L B (Kenya) April, 1997 Epidemiology of *Pseudomonas andropogonis* causal agent of bacterial leaf stripe of grain sorghum Ph D diss Kansas State University Manhattan 97 p

Lu Ming (PRC) October 1997 Diversity pathogenicity and potential plant growth ability of *Gibberella fujikuroi* in maize and sorghum Ph D diss Kansas State University Manhattan 107 p

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Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-205
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Summary

In Honduras sorghum and maize are attacked annually by a complex of lepidopterous caterpillars consisting of at least four species This complex annually damages or destroys these grain crops on subsistence farms, thus requiring costly replanting if resources are available Studies on aspects of the biology, ecology, behavior and population dynamics of the three armyworm species in this complex have identified the role of these insects in crop production systems in southern Honduras A system was developed for integrated management of this lepidopterous pest complex Recommended practices include two low cost, but labor intensive cultural practices (planting date and weed management) utilizing family labor Delayed planting (8-12 days) and weed control 12-16 days after crop emergence results in less crop damage A single insecticide application may be required if a 40% infestation occurs Improved sorghum cultivars and early maturing maize are recommended to escape or tolerate insect damage Seed treatment with insecticide provides some protection to seedlings Natural enemy parasitization did not appear to influence crop damage by the defoliators and weed management practices did not influence parasitoid populations This information indicated the limited role that naturally occurring biological control agents might play in developing integrated insect pest management strategies for this lepidopterous caterpillar complex on sorghum and maize during the early crop growing season in this agricultural ecosystem and may possibly relate to other areas in Central America with similar insect pest constraints to production of these grain crops in similar agricultural environments Sorghum production using the pest management system developed was increased 20% and maize 35% at the farm level In years when grain yields and market prices are high, the recommended practices could return $2 9 million a year to the production area in southern Honduras and possibly similar returns in other areas experiencing identical insect problems in Central America Increased yields of both crops would improve diets and nutritional level of families

Objectives, Production and Utilization Constraints

Objectives

- Complete investigations on the influence of specific weed management practices on lepidopterous insect pests and natural enemy parasitoid populations on production farms in southern Honduras

- Study feeding preferences and performances (developmental rates) of *Metaponpneumata rogenhoferi*, one of the lepidopterous defoliators in the pest complex, on sorghum, maize, and sicklepod, a preferred weed species prevalent in production fields in southern Honduras

- Publish scientific papers in journals, as well as popular papers in Ceiba (the scientific and technical journal of

Zamorano), and extension articles for distribution throughout the sorghum and maize production areas in Honduras

- Extension of MSU-205 INTSORMIL activities into Nicaragua, establishing collaborative research programs with INTA

- Develop collaborative IAR entomological research programs on sorghum in Ethiopia

- Evaluate insecticides for control of stem, whorl and panicle feeding insects on sorghum in Mississippi

- Direct graduate students and travel to host countries to plan research and collaborate in entomological investigations

Constraints

Ninety percent of the sorghum acreage in southern Honduras is intercropped with maize because of adverse environmental and agronomic conditions In this area, tall, photoperiod sensitive, low yielding sorghum, called "maicillo criollo" are intercropped with maize If the maize crop is lost to drought, farmers substitute sorghum for maize to feed their animals and family Thus, sorghum is an insurance crop during dry years when the maize 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

A lepidopterous pest complex is considered by subsistence farmers to be the principal threat to their sorghum-maize crop during the early period of crop development Biological and ecological studies have been conducted in MSU-205 with the armyworm species [*Spodoptera frugiperda* (fall armyworm), *S latifascia* (black armyworm), 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 maize Noncrop plant "source habitats" and crop plant "sink habitats" have been determined Crop mortality factors have been partitioned in limited studies in sorghum-maize 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 this complex, studies during 1996-97 emphasized a third species, *M rogenhoferi* The relationships of this little researched species with non-crop vegetation and crop plants in sorghum-maize 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 these insects in intercropped sorghum and maize in specific agroecosystems Aspects of this research are transferable to other areas in Central America

The international significance of the *Spodoptera* species, as well as *M rogenhoferi*, particularly in relation to migration, 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 migratory pest throughout the Americas)

Alternative insect pest management practices (limiting insecticide use) which are practical for use by low income subsistence farmers (including cultural practices) have been evaluated in MSU-205 A package of sustainable and economically feasible crop production practices has been developed for use by farmers who lack economic resources to purchase off farm inputs such as insecticides, herbicides and fertilizers Investigations have been designed to elucidate specific aspects of lepidopteros pest management tactics previously identified as practical for control of these particular insects The Honduran National Sorghum Breeding Program with EAP and INTSORMIL collaboration is designed to develop improved maicillo varieties and photoperiod sensitive hybrids MSU-205 has been active in this program and has identified antibiosis resistance in the native landrace cultivars, and research has elucidated the antibiosis mechanisms of resistance

The extension of MSU-205 into Nicaragua is the result of expanding INTSORMIL's presence and participation in several host countries in Central America Sorghum production in Nicaragua is predominantly in commercial systems on large farms and the coastal plains The principal insect pest constraint to production is the sorghum midge Studies will be conducted to determine distribution, host plant relationships, and cultural and chemical control strategies that are effective and ecologically acceptable for this region

MSU-205 activity in Ethiopia involves the collaboration of IAR and INTSORMIL scientists in defining scientific studies that are practical and economically suitable for crop production systems in that country The principal insect pest constraints to sorghum production are stalk borers

Research Approach and Project Output

Research Methods and Research Findings

Honduras

Weed Management Influence on Insect Pest and Natural Enemy Populations

The influence of weed management systems on pest and natural enemy (parasitoid) populations were evaluated for the second year in on-farms studies with intercropped sorghum and maize in southern Honduras Systems included agronomic practices with farmers decision to control weeds and a system with delayed weed control As in 1996, five fields on five separate farms were established for study Fields were planted during the second week of June

Crop fields with delayed (14 days after planting) weed control were infested with greater levels (50% to 100%, mean 60%) of weeds per square meter (during the first two weeks of crop growth), were infested with the same lepidopteros defoliator species (the "longosta" complex *Spodoptera frugiperda*, *S latifascia*, *Metaponpneumata rogenhoferi* and *Mocis latipes*), but experienced less damage (18%), and the level of pest parasitization was the same as in intercropped fields having weed control according to current farmer practices (hand weeding prior to planting and during early crop development)

Spodoptera frugiperda (fall armyworm) was the most abundant species encountered (throughout the crop growing season) contributing to 62% and 68% damage to sorghum and maize, respectively A nematode, *Hexamermis* sp (Nematoda Mermithidae), parasitized up to 61% of the larvae on sorghum and 68% of larvae on maize, respectively Levels of parasitization were greatest when larvae infested the crop plants in the 6 to 10 leaf stage, and declined thereafter An ichneumonid parasite, *Chelonus insularis* (Hymenoptera Braconidae), was the second most important parasite of *S frugiperda* Only 2% of larvae were parasitized This ichneumonid attacks *S frugiperda* eggs and emerges from first or second instar larvae to pupate Two additional inchneumomid parasitoids, *Eiphosoma vitticolle* and *Corsoncus magus* parasitized less than 1% of *S frugiperda* eggs (emerges from larvae) Three species of parasitic flies *Archytas marmoratus*, *Lespesia archippivora* and *Lespesia* sp (Diptera Tachinidae) attack *S frugiperda* larvae and emerge from the pupae causing less than 1% mortality

This information on naturally occurring parasitoid population levels and parasitization mortality indicates the limited role that these biological control agents might have in developing integrated insect pest management strategies for the lepidopterous caterpillars on sorghum and maize in this agricultural ecosystem in Honduras and may possibly relate to other areas in Central America with similar insect pest constraints to production of these grain crops in similar agricultural environments

Biology of Metaponpneumata rogenhoferi useful in developing management practices for the insect pest complex on sorghum and maize (Notes on Spodoptera latifascia Spodoptera sunia and Mocis latipes)

Metaponpneumata rogenhoferi was the second most abundant species on the sorghum and maize crops throughout the growing season, but was particularly prevalent in southern Honduras during the period of seedling and early whorl growth stages of the crops This pest, almost exclusively, was responsible for up to 100% plant destruction in some fields in 1997, resulting in replanting by those farmers that could afford to do so Larvae were observed feeding on *Senna obtusifolia* (= *Cassia sensu stricto*) on May 21, thus apparently representing the first generation of the year Larvae collected on *S obtusifolia*, as well as on sorghum and maize in mid-June, apparently represented the second generation of this species in the study area No larvae were observed on the crop or noncrop plants after June 28 This observation indicates that this species apparently has two generations during May and June in this area of southern Honduras

To further investigate the biology of *M rogenhoferi*, larvae of the second generation were collected in the field in southern Honduras from sorghum, maize and *S obtusifolia* and placed on a stand of the broadleaf weeds covered by four Saran screen cages (6x6x6ft) One hundred, 3^{rd} to 4^{th}, instar larvae were released in each cage Many larvae developed to pupae, but no adults eclosed within the cage Pupae collected from the soil and taken to the laboratory did not develop to adults during a 30 day observation These observations further support the previous data suggesting that *M rogenhoferi* develops through two generations and enters a dormant state to survive periods of unfavorable weather

Metaponpneumata rogenhoferi was parasitized by the *Hexamermis* sp nematode (< 5% parasitization), two tachinid flies (*L archippivora* and *Lespesia* sp, < 1% parasitization), and one ichneumonid wasp (*E vitticolle*, < 1% parasitization)

Preferred noncrop hosts including *S obtusifolia*, *Ipomoea* sp , and *Bromelia caratas* were the preferred food host plants of *M rogenhoferi* in the test area Percent parasitization of larvae on these noncrop host plants was less than 5% in the crop field, as well as on host plants outside the crop field

Spodoptera latifascia, the black armyworm, was present on the crops and noncrop vegetation (*S obtusifolia*, *Ipomoea* sp and *Bromelia caratas*) during early growth stages (first three weeks of growth) of the host plants, but was not observed in any appreciable numbers in the test area after this period (late June – early August) Less than 5% of the larvae were parasitized, with *Hexamermis* sp responsible for almost all parasitization A tachinid fly *Archytas* sp , was reared from a small number of pupae collected in the field

The fourth lepidopterous species, *Mocis latipes*, in the complex of defoliators identified in the langosta complex by MSU-205 in earlier investigations attacked the grain crops during the fifth to eighth week of crop growth (near mid-season) At this time the crops were under drought stress *Ixporus unisetus* was a preferred host for *M latipes* No nematode parasites were recovered *M latipes* is a pest that usually attacks the grain crops during mid-growing season when the plants are larger The larvae are not exposed to splashing water (rainfall) contaminated with soil infested nematodes

A fifth lepidopterous species, *S sunia* infested the weeds and the crop plants during May and June Preferred feeding hosts included *S obtusifolia*, *Ipomoea* sp and *Portulaca oleracea* This defoliator pest was encountered at extremely low levels and thus, the larvae were responsible for only minor damage to the crops during the first four weeks of crop growth *Hexmermis* sp parasitized less than 5% of the larvae

Further studies on *M rogenhoferi* development on maize, *Senna obtusifolia* (a preferred wild broadleaf host plant) and artificial diet (pinto bean diet) were conducted in the laboratory to determine ability of the insect pest to develop on these plant hosts, as well as developmental times (generation times) on each diet This information is useful in identifying the preferred host (diet) and provides data on the biological development (life cycle) of this important insect pest

Larvae (collect from *S obtusifolia*) developed faster on *S obtusifolia* foliage ($\bar{x}$ 26d) compared with development on maize foliage ($\bar{x}$ 29 5d) and artificial diet ($\bar{x}$ 34 5d) at 28° C and 78% Rh However, pupal weight was greater for insects reared on artificial diet ($\bar{x}$ 0 047g, SD 0 013) than for insects reared on maize ($\bar{x}$ 0 035g, SD 0 012) and *S obtusifolia* ($\bar{x}$ 0 028g, SD 0 008) Larvae developed through two generations in the laboratory, having been collected as larvae during the first field generation and reared in the labora tory under the environment described above Second generation pupae, in an apparent dormant state, were held for other laboratory studies

A taxonomic study of *M rogenhoferi* was completed This lepidopterous defoliator is a principal pest of sorghum and maize in many regions in Central America Whereas other insect species in the complex of defoliators on these grain crops have received taxonomic characterization, descriptive information of *M rogenhoferi* is lacking Given the importance of this insect pest in sorghum and maize production during the first crop growing season, a detail characterization of the species was considered to be a significant part of identifying aspects of integrated pest management associated with specific insect pests for the crop production systems

As only a partial description of the *M rogenhoferi* adult moth has been published since the original description of the species, the life stages of this important insect pest were described using illustrations and scanning electron microscope pictures of the egg, larva, pupa, and adult (♀ & ♂ genitalia) stages Comparative notes on host plants and geographical distribution of related species in the tribe Eustrotiin (Noctuidae) are presented

Publication for Scientific Community and for Practical Application

Collaborative research findings have been summarized and published in scientific journals of international recognition A popular article describing INTSORMIL entomological investigations on sorghum and maize in Honduras during the past 15 years is being published by the EAP This article has been prepared for farmer utilization and presents information on seasonal occurrence of the insect pests on sorghum and maize, biological and ecological relationships of the insects with weeds, and insect pest management practices, including land preparation, weed control, planting systems, crop resistance to insects, and chemical control recommendations, as well as benefits to farmers An economic analysis of on-farm insect management investigations has been completed An insect pest management system including delayed planting and delayed weed control and a single insecticide application at insect pest threshold level increased yields of sorghum and maize by 20% and 35%, respectively In years when grain yields and market prices are high, these crop production practices could return $ 2 9 million a year to the production area in southern Honduras Increased yields of both crops would improve diets and nutritional level of families Pictures and graphics are included in this popular article

Nicaragua

The PI traveled to Nicaragua in mid-1997 to establish collaborative research relationships with INTA and other agricultural organizations involved in sorghum production in that Country This trip was successful in identifying the interest of INTA, as well as academic/research institutions in collaborating with INTSORMIL now and in the future A collaborative agreement between INTA and INTSORMIL was signed in May 1998 A graduate student (EAP graduate and M S candidate at Mississippi State University, a Nicaraguan) traveled to the PCCMCA meeting in Nicaragua in April to discuss proposed research plans with collaborators at the EAP and INTA As the sorghum midge has been identified as the principal insect pest on sorghum in commercial production fields on the coastal plain, the MSU-205 project will concentrate in collaborative research on this pest constraint to production The student's research proposal has been accepted by MSU-205 collaborator scientists and research in Nicaragua is scheduled to begin in August Ing Laureano Pineda, sorghum breeder in INTA is the principal collaborator at this time in Nicaragua

Ethiopia

MSU-205 PI participated in the IAR-INTSORMIL Traveling Workshop in Ethiopia (and Eritria) in October of 1997 The PI had previously corresponded with the INTSORMIL/Horn of Africa Coordinator, Dr Gebisa Ejeta, Purdue University, and the IAR collaborator in Ethiopia, Mr Tsedeke Abate, in reviewing proposed entomological research programs for conduct in Ethiopia These programs involve 1) development of pest management strategies for sorghum stalk borers and panicle feeding insects emphasizing integration of cultural, chemical, and biological control tactics, and 2) economic impact of insect pests on sorghum production to be determined and value of management tactics to be assessed

The principal entomological research activities in Ethiopia will include studies on insect pest biology, ecology, behavior, dynamics and pest control using selective insecticides and/or cultural control tactics The principal insect pest constraints on sorghum include stalk borers, and panicle feeding head bugs Participation in this project during the next few years would extend MSU-205 research activities into East Africa (Greater Horn of Africa)

Efficacy of Insecticides Applied to Sorghum for Insect Pest Control

A select group of insecticides were evaluated for control of fall armyworm and sorghum midge on sorghum in northeastern Mississippi Insecticides were applied at various rates of application to plants in the various growth stages The efficacy of materials was recorded on armyworms in various instars to determine activity of the insecticides against larvae of various age classes Insecticides were applied once or twice for sorghum midge control, depending upon pest thresholds following the insecticide treatment This information is useful in providing recommendations for control of fall armyworm and sorghum midge on sorghum

Direction of graduate students in INTSORMIL program and travel

The PI directed the INTSORMIL research activities of four graduate students (M S degree candidates), coordinated thesis preparations, prepared papers for publication of INTSORMIL research in scientific journals, as well as popular articles, and traveled to Honduras Ethiopia and Nicaragua to work with collaborators and graduate students

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-205 Some financial support is provided annually to students for research expenses while in Honduras This support will continue with further participation in Honduras, and extension of MSU-205 activities into Nicaragua

Publications and Presentations

Journal Articles

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Striga Biotechnology Development and Technology Transfer

Project PRF-213

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Summary

Witchweeds (*Striga* spp) are obligate parasitic weeds of significant economic importance Control methods available to date have been costly and beyond the means of farmers in developing countries While combining several control measures may be necessary for eradication of *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance Our goal is to exploit the unique life cycle and parasitic traits of *Striga* especially the chemical signals required for germination, differentiation, and establishment

In year 19, we report on the results of an evaluation of a physiological basis of dormancy of *Striga* seeds We examined the effect of relative humidity in storage on the moisture content of *Striga* seeds and germination Seeds with moisture content of less than 10% at the start of conditioning, gave germination percentage of greater than 90% High moisture content and storage at high relative humidity resulted in low percent germination of *Striga* seeds We also found that prolonged conditioning resulting in wet dormancy decreased germination percentage of *Striga* seeds When these non-germinable seeds were then stored at 13% relative humidity, germination was increased suggesting that wet dormancy is a reversible event The evolution of CO_2, activity of ACC oxidase, and germination of *Striga* seeds decreased with high pre-conditioning moisture content We believe that these results from our study may have significant ramification on both *Striga* research as well as strategies for integrated control of *Striga*

Objectives, Production and Utilization Constraints

The overall objectives of our research are to further our understanding of the biological interactions between *Striga* and its hosts, and to devise control strategies based on host resistance In addressing our goal of developing sorghum cultivars that are resistant to *Striga*, we emphasize the vital roles of the multiple signals exchanged between the parasite and its hosts, which coordinate their life cycles To develop control strategies based on host-plant resistance, we employ integrated biotechnological approaches combining biochemistry, tissue culture, plant genetics and breeding, and molecular biology

Striga spp is an economically important parasites of sorghum, millets and other cereals in tropical Africa and Asia Yield losses of sorghum due to *Striga* infestation, coupled with poor soil fertility, low rainfall, and lack of production inputs, all contribute to survival difficulties for subsistence farmers Eradication of *Striga* has been difficult due to the unique adaptation of *Striga* to its environment and the complexity of the host-parasite relationship Suggested control measures including mechanical or chemical weeding, soil fumigation, nitrogen fertilization, have been costly and beyond the means of poor subsistence farmers Host plant resistance is probably the most feasible and potentially durable method for the control of *Striga* 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 and disrupt their interactions at each stage of the *Striga* life cycle The specific objectives of our collaborative research project are as follows

- To develop effective assays for resistance-conferring traits and screen breeding materials assembled in our *Striga* research program for these traits

- To elucidate basic mechanisms for *Striga* resistance in crop plants

- To combine genes for different mechanisms of resistance, using different biotechnological approaches, into elite widely adapted cultivars

- To test, demonstrate, and distribute (in cooperation with various public, private, and NGOs) elite *Striga* resistant cultivars to farmers and farm communities in *Striga* endemic areas

- To develop integrated *Striga* control strategies, with our LDC partners, to achieve a more effective control than is presently available

- To assess (both *ex ante* and *ex post*) of the adaptation and use of these control strategies, in cooperation with collaborating agricultural economists

- To train LDC collaborators in research methods, breeding approaches, and use of integrated *Striga* control methods and approaches

Research Approach and Project Output

Research Methods

Field evaluation of crops for *Striga* resistance has been slow and difficult, with only modest success Our research addresses the *Striga* problem as a series of interactions between the parasite and its hosts, with potential for intervention We recognize that successful *Striga* parasitism is dependent upon a series of chemical signals produced by its host

The working hypothesis is that an intricate relationship between the parasite and its hosts has evolved exchange of signals and that the interruption of one or more of these signals results in failed parasitism leading to possible development of a control strategy Our general approach has been to assemble suitable germplasm populations for potential sources of resistance, develop simple laboratory assays for screening of these germplasm, establish correspondence of our laboratory assay with field performance, establish mode of inheritance of putative resistance traits, and transfer gene sources into elite adapted cultivars using a variety of biotechnological means Whenever possible, the methods developed will be simple and rapid, in order to facilitate screening large numbers of entries

We place major emphasis on developing control strategies primarily based on host-plant resistance To this end we have in place, a very comprehensive *Striga* resistance breeding program in sorghum Over the last several years, we have generated and selected diverse and outstanding breeding progenies that combine *Striga* resistance with excellent agronomic and grain quality characteristics All previously known sources of resistance have been intercrossed with elite broadly adapted improved lines Almost all resistant sources ever recorded have been assembled and catalogued We undoubtedly have the largest, most elite and diverse *Striga* resistance germplasm pool, unmatched by any program anywhere in the world However, while all resistance sources have been introgressed to elite and most readily usable backgrounds, the only mechanism of resistance we have fully exploited has been the low production of germination signal We have not had the ability to screen for other mechanisms of resistance in the infection chain or the host-parasite interaction cycle Future emphasis, therefore, will be placed on developing additional effective methods for screening host plants for *Striga* resistance at stages in the parasitic life cycle beyond germination, including low production of haustorial initiation signal, failure to penetrate, hypersensitive reaction, incompatibility, or general cessation of growth after penetration Work is currently in progress on development of assays for some of the above stages of parasitic development

The wealth of germplasm already developed in this program also needs to be shared by collaborating national programs in *Striga* endemic areas of Africa To this end, we have organized international nurseries for distribution of our germplasm on a wider scale This will also serve as an effective way to network our *Striga* research with NARS that are not actively collaborating with INTSORMIL As we combine and confirm multiple mechanisms of resistance in selected genotypes, the efficiency and durability of these resistance mechanisms can be better understood through such a wide testing scheme

Furthermore, in cooperation with weed scientists and agronomists in various NARS, we plan to develop and test economically feasible and practicable integrated *Striga* control packages for testing on farmers' fields in selected countries in Africa While most INTSORMIL projects have been directed as bilateral collaborative ventures focusing on individual NARS, this *Striga* project is handled as a regional or more "global" program, because of the commonality of the *Striga* problem and because no other agency has the mandate or is better suited to do the job

Research Findings

Evaluation of the Physiological Basis of Dormancy of Striga Seeds

As a noxious parasitic weed of tropical cereals and legumes, *Striga* spp are *exquisitely* adapted to the climatic and edaphic condition of the areas where they have become en demic Because *Striga* seeds are small, resource depletion must be controlled during the events before host attachment when host resources become available Freshly harvested seeds of *Striga* will germinate in response to host-produced chemical stimuli, but only after the passage of time, (an-after ripening period), and exposure to moisture at a suitable temperature, (a conditioning period) However, dormant seeds are often unresponsive and may remain in the soil for decades and become sensitive to stimuli upon hydration and after-ripening A second dormancy is associated with prolonged hydration and is termed "wet dormancy " *Striga* specie have used these two states of dormancy to time the events associated with germination and establishment of parasitism

Striga seeds are small, with limited energy resources, the survival strategy of the seed could, therefore, be related to its moisture content Data on moisture content of *Striga* seed has not been reported in the literature, so it is not clear whether seed moisture content is related to dormancy The purpose of the *Striga* was therefore to establish the role of seed moisture content in the regulation of the after - ripening period To text for the effect of relative humidity on after-ripening, seeds were sealed into small glass containers above saturated of various salts selected because their vapor pressure create a range in relative humidity that changes little with temperature The moisture content and germination percentage of the seed were determined monthly over a six month period The effect of storage relative humidity on the moisture content of *Striga* seeds were examined at intervals after placing fresh harvested seeds in containers with specific relative humidity Seeds were placed in chambers having specific relative humidity of 6%, 14%, 33%, 75%, and 97% for 30, 60, 90 and 150 days The initial seed moisture was 14 7% The seeds were then conditioned and germination percentage, response to tetrazolium, and seed moisture contents were measured

Several interesting results were obtained In general, seeds at moisture content less than 10% at the start of conditioning had germination of greater than 93% Seeds at moisture content of over 10% at the start of conditioning could germinate between 60% and 3%, with germination decreasing as seed moisture content at the start of conditioning decreased The highest moisture content (17%) and lowest germination percentage (3%) occurred in seeds stored at 97% relative humidity for 150 days There was a high degree of correlation ($r^2 = 0\ 997$) between a positive tetrazolium color test and germination percentage, indicating that seeds having a positive tetrazolium response will germinate if provided with chemical stimulants Seeds brought to a low rate of germination, or which did not germinate after 30 days of storage at high relative humidity (91%), had a much less positive response to tetrazolium, even though initially they had nearly a 100% positive response Seeds with as little as 3% positive response to tetrazolium can be brought back to give a high percentage positive response if they are placed in a container with 6% or 13% relative humidity for 2-3 months The negative tetrazolium response was not due to loss in seed viability as previously reported, but we suggest that the tetrazolium test measure the ability to germinate in response to conditioning and was not strictly an indicator of viability

To examine the effect of prolonged conditioning (wet dormancy) and its reversibility, *Striga* seeds with a high rate of germinability were incubated in water for 16 weeks, and germination tests were run at four week intervals Prolonged conditioning decreased germination percentages from 96% to only 3% after 16 weeks of incubation in water When these non-germinable seeds were then stored at 13% relative humidity, germination increased from 3% to 92% after 16 weeks Storage at 5 5% relative humidity increased germination from 3% to 91% in 12 weeks In these circumstances, wet dormancy appears to be a reversible process

We believe that the results presented in this study have direct relevance to *Striga* research as well as control Our results may have ramification on the widely accepted application of ethylene gas in a *Striga* eradication program If seeds buried in the soil have a moisture content above the threshold, then application of ethylene will not cause suicidal germination One does not need to condition the seeds to observe readiness to germinate, but may only have to measure moisture content This information may also be used to manipulate the life cycle of the parasite for *Striga* control Pre-watering the soil in irrigated fields or delaying sowing dates under rainfed farming would ensure that *Striga* seed moisture content would increase and reduce germination and thus could be a strategy for an integrated approach to *Striga* control

International Testing of Striga Resistant Sorghum Selections

Over the last 10 years, an interdisciplinary research program on *Striga* resistance in sorghum has been conducted at Purdue University The findings we have made in basic biology and genetics of *Striga* resistance are continually being incorporated into our sorghum breeding program to generate breeding germplasm with good agronomic qualities, combined with varied mechanisms of resistance to *Striga* In order to allow selection of experimental varieties in a

Table 1 Results of INTSORMIL/Purdue International *Striga* Resistance Breeding Nursery, 1997

Pedigree	Yield (kg ha^{-1})				*Striga* COUNT (number of emerged *Striga* per 15m^2 plot)			
	Burkina Faso	Cameroon	Chad	Ethiopia	Burkina Faso	Cameroon	Chad	Ethiopia
P9401	238	145	1000	1691	3	32	4	11
P9402	133	117	1450	2267	7	57	13	243
P9403	288	247	1200	1567	10	60	6	66
P9404	238	273	1600	1378	2	106	3	805
P9405	263	210	1400	1786	13	41	4	154
P9406	258	170	1200	1246	5	67	11	75
P9407	206	339	1300	1798	8	70	20	94
P9408	313	323	750	780	6	10	20	106
(SRN39 × P954063)F15	275	415	750	1376	12	16	6	73
(IS9830 × SRN39) F14	331	367	950	1046	5	16	8	100
(SRN 39 × P954063)F14 (254)	350	310	1050	1736	17	93	14	325
(SRN 39 × P954063)F14 (259)	369	330	300	1907	2	1	12	210
(SRN 39 × P954063)F14 (269)	392	173	1050	2622	1	26	21	75
(SRN 39 × P954063)F14 (279)	294	272	900	1464	21	19	1	72
(SRN 39 × P954063)F14 (284)	306	340	750	1799	4	20	1	55
(Framida × SRN39)F12 (289)	269	272	1200	1830	13	11	93	55
(Framida × SRN39)F12 (299)	356	230	1000	1158	59	43	70	179
(N13 × SRN39)F14 (314)	444	285	650	1446	1	2	3	68
(N13 × SRN39)F14 (329)	256	357	1050	1367	5	10	54	518
(SRN39 × Dobbs)F12 (369)	308	243	950	1162	3	77	9	395
1988PP37 Selfed S9 (389)	325	359	600	1597	3	5	2	58
P954063	238	357	500	1355	5	14	10	328
HD 1	306	327	1150	806	24	59	495	858
SRN39	200	265	550	1786	8	36	35	32
Local variety	206	392	1450	1363	8	10	26	667
Mean	286	285	990	1533	10	36	38	225

field environment having *Striga* pressure, we rely on collaborators throughout Africa to establish an INTSORMIL International *Striga* Resistance Sorghum Nursery In 1997, we sent 25 entries to scientists in 12 African countries for field testing in *Striga*-sick plots Some data on yield and *Striga* count are presented from our 1997 trials (Table 1) Several experimental entries look promising, having both broad environmental adaptation and good resistance to *Striga* A second trial for the 1998 season is being conducted in 13 African locations International testing of sorghum germplasm from our breeding program provides mutually useful benefit to our *Striga* research program at Purdue and to collaborating scientists in developing countries In addition to providing a means of field testing resistant varieties, resulting from our breeding program, the INTSORMIL International *Striga* Resistant Sorghum Nursery serves as a vehicle for distributing germplasm to NARS in countries where *Striga* is an endemic problem

Networking Activities

Workshop and Program Reviews

Traveled to Eastern Africa to visit NARS in the region with INTSORMIL Director, Dr John Yohe and held discussions leading to the establishment of an INTSORMIL Regional Collaborative Research Program in the Horn of Africa, June, 1997

Served as chair of the organizing committee of an INTSORMIL/ Horn of Africa Traveling Workshop The week long traveling workshop was attended by three scientists from Kenya, two from Eritrea, one from Uganda, scientists from the Ethiopian Institute of Agricultural Research, four INTSORMIL principal investigators, and the Associate Program Director

Attended and participated in the 1997 World Food Prize Symposium, 16-17 October, 1997, Des Moines, Iowa

Served as Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research, June 1998

Participated in African Dissertation Internship Awards Selection, Rockefeller Foundation, November 1997 and April 1998

Attended the American Society of Agronomy National Meetings, Anaheim, California, October, 1997

Participated in Pioneer Hi-Bred In-house Review of Public/Private Plant Breeding Programs, April 1997, Des Moines, Iowa

Research Investigator Exchange

Interactions with public, private, and international sorghum research scientists continues to be an important function of PRF-207 The following individuals visited our program or worked in our laboratory during the project year

A large number of sorghum scientists from the U S and around the world visited our sorghum research program, field and laboratory facilities, on the way to and from the International Sorghum and Millet Genetic Conference in September, 1997

We were also visited by the new Director General of ICRISAT, Dr Shawki Barghouti, where current state of ICRISAT and future collaborative possibilities with Purdue were discussed

Germplasm Exchange

We continue to provide an array of sorghum germplasm from our breeding program to national research programs in developing countries Our germplasm is provided in either a formally organized nursery that is uniformly distributed to all collaborators that show interest or upon request by a national program of specific germplasm entries or groups from or germplasm pool Germplasm was distributed to cooperators in over 15 countries in 1997

Publications

Refereed Papers

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Rosenow D T G Ejeta, L E Clark M I Gilbert R G Henzell A K Borrell and R E Muchow 1997 Breeding for Pre and Post flowering drought Stress Resistance in Sorghum p 400 411 *In* Rosenow et al (eds) Proc International Conference on Genetic Improvement of Sorghum and Millet, 22-27 September Lubbock Texas

Andrews D J G Ejeta, M Gilbert, P Goswamy A Kumar A B Maunder K Porter K N Rai J F Rajewski B V Reddy W Stegmeier and B S Talukdar 1997 Breeding Hybrid Parents p 173 187 *In* Rosenow et al (eds) Proc International Conference on Genetic Improvement of Sorghum and Millet 22 27 September Lubbock, Texas

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House L R B N Verma, G Ejeta, B S Rana, I Kapran A B Obilana, and B V S Reddy 1997 Developing Countries Breeding and Potential of Hybrid Sorghum p 84 96 *In* Rosenow et al (eds) Proc International Conference on Genetic Improvement of Sorghum and Millet 22 27 September Lubbock Texas

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Butler L G G Ejeta A G Babiker and D E Hess 1997 *Striga* Host Relationships and Their Role in Defining Resistance p 490 504 In Rosenow et al (eds) Proceeding of the International Conference on Genetic Improvement of Sorghum and Pearl Millet 22 27 September Lubbock Texas

Axtell J D I Kapran Y Ibrahim G Ejeta, L House B Maunder and D Andrews 1997 Heterosis in Sorghum and Pearl Millet Paper presented at the International Conference on the Genetics and Exploitation of Heterosis in Crops CIMMYT Mexico

Published Abstracts

Kapran I J Axtell G Ejeta, and T Tyler 1997 Expression of Heterosis and Prospects for Marketing of Sorghum Hybrids in Niger Presented at the International Conference on the Genetics and Exploitation of Heterosis and in Crops CIMMYT Mexico

Invited Research Lectures

Ejeta G 1997 Strategies in breeding sorghum for stress tolerance Presented at the Summer Institute for Agricultural Research June 8 14 Univ of Wisconsin Madison

Ejeta G 1997 Interdisciplinary collaborative research in sorghum and millets Presented at the Greater Horn of Africa INTSORMIL Traveling Workshop Sept, 22 Oct 5 Nazret, Ethiopia

Ejeta G 1997 Response to the Sasakawa Global 2000 Program Presentation Presented at the 1997 World Food Prize Symposium Food Security and the Future of Sub Saharan Africa Oct 17 18 Des Moines Iowa

Ejeta, G 1997 Agricultural Research Population and Global Food Production Presented at the HOBY World Leadership Congress July 21 Purdue University West Lafayette Indiana

Ejeta, G 1997 Breeding for *Striga* Resistance in Sorghum Special Seminar Purdue University Dec 11 Purdue University West Lafayette Indiana

Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-224
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Summary

Collaboration with West Africa was enhanced through the training and work of Mr Kollo as a graduate student at Texas A&M University In concert with INRAN, Mr Kollo is conducting his research on factors affecting sorghum and millet stands and Acremonium wilt of sorghum in Niger during the current growing season Collaborative research on the reaction of sorghum to ergot were established in Puerto Rico, Honduras and in Mexico Current work by collaborators has defined a new and improved rating system, at least one possible source of host resistance development of sclerotia in the Americas and limited information on host reactions to the pathogen Our work on host resistance to head smut was inactive in 1998 but the populations and tools for mapping both genes for meristematic and non meristematic resistance are in place Populations of sorghum head smut can be separated from those attacking maize Unique differences between and within the genome of the fungus attacking maize and sorghum is reported Collaborative research on grain mold with ICRISAT was terminated but several antifungal proteins were cloned from hyperparasites that have the potential of being expressed in sorghum ovules

Research Objectives

Honduras

- Evaluation of sorghum lines and hybrids for reaction to ergot

India/ICRISAT

- Continue collaboration with ICRISAT on growing, distributing, and evaluating the International Sorghum Anthracnose Virulence Nursery
- Continue collaboration on ergot
- Begin a collaborative initiative on application of biotechnology for control of grain mold

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 in the Niger Sorghum Improvement Program, along with evaluation for resistance to head smut, Acremonium wilt, and anthracnose
- Summarize data on the survival of spores of the long smut pathogen
- Summarize data on a trial on the effect of different fertilization treatments on the incidence of *Striga hermonthica* in pearl millet
- Determine the role of nematodes in diseases of sorghum and 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 bio-technical methods
- Improve disease screening methods
- Study biology of sorghum pathogens and disease epidemiology as needed
- Organize, maintain, and distribute the international sorghum disease and pathogen identification nurseries in collaboration with ICRISAT, and with TAM-222 and TAM-228
- 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 collaborate 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 This includes the application of such technologies to manage ergot

Collaborative Research in Niger

During 1997 three trials were conducted in the sorghum growing areas of Konni in Niger on Acremonium wilt (*Acremonium strictum*) of sorghum

Effect of nematicide treatment on the development of Acremonium wilt (Prepared by A Issoufou Kollo)

This trial was conducted in hot spots at the research station at Konni and on a farmer's field at Guidan Ider, a village located 40 km from the research station The nematode population at planting time was estimated At the research station the nematode density was low, most of the plots did not have a detectable level of pathogenic nematodes At the farmer's field most of the plots were infested with *Pratylenchus spp* The number of larvae at planting time ranged from 0 to 200 individuals per liter At 45 days after planting the number of *Pratylenchus* spp ranged from 100 individual to more than 3,000 individuals per liter In that field all the plants developed Acremonium wilt symptoms and died before heading However the death of the plant was delayed by the application of both Carbofuran and Counter by at least two weeks The low effect of the nematicides could be explained by the lack of rains at the beginning of the cropping season The *Pratylenchus* species was identified as *P zea* At the research station, Acremonium wilt symptoms developed late in the season when the plants had reached their reproductive stage The correlation between disease incidence and grain yield was low but significant (correlation coefficient =-0 57)

Effect of Liming and Form of Nitrogen on Acremonium wilt of Sorghum

The lime was obtained from the cement plant of Malbaza located 70 km from the Konni research station The hybrid NAD-1 (MR732 × Tx623) which is highly susceptible to *A strictum* was used in this experiment Two levels of lime (2 and 0 t per ha ^{1}) were used Three forms of nitrogen (urea, calcium ammonium nitrate and manure) were used The control plots did not receive added nitrogen The incidence of Acremonium wilt and yield of sorghum as well as the yield components were measured

Disease developed late and the correlation between grain yield and disease incidence was not significantly different from zero The correlation coefficients between disease incidence and number of plants at one month after planting (-0 57) and at harvest (0 38) were significant The number of grain per head, but not the grain weight, was negatively affected by the disease incidence (correlation coefficient = -0 31, *P≤ 0 037)*

On an average, the application of lime improved the stand establishment In plots which received lime, the number of sorghum plants at one month after planting is at least 40% higher than in the number of plants in the control At 50 days after planting, disease was 2-4 times higher in plots treated with calcium ammonium nitrate or manure than in plots which have received urea or in control plots There was no interaction between lime and nitrogen Lime did not effect disease incidence

Grain yield, stover yield, number of grain per panicle, the interaction between lime and form of nitrogen was statistically significant (Tables 1 and 2) Grain weight was not significantly affected by the sources of nitrogen or by the application of lime

Effect of Plant Population and Nitrogen Fertilization on the Incidence of Acremonium wilt and Sorghum Yield

This experiment was conducted at the Konni Research station Two sorghum genotypes, the hybrid NAD-1 and Mota, which is a local landrace, were used Mota is resistant to *A strictum* while the hybrid is highly susceptible Three plant population densities were used 80,000, 120,000, and 160,000 plants per ha Four nitrogen levels were used 0, 30, 60 and 90 kg N/ha The nitrogen source was urea

The number of plants a month after planting, disease incidence, grain and stover yields, grain weight, and number of grain per panicle were measured

The analysis of variance showed that for disease incidence there was a highly significant difference between the cultivars There was no interaction among the factors (plant population and nitrogen levels) Nitrogen and plant population did not significantly affect Acremonium wilt incidence The correlation between disease incidence and grain yield is low but significant (r = -0 26, P ≤0 008) The disease reduced yield by substantially lowering the grain weight (r= -0 66, P≤ 0 0001)

Collaborative Research in Mali

Dr M Diourte returned to Mali and is beginning research this season We have made plans to continue work on the survival of inoculum of *Colletotrichum graminicola* in particular the survival of microsclerotia and their value as sources of inoculum in disease evaluation trials Dr Diourte has also requested perforated plastic bags for protecting sorghum heads from head bugs for evaluations of lines to grain mold The head bug/grain mold complex needs to be examined carefully both on and off the experiment stations

Collaborative Research in Honduras

In Honduras, Ing Jorge Moran inoculated the ergot pathogen onto sorghum lines proposed by W L Rooney This experiment was designed to determine the duration of receptibility of sorghum stigma to pollen and ergot spores The first experiment was conducted in Honduras and repeated in Mexico, Puerto Rico and College Station, TX in spring and summer, 1998 Common open pedigreed sorghum were compared as hybrids, as line, and in a four entry diallel Ing Jorge Moran is planning on using data from these trials for his Master's thesis There are significant differences among the lines in their reaction to ergot (see section on ergot research)

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

Table 1 The effect of lime and nitrogen source on sorghum yield (kg/plot)

Lime	No added N		Urea		CAN*		Manure	
(t ha ¹)	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
0	0 60	5 87	0 70	6 03	0 78	7 42	0 76	7 50
2	0 88	7 75	0 89	8 044	0 91	4 79	0 61	7 12

Grain yield cv = 12 69 / *P*≤ 0 030
Stover yield cv = 15 22 / *P≤ 0 012*
CAN= calcium ammonium nitrate

Table 2 Effect of lime and nitrogen sources on number of grain per head and number of plant harvested

Lime (t ha ¹)	Check	Urea	CAN	Manure
0	1757	1828	2043	1692
2	2356	2099	1976	1997

Number of grain cv = 11 48% *P≤ 0 038*
Number of plant harvested *cv = 15 43* *P≤ 0 073*
CAN= calcium ammonium nitrate

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

Recombinant inbred populations are being 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 Currently, W L Rooney and graduate students have made and are continuing to collaborate on the resistance and mapping to anthracnose We are continuing to develop near-isogenic lines of Tx430 and TAM428, each possessing downy mildew resistance from four different sources Two B-line populations of the cross (BTx623 * QL3 [India]) have been developed and are considered for release Both have resistance to the sorghum downy mildew and head smut pathogens Both populations are immune to maize dwarf mosaic virus Also, 40 A- and B-line pairs have been developed from the two B-line populations, and are under further evaluation Some of the B-lines have been crossed to BTx635 for grain quality improvement These are in the F_4 generation

Twenty-six sorghum lines were introduced during the past year from ICRISAT (grain mold resistance), Zambia and Zimbabwe as genetic stocks

Sorghum Head Smut

Approximately 1500 recombinant inbred lines were grown in Corpus Christi for evaluation to head smut in summer 1997 The data and lines have been summarized by Dr Ramasamy Perumal, a Rockefeller Foundation fellow who will finish the mapping of the resistance from TX635 This line possess both meristematic and non meristematic resistance In the field at Corpus Christi, both sources of resistance are expressed Consequently before mapping, the phenotypic differences between these resistances can be expressed through "artificial inoculation" of greenhouse grown plants Artificial inoculation bypasses non meristematic resistance when the appropriate isolate is used

Genetic Diversity of Sporisorium reilianum the Head Smut Pathogen of Sorghum and Maize (Prepared by H Torres)

The population structure of the sorghum head smut pathogen *Sporisorium reilianum* has been assessed Graduate student Heriberto Torres has developed nuclear DNA restriction fragment length polymorphisms (RFLPs) as genetic markers that he is using to characterize the genetic structure of nine field populations of *S reilianum* Three populations collected from the northern region of Tamaulipas Mexico [Rio Bravo (RbMx), Matamoros (MtMx), and San Fernando (SfMx)], four from Texas [Corpus Christi (CoCr), Beeville (Beev), Danevang (Dane), and Taylor (Tayl)], and two from Niger, in West Africa [Konni (Koni), and Tillabery (Tbry)] were studied with the anonymous probes developed Seven RFLP loci were used to measure the gene and genotypic diversity of these populations About 50 isolates from each population were collected in a hierarchical grid of 10 x 10

The preliminary results show that low levels of genetic diversity were detected in the nine populations studied The seven populations from the Western Hemisphere shared the majority of frequent alleles at a number of loci Other alleles were present in the African populations On an average, 12 5 different multilocus genotypes (MLGTs) were present per population studied Danevang in central Texas had only six different MLGTs while Konni in Niger was the population with the highest number of different MLGPs with 23

Genotypic diversity was moderately high with a value of 6 16 In total, fifty-three MLGPs were identified The two African populations had 30 MLGPs that were not present in the Mexican and U S populations We found more MLGTs in Africa, most likely the center of origin of *S reilianum* In spite of that, the gene and genotypic diversity was still low for this sexually reproducing organism

The low number of polymorphic probes detected and the low gene diversity found in the populations studied suggest that in nature, the sister sporidia intermate during the sexual cycle leading to high levels of inbreeding Similarly, inbreeding has also been reported in other smut fungi like *Tilletia* species On the other hand, high diversity of the b mating type locus in the common corn smut pathogen *Ustilago maydis* suggests that *U maydis* populations are largely outbreeding

Sorghum Anthracnose/Sorghum Leaf Blight

Dr K Boora completed his work on mapping of anthracnose and leaf blight resistance in January, 1996 and he returned to Texas A&M University on a Rockefeller Foundation scholarship to continue preparing his work for publication in 1997 - 1998 The study on mapping of resistance to anthracnose by Dr Boora is in press The inheritance of resistance study by Mr Curtis Wiltze was submitted for publication

Other Collaborative Research

Ergot

In 1995, sorghum ergot caused by *Claviceps africana* was found in Brazil In 1995 and 1996, the pathogen spread throughout Latin America Finally, the disease reached South Texas in March of 1997 and then the pathogen spread to Nebraska by September, 1997 Several major projects were developed with funding by INTSORMIL, ICRISAT, USDA/ARS and the Texas Agricultural Experiment Station (TAES) As part of this program, Dr Ranajit Bandyopadhyay (ICRISAT, Senior Plant Pathologist) was hired to work in Puerto Rico during the Winter of 1998 and in Texas through the end of the growing season This program, jointly funded by TAES and the USDA began with the cooperative evaluation of sorghum lines and hybrids for reaction to ergot In these studies, an improved method of scoring the disease has been developed

Host-plant Resistance to Ergot (Prepared by Dr R Bandyopadhyay and J Dahlberg)

In the past, qualitative and quantitative ergot evaluation methods and artificial inoculation techniques have been used to screen germplasm for resistance to ergot in both the field and the greenhouse However, quantitative assessment requires counting the number of infected spikelets, and visual ratings have been traditionally based on an estimate of the percent infected spikelets Quantitative assessment is costly and time consuming, while the percent visual rating can be misleading In research conducted in Puerto Rico, a dual ranking system was developed that takes into account both percent incidence and a disease severity rating of each accession This resistance evaluation is rapid, simple and efficient for routine screening of large numbers of breeding lines and germplasm over several locations and years in replicated trials

Vulnerability of commonly used sorghum hybrids and seed parents to ergot in the U S is not known since ergot is a new disease in the Americas In collaboration with W L Rooney, 12 commonly used A/B line pairs and 12 popular R-lines were evaluated for ergot reaction in Puerto Rico in several sowing dates In addition, several sources of resistance reported in the literature were also evaluated None of the A/B and R-lines were free from ergot though various degrees of susceptibility were observed In general, A-lines were most susceptible, as expected and R-lines were more susceptible than the B-lines with respect to ergot incidence and severity Within A-lines, ATx631 was most susceptible to ergot, whereas ATx2752 and AOK11 were less susceptible The newer releases of A/B-lines, such as A/BTx631, A/BTx635, and A/BTx626 were significantly more susceptible than older releases such as A/BTx2752 and A/BTx378 R-lines varied considerably in their vulnerability to ergot In general, R-lines with good pollen shed and seed set tended to be less susceptible to ergot This was, however, not the case for RTx2737, one of the more popular R-lines currently used in the sorghum industry RTx2737 is an excellent pollen-shedder, but is almost as susceptible as the A-lines Further observations showed that stigma emerge from flowers of RTx2737 at least 2-3 days before anthesis, thus providing a three day period in which the ergot pathogen may have an advantage for infection The A/B-line and R-line evaluation for ergot reaction is also currently underway in College Station and Corpus Christi, Texas

The resistant sources tested in Puerto Rico were from suggested accessions from ICRISAT and had been previously tested in the highlands of eastern Africa The accession E62 from Uganda showed the greatest potential for use in a host-plant resistance strategy to manage the disease It had low ergot, and when crossed to A_3 cytoplasm source, it showed low level of ergot in a sterile background This line is being widely distributed for use in several public and private breeding programs

Currently, studies are continuing on examining the role of flowering biology on ergot susceptibility In addition, a set of 96 hybrids marketed by private seed companies are being tested for their reaction to ergot

Microcyclic Sporulation in Claviceps africana (Prepared by Dr R Bandyopadhyay)

Sphacelia of the ergot fungus produces a sweet and sticky honeydew in which macroconidia of the fungus are released Under humid conditions, the macroconidia in the honeydew germinate to form sterigmata that extends outside the honeydew surface At the tip of the sterigmata, secondary conidia are formed that can be disseminated by wind and infect stigma of unfertilized ovary It was generally believed that macroconidia and secondary conidia, once disseminated from honeydew, have to deposit on stigma to infect flowers However, it has been observed by breeders that panicles bagged prior to flowering during selfing and crossing operations are often infected by the ergot pathogen although the stigmas were not exposed to the inoculum before covering the panicle with the bag In a series of experiments, we found that under humid and wet conditions, macroconidia on leaf and glume surfaces can germinate to produce secondary conidia These secondary conidia can germinate again to produce tertiary conidia within 24 hours if they do not encounter stigma At least four cycles of such repetitive sporulation have been observed under controlled conditions Conidia from any of these repetitive cycles can cause infection once they get in contact with stigma Indeed, our controlled inoculation and microscopy studies have shown infection by secondary conidia in flowers of plants sprayed with a macroconidia suspension only on the foliage Similarly, flowers with unexposed stigma at the time of inoculation were found to be infected by secondary conidia

These observations suggest that the sorghum ergot pathogen has tremendous versatility to repetitively produce wind-disseminable spores to offset the handicap posed to it by the short window of infection (stigma emergence to fertilization) It also implies that in an ergot favorable environment, a through spray coverage with a fungicide is necessary to kill ergot spores on plant surfaces for obtaining good control of the disease

A Global Conference on sorghum ergot was jointly prepared with INTSORMIL at Corpus Christi, TX June 25-26, 1998 The proceedings in part are already published on line See http //www ars-grin gov/may/sorghum html

Manipulation of Grain Mold Resistance Genes in Sorghum (Prepared by Dr Y Cui)

Grain mold is a serious problem in many sorghum regions of the world Grain molding reduces seed germination, but more significantly, where sorghum is used as a food source, both grain quality and appearance are diminished Despite extensive breeding efforts, relatively little progress has been made in improving sorghum grain mold resistance Geneticists and breeders have identified several quantitative traits that affect and enhance grain mold resistance For example, the presence of a pigmented testa is a significant source for grain mold resistance, but the high concentration of tannins present in a pigmented testa makes this method of control unacceptable because tannins lower digestibility of the seed

While no single gene trait that can confer universal resistance to grain mold, several genes have been identified that play a role in defending plants against a broad range of fungal pathogens Such proteins, referred to as antifungal proteins (AFPs), include chitinases and β-glucanases, enzymes that degrade the major structural components of fungal cell walls (i e chitin and β-glucan polymers) The action of these enzymes on intact fungi can result in cell lysis and death Other AFPs include sormatin, a protein that alters fungal membrane permeability and ribosome-inhibiting proteins (RIPs) that inhibit translation of fungal ribosomes Over-expression or more effective forms of these proteins may help to control fungal ingress

In this project, we will identify, tag, and clone sorghum genes that express antifungal proteins This information will give us the potential to enhance resistance to grain mold by creating cultivars with an improved combination of alleles through marker-assisted selection

Results

Molded sorghum seeds, which were harvested from the field of College Station, TX in 1997, were inoculated at PCNB medium and were incubated at room temperature and in a 37°C incubator respectively The fungus *Fusarium moniliforme* has been isolated and identified from the plates incubated at room temperature, while *Curvularia lunata* was recovered from seed incubated at 37°C Inhibition of the growth of these *F moniliforme* and *C lunata* isolates by *Trichoderma virens* was tested on minimal and PDA media The growth inhibitory effect of *T virens* appears to be very significant on both media and to both fungi

Seven distinct chitinases and three β-glucanase genes have been cloned from *Trichoderma virens* in Dr Doug Cook's lab at Texas A&M University So far, four cDNA clones (chit-1, chit-2, chit-4 and chit-5) have been made The pET protein overexpression system has been set up and the four chitinase cDNAs have been treated to make them ready for cloning A ligation independent cloning method has been used successfully for transferring the cDNAs into the pET vector We have adjusted the cloning and transformation parameters The third try is underway We are expecting the expressed protein can be obtained within the next few weeks, and then will test the individual proteins for activity against the grain mold fungi

Networking Activities

Conferences

R Frederiksen made several trips regarding ergot September, 1997 to Washington D C where he presented the current status of the work on ergot and anticipated funding needs for the program in 1998 Frederiksen also traveled to Washington in April, 1998 to meet with EPA, USDA and others to present the status of ergot and various research programs on the disease

Research Information Exchange

Dr Frederiksen also reviewed the sorghum downy mildew collaboration with Egyptian counter parts in October, 1997

Issoufou Kollo and Heriberto Torres went to Niger in October, 1997 Mr Kollo collected data from his many National Trials on sorghum and millet research and Mr Torres collected head smut specimens for his research on population biology of the organism

During the year, R Frederiksen served as a member of the Editorial Advisory Board of the African Crop Science Journal

Other Cooperating Scientists

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

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

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

Publications and Presentations

Journal Articles

Boora, K S R A Frederiksen and C W Magill 1998 DNA based markers for a recessive gene conferring anthracnose resistance in sorghum Crop Science In Press

Hanson L A B Bailey R A Frederiksen J D Smith and C W Magill 1997 Early events in the interaction between maize and southern rust Maydica 42 339 346

Morris S W B Vernooij S Titatarn M Starrett S Thomas C C Wiltse R A Frederiksen A Bhandhufalck S Hulbert and S Uknes 1998 Induced resistance responses in maize MPMI 11 643 657

Osorio J A and R A Frederiksen 1998 Development of an infection assay for *Sporisorium reilianum* the head smut pathogen on sorghum Plant Disease In Press

Rosewich U L R E Pettway B A McDonald R R Duncan and R A Frederiksen 1998 Genetic structure and temporal dynamics of a *Colletotrichum graminicola* population in a sorghum disease nursery Phytopathology In Press

Tenkouano A F R Miller R A Frederiksen and R L Nicholson 1998 Ontogenetic characteristics of resistance to foliar anthracnose in Sorghum African Crop Science Journal In Press

Miscellaneous Publications

Frederiksen R A 1997 Sorghum ergot so now what? Proceedings U S Conference on Sorghum Ergot June 11 1997 Amarillo TX National Grain Sorghum Producers P O Box 530 Abernathy TX 79311

Insect Pest Management Strategies for Sustainable Sorghum Production

Project TAM-225

George L Teetes
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Dr Richard A Frederiksen, Professor/Plant Pathologist, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843-2132

Summary

The Principal Investigator (PI) traveled to Mali during this reporting period and completed two important activities Segregating populations of sorghums resistant and susceptible to panicle-feeding bugs were evaluated for RFLP research A new variety of sorghum developed by IER breeders was evaluated for bug damage in Malian farmers' fields A Malian Ph D student's manuscript entitled, *Floret Morphology of Sorghum Midge-Resistant Sorghum* was published and one entitled, *Spikelet Flowering Time Cause of Sorghum Resistance to Sorghum Midge (Diptera Cecidomyiidae)* was accepted for publication in refereed entomology journals Greenbug- and sorghum midge-resistant sorghum lines and hybrids were evaluated for resistance in collaboration with Dr Gary Peterson (TAM-223) Insect-resistant sorghum genotypes were advanced in crosses with elite germplasm Several new sorghum midge-resistant parental A- and R-lines were evaluated for release to commercial seed companies Experimental sorghum midge-resistant hybrid sorghums were evaluated and results were published Greenbug biotype I and K parental lines were evaluated for release Experiments identified insecticides effective against sorghum midge, panicle caterpillars, and stink bugs and results were published Dissertation research on molecular analysis of greenbug resistance in sorghum and other Poaceaeous host plants was completed and drafts of two manuscripts were prepared for publication Efforts were made to assess genetic diversity among populations of greenbug Extraction protocols were modified to produce suitable restriction enzyme digestion of greenbug DNA Multiple Southern blots were completed, autoradiograms produced, and numerous probes used to determine probe-enzyme combinations that show RFLPs suitable for screening natural populations of greenbug Dissertation research on failure of a corn-sorghum rotation scheme to reduce abundance of Mexican corn rootworm in corn grown after sorghum was completed and one manuscript was prepared and two others are planned Education programs were directed of two graduate students, one Malian and one Nigerian, conducting research in Niger

Objectives, Production and Utilization Constraints

Objectives

Mali

- Long-term objectives are to collaborate with IER/Malian scientists to develop integrated pest management (IPM) strategies for sorghum insect pests, especially panicle-feeding bugs and sorghum midge, attacking traditional and improved insect-resistant and susceptible sorghums To achieve these long-term goals requires increased entomological research efforts in farmers' sorghum fields The reporting period objectives were to (1) substantiate, for use by sorghum breeders, the most reliable and efficient method to protect sorghum panicles from panicle-feeding bugs so resistance can be assessed by comparing protected with naturally infested panicles, (2) determine the role of insects and pathogens in kernel deterioration by applying different combinations of insecticides and fungicides, and (3) assess the importance of panicle-feeding bugs and sorghum midge on traditional and improved sorghum varieties in farmers' fields

U S

- Long-term objectives are to collaborate with Texas A&M University sorghum breeders and molecular biologists to develop, evaluate, and deploy sorghums resistant to sorghum midge, greenbug, and yellow sugarcane aphid, assess density/damage relationships, determine mechanisms and causes of resistance, and identify the role of insect-resistant sorghums in IPM, and apply biotechnology to increase resistance durability by understanding the genetic relationship of insects and resistant plants Reporting period objectives were to (1) conduct field and greenhouse experiments to evaluate sorghums resistant to greenbug, sorghum midge, and yellow sugarcane aphid, and (2) supervise graduate student research Graduate students supervised are 1) U S Ph D student using RFLP technology to assess genetics of greenbug resistance in sorghum, 2) U S Ph D student using RFLP/RAPD technology to assess genetic variability of greenbug and its biotypes, 3) U S Ph D student assessing the role of sorghum in population dynamics of Mexican corn rootworm, 4) M S student from Niger researching field biology and laboratory life table assessment of millet head miner in Niger (committee co-chair), and 5) Ph D student from Mali studying natural mortality of the millet head miner in Niger (committee co-chair) Participate in Entomological Society of America, International Plant Resistance to Insects Workshop, Consortium for International Crop Protection, CRSP, and other professional and scientific activities and meetings

Constraints

Mali

Insect pests especially panicle-feeding bugs are constraints to deploying improved non-photoperiod sensitive, compact-panicle sorghum varieties that yield more than traditionally grown, local varieties Resolution of the interrelationship of damage by bugs, infection by pathogens, and reduction in grain yield and quality requires an interdisciplinary, team approach Damage by bugs is exacerbated by pathogen infection that significantly increases in damaged kernels Damage by bugs and infection by pathogens dramatically reduce grain yield and quality and render the grain unusable for human consumption Other insect pests might occur when agronomic practices are changed and new sorghum varieties are used

U S

There is increasing human opposition to use of pesticides in the U S Although insecticides are readily available and lessen the yield-reducing impact of insect pests, they 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 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 IPM approach However, development of these cultivars requires a holistic approach including identification of insect resistance genes, incorporation of the resistance into agronomically elite hybrids, extensive evaluation, and deployment into production systems Much research is needed on the role these cultivars play in an IPM program so that research progresses and farmers readily accept resistant cultivars as part of an IPM approach

Research Approach and Project Output

Three primary methods are used to achieve project output – collaboration/partnering, graduate student education, and technology development Project outputs are divided into these research approaches

Collaboration

Collaborative Sorghum Panicle-feeding Bug Research in Mali

The PI traveled to Mali during November of this reporting period to evaluate for RFLP research segregating populations of sorghum resistant and susceptible to panicle-feeding bugs and to evaluate for insect damage in Malian farmers' fields an improved sorghum variety developed by IER breeders These activities were carried out in collaboration with Dr Niamoye Diarisso, a recent Texas A&M University Ph D graduate under the direction of the PI Other IER and U S /INTSORMIL scientists collaborating in these activities included Dr Aboubacar Toure IER sorghum breeder, Dr Alain Ratnadass, CIRAD/ICRISAT entomologist, and Drs Gary Peterson and Darrell Rosenow, Texas A&M University/INTSORMIL sorghum breeders The fact that Dr Diarisso traveled and worked with the PI while he was in Mali is indicative of her commitment to collaborative research because she had returned to Mali in June and had yet to be assigned a research position Two sorghum trials designed to evaluate segregating populations of sorghum for resistance to panicle-feeding bugs were planted at three locations, Sotuba, Samanko, and Cinzana The research is part of the Rockefeller Foundation-supported postdoctoral program of Dr Aboubacar Toure The rating scale used was developed through collaborative research between IER, INTSORMIL, and ICRISAT breeding/entomology programs Seed samples obtained in 1996 with varying degrees of bug damage were used as standards to rate entries in all trials The PI and Dr Diarisso with Dr Tom Crawford, INTSORMIL Associate Program Director, and Dr Jerry Maranville, INTSORMIL PI, met with World Vision personnel near Cinzana to review a collaborative technology transfer project between IER, INTSORMIL, Bean/Cowpea CRSP, and World Vision A new sorghum variety developed through IER/INTSORMIL collaboration was grown by local farmers in a World Vision project The variety yielded well, and farmers recognized the potential The variety commonly has weak peduncles that break easily However, insect damage to local, traditional varieties and the new variety was absent In other locales and trials where non-photosensitive sorghums with compact panicles were grown, damage by panicle-feeding bugs was severe Collaboration between IER and INTSORMIL scientists and World Vision should be continued

After Dr Diarisso's assignment to a research position at Sotuba, much effort was made to develop future collaborative research plans Drafts of these research plans have been shared and revised Research workplans will be submitted to IER administration Also, the PI believes it very important that IER scientists who have direct collaborative research efforts with INTSORMIL scientists should receive funding from the INTSORMIL country budget This funding process has been discussed with INTSORMIL and IER country project leaders

Technology Development

Following are summaries of results of research that support international research collaboration, especially with regard to evaluating sorghum midge- and aphid-resistant sorghums, and research projects of graduate students associated with INTSORMIL Research efforts of TAM-225 are in collaboration with TAM-223, the project of Dr Gary Peterson, Sorghum Breeder at the Texas A&M University Agricultural Research and Extension Center at Lubbock

In collaboration with TAM-223, standard, annual evaluations of sorghum midge-resistant lines and hybrids were conducted during 1997 at Corpus Christi and College Station Resistance to sorghum midge of 52 hybrids (43 resistant × resistant experimental hybrids, 3 resistant × resistant checks, 1 resistant × susceptible check, and 5 susceptible checks) was evaluated Susceptible sorghum planted three weeks early adjacent to the experimental area provided a source of sorghum midge to infest the experimental sorghums At Corpus Christi, seeds of the experimental sorghums were planted 8 April in 6-m-long plots, with 97 6 cm between rows Sorghum was planted at College Station 8 May, with 76 2 cm between rows Damage caused by sorghum midge and grain yield (kg ha ^{1}) were compared between experimental hybrids and checks Sorghum at physiological maturity was rated by plot for sorghum midge damage based on a scale of 1 = 1-10, to 9 = 81-100% of kernels that failed to develop Sorghum panicles from 0 0025 ha per plot were hand harvested Threshed grain weight (g) was converted to kg ha ^{1} to obtain grain yield ANOVA and $LSD_{0\ 05}$ were used for data analysis and mean separation, respectively

Although differences were not always significant between experimental hybrids and resistant × resistant checks, most experimental hybrids were significantly less damaged by sorghum midge and produced significantly more grain within and over locations than susceptible × susceptible checks Sorghum at Corpus Christi was damaged significantly more by sorghum midge (5 2 vs 3 0 rating) and yielded less grain (1,492 vs 5 563 kg ha ^{1}) than at College Station Hybrids that performed well under high sorghum midge abundance (Corpus Christi) also performed well under moderate abundance (College Station) Female parental lines designated ATx639, ATx640, and ATx641 have consistently performed well for the past five years and were released recently to private industry Hybrids from these female parents had 1 9 and 4 1 damage rating scores and yielded 7,035 and 2,195 kg ha ^{1} at College Station and Corpus Christi, respectively Hybrids with female parent A94 are being evaluated for commercial release Hybrids produced from lines designated A94-6, A94-7, or A94-15 were rated 1 7 and 3 4 and yielded 6,397 and 2,157 kg ha ^{1} at College Station and Corpus Christi, respectively By comparison, susceptible × susceptible checks were rated 6 5 and 9 0 and yielded only 2,183 and 186 kg ha^{1} at College Station and Corpus Christi, respectively Data indicated that when planted late, many sorghum midge-resistant hybrids yield significantly more grain without the use of insecticide than do susceptible hybrids

Numerous sorghum lines developed through project TAM-223 and in the process of being selected as parental lines for release and use in hybrids were evaluated for resistance to biotype I and K greenbug in greenhouse experiments Several of these lines possessed high levels of resistance to biotype I greenbug and moderate levels of resistance to biotype K Approximately 50 sorghum lines from Cargill Seed Company were evaluated for resistance to biotype I and K greenbug Results indicate that both INTSORMIL scientists and the commercial seed industry are making good progress in developing hybrids resistant to greenbug biotypes I and K Details of results of these evaluations are not presented here because of space limitations However, sufficient progress is being made to conclude that sorghum lines resistant to these new greenbug biotypes will be released in the near future Agronomic data required for release and registration are being collected Greenbug biotype I and K resistant lines are agronomically diverse For example, some are tan plants with red kernels and tan glumes These lines will be valuable to the sorghum seed industry both for these agronomic characters and resistance to greenbug

Asana XL 0 66E, Baythroid 2E, Beauveria bassiana, Curacron 8E, Decis 1 5E, Diazinon 2E, FCR 4545 1E and 125 F, Karate 1E, Lorsban 4E, Phaser 3E, Sevin 80S, and TD 2344 0 83E were evaluated for control of sorghum midge in plots near College Station Sorghum midge abundance ranged from 7 0 adults per panicle before the first application to 1 4 per panicle before the third and final application Based on visual ratings of damage on a scale of 1-9, where 1 = 1-10 to 9 = 81-90% kernels destroyed per panicle, treated sorghum was damaged significantly less than non-treated sorghum Damage ranged from 2 75 with Baythroid, Decis 1 5E, Lorsban 4E, and Phaser 3E to 5 5 in the non-treated plot Highest yield, 6,086 pounds per acre, resulted from sorghum treated with Baythroid, but no significant yield differences were found among the pyrethroid treatments The non-treated plot yielded only 4,322 pounds per acre

Baythroid 2E, Curacron 8E, Decis 1 5E, FCR 4545 1E, Karate 1E, Lorsban 4E, Parathion 8E, Phaser 3E, Sevin 80S, and TD 2344 0 83E were evaluated for control of rice stink bug, corn earworm, fall armyworm, and sorghum webworm near College Station Insect abundance was assessed by using the "beat-bucket" technique

Abundance of rice stink bugs averaged 1 1 nymphs and adults per panicle in all plots before insecticide application Treated sorghum contained significantly fewer stink bugs than non-treated sorghum One day after treatment, stink bug abundance ranged from 0 03 per panicle with Decis (98% control) to 1 4 in non-treated sorghum Pyrethroid insecticides, Parathion, and Phaser most effectively and about equally controlled stink bugs Application of Curacron, Sevin, and Lorsban reduced rice stink bug abundance by less than 50% Three days after treatment, rice stink bug abundance on sorghum panicles treated with any of the insecticides (range of 0 3 rice stink bugs on panicles treated with FCR 4545 1E to 1 4 per panicle treated with Lorsban) was significantly less than on non-treated sorghum (2 1 rice stink bugs per panicle) Percentage of control was less at three than at one day after treatment In general, pyrethroid insecticides best controlled rice stink bug three days after treatment

Abundance of caterpillars before insecticide application averaged less than one per panicle One day after treatment numbers of panicle caterpillars on sorghum treated with pyrethroid insecticides Sevin, and Phaser (range of 0 03 to 0 18 per panicle, 61-94% control) were less than the number on non-treated sorghum (0 4 per panicle) Caterpillar abundance on panicles treated with Parathion (0 3 per panicle), Curacron (0 2), and Lorsban (0 4) was not significantly lower than on panicles of non-treated sorghum (0 4 per panicle) Reductions in caterpillar numbers and percentages of control were similar at three as at one day after treatment In general, pyrethroid insecticides provided superior control (67-100%) of panicle caterpillars three days after treatment

In 1997, much valuable integrated pest management information was obtained from responses to a six-page "Questionnaire on Insect IPM of Grain Sorghum" mailed to 739 members of the Texas Grain Sorghum Association The results of the survey indicated that 55% of sorghum growers considered themselves IPM users, but based on very stringent criteria of multiple management-tactic use, 87 4% of sorghum growers are IPM users IPM evaluation and impact is a continuing activity of TAM-225 With a grant from the Texas Pest Management Association and the Texas Department of Agriculture, an activity is underway to determine the impact of IPM and develop methodology to evaluate IPM contributions and success in Texas

Graduate Student Research

Molecular Analysis of Greenbug Resistance in Sorghum and Other Poaceaeous Host Plants

Four F_3 populations of sorghum were used to identify RFLP markers diagnostic of resistance to greenbug biotypes C, E, I, and/or K A complete RFLP map of sorghum (Chittenden et al 1994) was used to identify DNA markers to scan the sorghum genome at 20-cM intervals Nine greenbug resistance loci on eight linkage groups were identified In most cases, sorghum resistance was additive or incompletely dominant Several digenic interactions were identified In each case, these non-additive interactions accounted for a greater portion of the resistance phenotype than did independently acting loci Resistance to greenbug had previously been assigned to Triticeae homeologous groups 1 and 7 (Hollenhorst and Joppa 1983) Greenbug-resistant and susceptible near-isogenic barley lines were assigned to represent the Triticeae genome Conserved cDNA markers mapping to homeologous groups 1 and 7 were utilized to directly target potential orthologous regions in sorghum and barley In two cases, the same markers co-segregating for greenbug resistance in sorghum co-segregated for greenbug resistance in barley Moreover, Triticeae crops have resistance genes at locations that approximately correspond to some of the sorghum genes, possibly suggesting that similar resistance mechanisms have been applied repeatedly Where Triticeae crops are rotated frequently with sorghum, traditional rotation may merely be challenging the greenbug with a series of related genes Use of greenbug resistance genes in improved cultivars of divergent crops may help to better manage and more effectively preserve the integrity of gene rotation strategies Further, the large epistatic component of greenbug resistance in exotic sorghums versus the relatively simple inheritance of improved cultivars suggests a need for accelerated efforts to introgress exotic genes into cultivated germplasm to further support resistance durability The information obtained from these experiments will help determine whether resistance to greenbug is conferred by orthologous genes, modified by genetic background, or conferred by completely unrelated genes

Use of RFLP to Characterize Genetic Diversity of Natural Populations of Greenbug

Previously developed probes were radiolabeled via nick translation and hybridized to screening blots yielding autoradiograms During the probe screening process, greenbug was found to have very low levels of polymorphism Low levels of polymorphism require screening more probes to find probes that show useful polymorphisms A new greenbug genomic library was constructed New probes were made from the library These probes continue to be used in the probe screening process

Portions of the 16S rRNA and Cytochrome Oxidase II (CO II) genes have been PCR amplified from the mitochondrial genome of greenbug biotypes C, E, I, K and two outgroups The nucleotide sequence of these amplified genes has been determined Preliminary phylogenetic analysis of greenbug biotypes has been performed using these DNA sequences

Failure of Sorghum in Rotation with Corn to Manage Mexican Corn Rootworm

Mexican corn rootworm, *Diabrotica virgifera zeae* Krysan & Smith, adults lay eggs in the soil of corn fields during the summer Eggs overwinter in the soil and hatch in the spring Larvae then feed on the roots of corn plants, causing plant lodging and yield loss Together with northern corn rootworm, *D barberi* Smith & Lawrence, and western corn rootworm, *D virgifera virgifera* LeConte, these pests have been estimated to cost $1 billion annually in yield losses and control costs Sorghum has played an important role in management of Mexican corn rootworm in Texas Because larvae can survive only on the roots of corn and a few grass species, annual rotation of corn with sorghum terminates the life cycle of corn rootworm Corn planted in the season following sorghum should be free of damage by corn rootworm larvae Recent reports, however, have linked Mexican corn rootworm to damage to corn planted the season following sorghum Similar reports have surfaced in the Midwest where soybeans were rotated with corn to manage northern corn rootworm and, most recently, western corn rootworm Without crop rotation, these pests must be managed using soil insecticide Soil insecticide application typically reduces by about 50% the number of larvae surviving to adulthood This level of suppression, however, is not sufficient to prevent the need for soil insecticide the following season Experiments were conducted in Bell County, TX to determine factors contributing to failure of crop rotation using sorghum to prevent damage by Mexican corn rootworm to corn

Factors that could reduce the effectiveness of crop rotation include prolonged diapause of corn rootworm eggs, development by larvae of an ability to survive on roots of sorghum, and oviposition by adults in sorghum fields In some areas of the Midwest, as much as 51% of northern corn rootworm eggs sampled remained in diapause for two years A two-year egg diapause allows eggs to remain dormant while a non-host crop is growing These eggs hatch when corn is replanted Mexican corn rootworm eggs sampled from Bell County did not exhibit prolonged egg diapause Eggs began hatching 269 days after oviposition, and 90% had hatched 280 days after oviposition

Traps to capture Mexican corn rootworm adults emerging from the soil were placed over corn and sorghum plants Capture of adults in these traps indicates the level of survival by larvae on the roots of each of the plant species Survival by Mexican corn rootworm larvae on sorghum was 3 0-11 2% of that from corn This suggests that survival by larvae on the roots of sorghum was not a significant factor in the failure of crop rotation to prevent damage by Mexican corn rootworm to corn In 1997, larval survival measured on cotton, soybeans, and Texas panicum was 2 0, 1 6, and 0 5% of that on sorghum

Mexican corn rootworm oviposition in sorghum did not differ significantly from that in corn An average of 1 egg per liter of soil was found in sorghum compared to 1 7 eggs per liter of soil in corn In 1997, oviposition was measured in corn, sorghum, cotton, soybeans, and Texas panicum Again, there was no significant difference in oviposition in sorghum and that in corn However, oviposition in cotton, soybeans, and Texas panicum was significantly lower than that in corn Average numbers of eggs per 0 5 liter of soil in corn, sorghum, cotton, soybeans, and Texas panicum were 6 8, 3 9, 1 2, 1 6, and 0 5, respectively Adult abundance and crop phenology also were monitored in these crops during 1997 Adults were most attracted to crops during the flowering stage of growth Manipulation of sorghum flowering by planting sorghum so it flowers before corn or selecting cultivars with shorter flowering periods may allow sorghum to escape oviposition by Mexican corn rootworm

Field Evaluation of Fecundity Longevity and Oviposition of Millet Head Miner

Millet head miner, *Heliocheilus albipunctella* de Joannis, has been a major pearl millet pest in the Sahel since 1972 In a review of millet head miner biology, its natural enemies, and a descriptive biological control research approach, Gilstrap et al (1995) concluded that a cohesive management strategy was not available for millet insect pests The objective of this research was to determine factors regulating development and abundance to improve understanding of millet head miner biology as a part of a larger research effort to assess the impact of natural enemies on millet head miner abundance

Research was conducted at the ICRISAT Sahelian Center at Sadore, Niger Seed of '3/4 HK' (an early maturing pearl millet variety) was planted in the field on 6 and 21 June and 7 July 1996, and 23 June and 4 and 16 July 1997 Planting dates were varied so relationships between millet head miner development and growth of pearl millet could be observed throughout the growing season Each plot of millet consisted of 35 rows, 25 m long and 0 75 m apart Hills in each row were 1 m apart After emergence, plants were thinned to three per hill to assure uniform plant growth

Exclusion cages were used to assess millet head miner adult fecundity, longevity, and oviposition period in the field Cages were 70-90 cm long x 30 cm diameter and constructed from wire frames covered with fine cotton-mesh screen Each cage was placed in the field over a spike exserted 5-10 cm Spikes were supported with strings attached to iron bars to prevent stalk breakage A pair of millet head miner adults from a laboratory colony was released into each cage at sundown to coincide with the time adults become active in the field Daily, a dissecting microscope was used to examine cut spikes for eggs Total number of eggs oviposited by each female during its life span was recorded Longevity, fecundity, and length of oviposition in the cage were assessed by maintaining individuals until they died Mean number of days for millet head miner pairs, longevity, female fecundity, and length of oviposition period were estimated on pearl millet spikes

Mean number of days millet head miner adult pairs lived and oviposition period are presented in Table 1 Also presented are the total number of eggs oviposited by each female during its life span in the exclusion cage In 1996, mean numbers of days of adult longevity on the spikes were 3 8 and 4 0 for males and females, respectively In 1997, mean numbers of days of adult longevity were 3 4 and 3 3 for males and females, respectively For both years, millet head miner in exclusion cages survived for 2 and 6 days This confirmed the conclusion reached by Ndoye (1992) that adults survived 5-6 days in nature or in closed cages For both years, the female oviposition period was 1-4 days Mean oviposition period for a female was 2 4 and 3 1 days in 1996 and 1997, respectively The longest oviposition period of 3 4 days per female was recorded on pearl millet planted on 4 July 1997, while the shortest oviposition period of 2 9 days was recorded on pearl millet planted on 23 June 1997 Mean number of eggs oviposited per female was 29 6 This mean is very low compared to the 400 eggs in batches of 20 to 50 reported by Gahukar (1984) In 1996, total number of eggs oviposited by each female was between 7 and 52, while in 1997, the total number oviposited was 4-106 In 1997, number of eggs oviposited differed by planting date Ranges of 7-50, 13-106, and 4-88 eggs oviposited per female were recorded for the three planting dates Mean numbers of eggs oviposited per female were 29 6 and 44 9 in 1996 and 1997, respectively

These data will be used to construct a stage-specific life table to gain an understanding of factors that regulate the biology and abundance of millet head miner The life table can be used to develop an improved plan for managing millet head miner on pearl millet in West Africa

Impact of Natural Enemies on Abundance of Millet Head Miner in Niger

Gilstrap et al (1995) proposed that biological control might be effective against the millet head miner but that indigenous natural enemies first needed to be assessed The goal of this research was to use exclusion methodology to assess mortality, particularly impact and contributions of natural enemies, on abundance of millet head miner in the field

Research was conducted in 0 5-ha plots at the ICRISAT Sahelian Center, Sadore, Niger, and in farmers' fields at Daybon and Dogalkeina, 3 and 7 km from ICRISAT-SC Each week from emergence to maturity, 10 millet spikes in each plot were selected randomly, labeled with a number correlated to the date of emergence from the boot, and cut Millet head miner eggs and larvae were collected from the spikes and counted Parasites and predators were collected on spikes in the field by using aspirators, nets, and shaking bags at early spike emergence and during flowering

Cylindrical exclusion cages of wire frames covered by fine-meshed cloth were placed over 120 newly emerged spikes to prevent infestation Each spike was infested with

Table 1 Field longevity, fecundity, and oviposition period of millet head miner on enclosed spikes, ICRISAT, Sadore, Niger, 1996 and 1997

Planting date	Number of pairs	Longevity (days) %	Longevity (days) &	Oviposition period (days)	Eggs laid/female[a]	Eggs laid/day
6 June 96	5	3 8	4 0	2 4	29 6 (7 52)	12 2
23 June 97	10	3 5	3 5	2 9	27 60 (7 50)	10 0
4 July 97	10	3 4	3 4	3 4	69 8 (13 106)	21 6
16 July 97	10	3 2	3 1	3 0	37 2 (4 88)	12 4
Mean		3 4	3 3	3 2	44 9	14 7

[a]Numbers in parentheses represent the range of eggs oviposited during a female life time

25 eggs from female millet head miners collected in the field or reared in a laboratory One group of spikes remained covered after infestation and until prepupae dropped to the base of the cage to prepare for the dry season The other groups of spikes were uncovered 3, 13, 23, and 36 days after infestation to allow access of natural enemies to millet head miner eggs, early-instar larvae, late-instar larvae, and prepupae The groups of spikes were harvested 3, 10, 10, and 13 days after being uncovered and were taken to a laboratory, where emerging parasitoids were collected and identified

In another experiment, 50 spikes at the boot stage were covered Twenty-five eggs were placed 3, 6, or 9 cm from the distal end of each of 10 emerged spikes Eggs were removed 48 hours later, counted, and incubated in the laboratory Partially destroyed eggs were assessed for predation Another set of 10 spikes was examined one week later for parasitism of middle-instar larvae The last set of 10 spikes was examined one week later for parasitism of full-grown larvae

Natural enemies were abundant in farmers' fields Ants of the genus *Cremastogaster* were most abundant, followed by the egg predator, *Orius* sp , and egg and larval parasite, *Cardiochiles* sp Also collected were *Bracon hebetor* in the field and *Copidosoma* sp in the field and from field larvae reared in the laboratory *Orius* sp and *Cardiochiles* sp were more abundant in September than in August or October

Many millet head miner eggs and larvae disappeared from spikes enclosed in exclusion cages Natural enemies consumed more than 100 millet head miner eggs within three days after infestation Large numbers of eggs were missing 14, 24, and 37 days after infestation Numbers of brown, wrinkled eggs, indicating predation by predators such as *Orius* sp , and total numbers of dead larvae were almost equal 4 and 37 days after infestation Of 2,400 millet head miner eggs placed on spikes in exclusion or open cages, 1,016 (42 3%) were missing, 277 (11 5%) were nonhatched (attacked) brown eggs, and 40 (1 7%) hatched Two hundred thirty (70%) live and 100 (30%) dead larvae developed from the 2,400 eggs placed on spikes in exclusion cages

Many eggs disappeared when exposed to natural enemies In mid-September, fewer egg remains indicating predation were found than nonhatched brown eggs and more second than third or fourth instar larvae were dead After 50 first instar larvae were exposed to natural enemies for one week, 3 (6%), 8 (16%), and 39 (78%) were dead, missing, and alive, respectively

Mortality of third, fourth, fifth, and sixth instar larvae was great between 8 and 30 September Mortality throughout the growing season was greatest for fourth, fifth, and sixth instars A total of 659 (33 5%) millet head miner larvae were live, 1,307 (66 5%) dead, and 119 (9 1%) parasitized

Networking Activities

Workshops

Greenbug Working Group Workshop, October 14-15, 1997, Oklahoma State University and USDA, Stillwater, OK

Entomology Science Conference, October 28-30, 1998, College Station, TX

Annual Texas Plant Protection Conference, December, 9-10, 1997, College Station, TX

Entomological Society of America, December 14-18, 1997, Nashville, TN

Southwestern Branch, Entomological Society of America, February, 9-12, 1998, Corpus Christi, TX

International Plant Resistance to Insects Biennial Workshop, March 15-18, 1998, Memphis, TN

First International Symposium of Sorghum, May 28-30, 1998, Rio Bravo, Mexico

INTSORMIL Principal Investigators Meeting, June 23, 1998, Corpus Christi, TX

INTSORMIL Impact Assessment Workshop, June 24, 1998, Corpus Christi, TX

Ergot Conference, June 25 - 26, 1998, Corpus Christi, TX

Research Investigator Exchanges

Scientists from Australia, Mali, Niger, and Mexico conferred with the PI relative to sorghum insect research and IPM during this reporting period During travel to Mali, the PI and collaborator, Dr Niamoye Diarisso, interacted with World Vision personnel and traveled with them to on-farm sites where local farmers were using a variety of sorghum developed by IER/INTSORMIL plant breeders This activity provided the opportunity to express interest in continued networking with World Vision as a means to transfer technology Plans are being developed to continue the relationship with World Vision during 1998-1999

The PI 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 contributed to revision of the Sorghum Disease Compendium and wrote a chapter in a sorghum monogram The PI continues to serve on the Editorial Board for the Journal of Insect Science and its Application

Germplasm and Research Information Exchange

PIs for projects TAM-225 and TAM-223 annually evaluate sorghum germplasm for resistance to insects Converted exotic sorghums regularly were evaluated for resistance to sorghum midge Also, sorghum accessions regularly are evaluated for resistance to greenbug and yellow sugarcane aphid

Each year, TAM-225 PI receives many requests for seeds of sorghums resistant to insect pests These requests are forwarded to TAM-223 PI

During this reporting period, the PI provided on a regular basis, technical advise and information to Extension Service personnel and numerous scientists in developing and developed countries

Publications and Presentations

Abstracts

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Diarisso N Y B B Pendleton G L Teetes G C Peterson and R M Anderson 1997 Relationship between sorghum glume closure and resistance to sorghum midge International Sorghum and Millets Newsletter 38 87 88

Katsar C S A H Paterson G C Peterson and G L Teetes 1997 RFLP analysis of greenbug resistant sorghum germplasm Annual Plant Resistance to Insects Newsletter 23 39 40

Peterson G C G L Teetes J W Jones R M Anderson B B Pendleton and K Schaefer 1997 Release of sorghum inbred lines resistant to sorghum midge International Sorghum and Millets Newsletter 38 37 38

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Peterson G C G L Teetes B R Wiseman J W Jones R M Anderson K Schaefer and B B Pendleton 1998 Registration of Tx639 Tx640 and Tx641 sorghum midge resistant sorghum inbred lines Crop Sci (in press)

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Books

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Pendleton B B G L Teetes and R A Frederiksen 1997 Integrated Crop Management in Sorghum (in preparation)

Book Chapters

Teetes George L Gary C Peterson Kanayo F Nwanze and Bonnie B Pendleton 1998 Genetic diversity of sorghum a source of insect resistant germplasm p 63 82 In Stephen L Clement and Sharron S Quisenberry (eds) Global Plant Genetic Resources for Insect Resistant Crops CRC Press Boca Raton FL

Teetes George L 1998 Insect pests In Richard A Frederiksen (ed) Compendium of Sorghum Diseases APS Press (in press)

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Teetes George L 1998 Integrated management of sorghum insect pests p 14 30 In Proceedings Primer Simposio Internacional de Sorgo 27 30 May 1998 Rio Bravo Mexico INIFAP

Anderson Roger M George L Teetes and Bonnie B Pendleton 1997 Insecticidal control of sorghum panicle feeding pests p 37 In Proceedings 9th Annual Texas Plant ProtectionAssociation Conference 9 10 December 1997 College Station TX

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Presentations

Teetes George L Integrated management of sorghum insect pests Primer Simposio Internacional de Sorgo 27 30 May 1998 Rio Bravo Mexico

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Anderson R M B B Pendleton and G L Teetes Insecticidal control of sorghum panicle-feeding pests 46th Annual Meeting of the Southwestern Branch of the Entomological Society of America 9 12 February 1998 Corpus Christi TX

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Biological Control Tactics for Sustainable Production of Sorghum and Millet

Project TAM-225B

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Summary

Project TAM-225B addresses arthropod-insect pests of millet These pests are key constraints to production in West Africa, and require detailed ecological understanding for a sustainable management strategy, especially during times of year when pests occupy noncrop portions of an agroecosystem Our collaborative research program in Niger addresses biological control of the millet head miner (MHM) An important part of the program in the U S 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 implemented

In INTSORMIL Year 17 (January 1996), I accepted two NARS scientists from West Africa to begin research programs in Niger, and they are working at the International Crops Research Institute for the Semi-Arid Tropics Sahelian Center (ISC) in collaboration with Dr Ousmane Youm One student is a Ph D candidate (S Boire Mali) and the other an M S candidate (H Kadi Kadi Niger) Their research objectives and results build on findings for MHM biological control reported by this project in INTSORMIL Years 15 and 16

In Year 19, Boire continued field studies he began in Year 18 on MHM immature stage mortality, adult MHM biology and fecundity, and MHM biology on alternate host plants All of his work is conducted in the field with some experiments at ISC, and others in nearby farmer s fields His charge is to assess sources and importance of natural mortality of MHM In Year 19, Kadi Kadi completed studies initiated in Year 18 on MHM immature stage development and adult biology using four temperatures and four artificial diets All results reported here are preliminary Boire will finalize his research in Year 20, and Kadi Kadi finished his research in Year 19 and is currently writing his thesis

Results from these student's research will be used to construct a stage-specific life table, thus providing an understanding of factors that regulate the abundance of MHM These results will be useful for developing an improved plan for managing MHM on pearl millet in West Africa Using the database available on climatic conditions in the Sahel, and research data from this and other research on MHM, improved approaches to managing MHM will be possible Ultimately, these data will support developing a Millet Head Miner Warning System model to forecast the probability of MHM outbreak in a given area so that appropriate measures can be implemented to control MHM before it damages pearl millet

Objectives, Production and Utilization Constraints

Objectives

The collaborative sorghum and millet research objectives of TAM-225B are

- Assess natural enemies for biological control of stalk borers and the MHM
- Implement effective biological controls

- Provide graduate level training on processes and strategies for biological controls in sorghum and millet
- Assess biological control for on-farm pest management of sorghum and millet pests in local crop protection practices

The listed objectives are pursued in the United States and in the Republic of Niger on millet

Graduate student research objectives — TAM-225B is training two scientists from West Africa, and their objectives are

- Improve methodologies for sampling and manipulating populations of MHM
- Assess the spatial distribution and mortality of all life stages of MHM
- Conduct experiments to show age-specific mortality in populations of MHM
- Identify and assess the role of alternate host plants occupied by MHM
- Determine the optimal survival of MHM in a laboratory environment
- Conduct field cage experiments to assess MHM fecundity Both students conducted research in Niger in collaboration with Dr Ousmane Youm, ICRISAT Sahelian Center Other graduate students associated with TAM-225B in Year 18 finished their degrees, or have finished their research and are writing their dissertations

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 MHM 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 Research in Niger

IPM of millet pests is a prominent goal of ROCAFREMI, and early in network activities, crop protection participants identified key pests of Sahelian millet as the millet head miner [*Heliocheilus albipunctella* (de Joannis)], millet stalk borers [*Coniesta ignefusalis* (Hampson)] and downy mildew disease [*Sclerospora graminicola* (Sacc) (Schroter)] The MHM 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 emphasizing effective natural enemies, i e , biological control It supports a large guild of natural enemies (reported in previous TAM-225B annual reports and by others), occupies a predictable habitat in an ecosystem with consistent annual presence, and has one generation per year

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

Boire - Research sites were fields at the ISC at Sadore, Niger, and in farmers fields at Deybon and Dogalkeina, 3 and 7 km respectively from ISC Millet used in this study was grown from ISC breeder seed

Distribution of Millet Head Miner Eggs and Larvae - We divided the field at the research station into two plots, each measuring 0 5 ha Also, we divided two farmers fields into two plots of 0 5 ha each Each week from early spike emergence to maturity, 10 millet spikes in each plot were randomly selected, labeled and cut We labeled spikes with a number correlated to the date of emergence from the boot MHM eggs and larvae were collected from whole spikes, counted and recorded

Sampling of Natural Enemies - MHM parasites and predators were collected on standing spikes using aspirators, hand nets and shaking bags in experimental and farmers field plots at early spike emergence and during flowering

Exclusion Cages to Determine Stage-specific Mortality of Eggs and Larvae - Cage exclusions were employed to assess the impact of natural enemies Individual head cages constructed from a 1 5mm diameter wire frame covered with a fine mesh (21 x 21 cells cm-2) were used We covered panicles of all experimental plants at boot stage

Exclusion and open spike cages were used for directly assessing the impact of natural enemies and permitted comparing MHM in the presence and absence of natural enemies The experiments determined causes and frequencies of specific mortality sources to MHM eggs and larvae Cages were cylindrical and constructed from wire frames covered with fine-mesh cloth Caging was initiated on newly emerged spikes to insure the MHM did not prematurely infest them

To prevent natural infestation by MHM, we covered 120 spikes with paper bags when plants reached the boot stage Four equal-sized treatments were used consisting of MHM eggs, early instar larvae, late instar larvae and prepupae We infested thirty caged spikes of each treatment at four day intervals, infesting spikes with about 25 eggs from females collected in the field or reared in a laboratory We put eggs on a small paper sticker (Super Sticker-PGC Scientific) pinned to a caged spike

Thirty of the 120 caged spikes remained covered after infestation and until prepupae drop to the base of the cage (equivalent to larvae dropping to the soil) This control group of caged spikes was used to assess the survival rate of MHM without the activity of natural enemies of eggs and larvae

Exposure of Millet Head Miner to Natural Enemies - These experiments exposed laboratory-reared MHM eggs and early instar larvae to naturally occurring natural enemies Fifty spikes were covered at the boot stage to prevent natural infestation by MHM At emergence, we marked these spikes at 3-cm intervals from the distal end Ten spikes were selected randomly each week from each marked group We put about twenty-five eggs each on small paper stickers (Super Sticker-PGC Scientific), and placed stickers at 3, 6 or 9 cm from the distal end of a spike Stickers containing exposed eggs were removed 48 hours later, counted and incubated in the laboratory Missing eggs were considered lost to undetermined causes, though these were generally attributed to predation Partially destroyed eggs were assessed for evidence of predation We examined full-grown MHM larvae on a second set of 10 spikes for parasitism

Assessment of pupal mortality - Pupal mortality was assessed by collecting pupae in 1-m 2 holes after the harvest and throughout the dry season At three week intervals, we conducted pupal sampling in experimental plots at ISC and in farmers fields at Deybon and Dogalkeina where pearl millet plant was grown the previous year We excavated holes on millet hills to ensure a large finding of pupae and prepupae (mummies) from soil depths at 5 cm increments (0-40 cm) A wire screen (36 cells cm2) was used to separate pupae and soil We give results of November-December 1997 in this report

We assessed soil moisture and temperature as abiotic factors influencing MHM pupal diapause We recorded soil temperatures at soil depths using a data logger in experimental plots A soil moisture probe (Type I H III, DIDCOT Instrument Co , Abing Oxon, England) was used to measure moisture from soil depths at 10 cm increments (10-50 cm) once every two weeks

Kadi Kadi - Laboratory Experiments - We designed experiments to determine ideal conditions for MHM cohort development under laboratory conditions Laboratory research focused on comparing development of MHM cohorts reared using only Bio-Serv diet # 9782, and three combinations of millet-based diet (i e , spike parts at early exertion, middle flowering, and soft-dough stages)

Experiments were conducted using adults (1 1♂) from a laboratory colony or captured in light traps These adults were placed in oviposition cages containing freshly cut millet spikes Collected eggs were soaked in 1% bleach and distilled water, washed, and then placed in a petri dish where we counted them with the aid of a dissecting microscope We then held the collected eggs in a petri dish for hatching Using a small camel-hair brush, we moved larvae individually to plastic cups containing 15 ml of artificial diet and/or millet-based diet

Longevity, fecundity, and oviposition period of MHM adults were assessed by maintaining individuals until they died We maintained overlapping generations of MHM in a laboratory We maintained rearing chambers at a photoperiod of 12 12 (L D), temperatures of 24° ± 1°C, 26° ± 1°C, 28° ± 1°C, and 30° ± 1°C, and relative humidity of 70%

Field cage exclusion experiments - Seed of 'HK' was planted in a field on 6 and 21 June, and 7 July 1996, and 23 June, 4 and 16 July 1997 Exclusion cages were used to assess MHM cohort development under field conditions Cages were 70-90 cm long x 30 cm diameter and constructed from wire frames covered with fine cotton--mesh screens Each cage was placed over a spike that was exerted 5-10 cm We artificially infested spikes at different times with laboratory -collected eggs A small camel-hair brush was used to place eggs within each millet spike Spikes were later checked to assess the number of eggs that hatched Cohort development and survival was assessed on millet planted at different times

In a second experiment, cages were placed over selected spikes at the booting stage 24 hours before pairing MHM adult moths A pair (1 1♂) of MHM adults from a laboratory colony was released into each cage at sundown to coincide with the time MHM adults normally become active in the field Daily, a dissecting microscope was used to examine cut spikes for eggs We recorded the total number of eggs oviposited by each female during its life time Longevity, fecundity, and length of oviposition period of MHM in the cage were assessed by maintaining individuals until they died We estimated mean number of days for MHM longevity, female fecundity, oviposition period, and cohort development on pearl millet spikes

Research Findings

Boire - Many MHM eggs and larvae disappeared from millet spikes enclosed in exclusion cages Predaceous natural enemies consumed more than 100 MHM eggs within three days after infestation Numbers of brown wrinkled eggs, suggesting predation by predators such as minute pirate bugs (Orius sp), and total numbers of dead larvae were almost equal 4 and 37 days after infestation Also, egg disappearance was high 18 days after infestation (about 100 eggs) and 12 days after infestation (more than 120 eggs) Larval mortality was evident in 28 to about 32 days Many live prepupae were found in cages at 45 to 49 days after infestation Ten dead prepupae were recorded 37 days after infestation A total of 2,400 MHM eggs were placed on millet spikes in exclusion or open cages, and examination revealed 1,016 missing (42 3%), 277 nonhatched (attacked) brown eggs (11 5%) and 40 hatched brown egg remains (1 7%) Two hundred thirty (70%) live and 100 dead larvae (30%) developed when 2,400 eggs were placed on millet spikes in exclusion cages

Many MHM eggs in farmers fields and experimental plots disappeared when exposed to natural enemies Fewer egg remains suggested that predators found most nonhatched brown eggs in mid-September More second than third or fourth instar larvae were dead in mid-September After we exposed 10 first instar larvae to natural enemies for one week, 3 (6%), 8 (16%) and 39 (78%) were dead, missing and alive, respectively

Mortality fluctuated for all MHM larval stages collected in farmers fields between 12 August and 22 October Mortality of third, fourth, fifth and sixth instar larvae was substantial between 8 and 30 September Mortality was greatest of fourth, fifth and sixth instar larvae throughout the cropping season A total of 659 live (33 5%), 1,307 dead (66 5%) and 119 parasitized (9 1%) MHM larvae were collected

Natural enemies are clearly abundant in farmers fields Ants of the genus Crematogaster were most abundant, followed by the egg predator, *Orius* sp , and the egg-larval parasite, *Cardiochiles* sp *Orius* sp and *Cardiochiles* sp (probably *C sahelensis*) were more abundant in September than August or October However, it should be noted that populations of these two natural enemies were also important during the last week of August Five *Cardiochiles* sp emerged from one first and one second dead instar larvae collected in open exclusion cages

A total of 13 pupae (5 live, 8 dead) and one mummy were found in 10 holes on November 27 and 28 in farmers fields at Dogalkeina A total of 292 pupae (238 live, 54 dead) and 81 mummies were found in 110 holes in experimental plots during December We found more live pupae at 10 and 15 cm than the other depths during the first three weeks of November and this trend follows approximately a normal distribution (from 0 to 35 cm depths) in December Pupal mortality was most frequent in 0, 5 and 10 cm depths for November and uniform from 0 to 35 cm depths for December Very few pupae and mummies were found in 35 cm depth and no pupae or mummies were recorded in 40 cm depths during November and December Results were used to assess causes and frequencies of pupal mortality according to soil depth and temperature These data helped to assess effects of soil condition and points of critical values on pupal mortality during the dry season

Results of analysis of four soil samples at 0-30 cm deep showed that soils in ISC and Dogalkeina regions are mostly sandy (90%) Loamy and clay soils are 3 3 and 10 05% respectively Analysis of soil temperature of December (dry cold season) showed a decrease from 30 to about 20°C in mid-December at all soil depths examined During this period temperature was highest at 35 and 40 cm than the other depths Temperature seemed to fluctuate 25 and 27°C during the rest of December and probably will show different trends during the dry hot season (March-May) We should note that more alive pupae were found at depths (10-25 cm) of lowest temperature We will give results of soil moisture content in the next progress report Solar radiation in 1996 and 1997 did not differ significantly except in March where it was slightly low and normally higher in April

Kadi Kadi - Laboratory studies - In 1996 and 1997, mean days longevity and oviposition period were very low (2-3 days) in the rearing chamber maintained at 24°C In rearing chambers maintained at 26, 28, and 30°C, longevity and oviposition periods were 3-4 days and 2 0-2 7 per MHM pair in 1996 and 1997, respectively But in 1997, in the rearing chamber set at 30°C, longevity and oviposition periods were 1-2 days for MHM adult pairs In the rearing chamber set at 28°C, more eggs (mean = 173) were oviposited in 1996 In 1997, most eggs (mean = 152) were oviposited in rearing chamber set at 30°C

In 1996, low numbers of eggs oviposited (mean = 119 and 98) and hatched (mean = 68 and 63) were recorded in rearing chambers maintained at 24 and 30°C, respectively In 1997, of 93 and 69 eggs oviposited, only 77 and 54 hatched in rearing chambers set at 24 and 26°C In 1996, only 46% of the eggs hatched in the rearing chamber set at 28°C Percentage of egg hatching was much higher (57, 59, and 64%) in rearing chambers set at 24, 26 and 30°C In

1997, percentage of egg hatching was 70-85% for eggs oviposited in rearing chambers set at 24, 26 and 28°C In 1997, in the rearing chambers set at 30°C, fewer eggs hatched (77), 52% of the eggs oviposited In both years, we recorded high number of eggs oviposited and hatched in rearing chambers maintained at 28°C

Field cage exclusion studies - In 1996, mean numbers of days of adult longevity on the spikes were 3 8 and 4 0 for males and females, respectively In 1997, mean numbers of days of adult longevity were 3 4 and 3 3 for males and females, respectively For both years, MHM in exclusion cages survived for 2 to 6 days This confirms the conclusion reached by others that adults survive 5-6 days in nature or in closed cages For both years, the female oviposition period was 1-4 days Mean oviposition period for a female was 2 4 and 3 1 days in 1996 and 1997, respectively We recorded the longest oviposition period of 3 4 days per female on pearl millet planted on 4 July 1997, while we recorded the shortest oviposition period of 2 9 days on pearl millet planted on 23 June 1997 Mean numbers of eggs oviposited per female were 29 6 and 44 9 in 1996 and 1997, respectively These means are very low compared with the 400 eggs in batches of 20-50 reported by others In 1996, total numbers of eggs oviposited by each female were between 7 and 52, while in 1997, total numbers oviposited ranged from 4 to 106 Numbers of oviposited eggs ranged between 7-50, 13-106, and 4-88 eggs per female for the three planting dates Mean numbers of eggs oviposited per female per day were 12 2 and 14 7 in 1996 and 1997, respectively

In 1996, 50-73% of 40 MHM eggs used to infest a pearl millet spike hatched Twelve to 35% of neonate larvae survived to the next instar In 1997, 71-92% of 5-20 eggs placed on millet planted 23 June hatched, while 70-77 and 70-96% of 5-20 eggs placed on pearl millet planted 4 and 16 July hatched Also, 30-80% of neonate larvae survived to the next instar on pearl millet planted 23 June and 4 July Few or no larvae survived on pearl millet planted 16 July Overall, 73-87% of the 5-20 eggs placed on a pearl millet spike enclosed in an exclusion cage hatched From 23 to 86% of the larvae survived after hatching from eggs placed on the spikes

In 1996 and 1997, more MHM survived and developed on pearl millet planted on the two early planting dates than on millet planted on 7 July 1996 and on 16 July 1997 High numbers of first instar and full-grown larvae, prepupae, and pupae were found on pearl millet planted 6 June 1996 and 23 June 1997 Overall, we found most pupae on pearl millet planted on 23 June and 4 July 1997 Mean numbers of pupae recorded ranged between 0 65 and 5 25 and 0 0 to 1 05 per spike Fewest MHM survived and developed to pupae (0 2-0 8) on spikes of millet planted on 7 July 1996

Networking Activities

Networking activities consisted of Hame Kadi Kadi sharing his research results with his colleagues at INRAN See country report for Niger

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

Project TAM-228
Gary Odvody
Texas A&M University

Principal Investigator

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Summary

Throughout 1997-98 TAM-228 continued to function as one of the primary sources for sorghum ergot information as the pathogen spread across Texas and into other states of the U S TAM-228 was one of the organizers of a U S ergot conference held in late June, 1998 in Corpus Christi, TX Across South Texas sorghum ergot overwintered in an ac tive disease phase predominantly on feral sorghum in abandoned fields and along roadsides or other areas but also on johnsongrass Only *Sorghum* spp were observed to be naturally infected by *C africana* in surveys made in Puerto Rico, Mexico and the U S Triazole fungicides continued to provide the best control of ergot on sorghum plants in the field but the necessity for good coverage and contact of the head has raised concerns over efficacy of aerial applications Previously tested and new advanced generation sorghum cultivars showing good agronomic characteristics and drought response at Corpus Christi in 1997 or previous years were selected by TAM-228 and TAM-222 for evaluation at Se-

bele, Botswana in the 1997-98 growing season TAM-222 generated the materials primarily using parents that had previously demonstrated good adaptation and drought tolerance under Botswana conditions This nursery of 171 cultivars experienced severe but variable drought stress at the Sebele Station Macia derivatives were predominantly the best throughout the test but, of individual crosses, the most consistently outstanding cultivars were those from Macia*Dorado and 87EO366*WSV387 (Kuyuma)

Objectives, Production and Utilization Constraints

Objectives

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

- Identify adapted sources of drought tolerance with adequate charcoal rot and other disease resistance in Botswana, and Zimbabwe

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

- Develop controls for sorghum ergot (*Claviceps africana*) through chemical control, identification of host plant resistance, and other means as determined through biological investigations of *C africana* in Zimbabwe, Zambia, Botswana, Brazil, Honduras, Puerto Rico, Mexico, and the United States

- Determine the level of host parasite compatibility that exists for *C africana* and several previously reported alternate hosts including pearl millet in Zimbabwe, Brazil, Honduras, Mexico, and United States

- Determine the risk of pre- and postharvest aflatoxin in grain sorghum in the United States

Research Approach and Project Output

Foliar Diseases (Anthracnose, Leaf Blight, and Sooty Stripe)

In 1997-98, four sorghum disease nurseries were planted at one or two locations in Zambia and two disease nurseries were planted at 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, 42 entries) were planted in both Zambia and Zimbabwe These nurseries consisted primarily of entries or derivatives 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 1997-98 season at the Henderson station in Zimbabwe there was a low incidence of sooty stripe and moderate incidence of leaf blight Cultivar response to leaf blight was consistent with response of previous years Incidences of both diseases were low at the Panmure station where ladder spot (*Cercospora fusimaculans*) and rust (*Puccinia purpurea*) were more common

In Zambia, sooty stripe incidence and severity were moderate at both Golden Valley and Mansa research stations Foliar and seed anthracnose were moderate at Mansa Sooty stripe has become an increasingly prevalent disease at the Mansa location possibly due to increased soilborne inoculum from sorghum production on the same nursery areas over several years Other diseases occurring at moderate severities on susceptible cultivars at Mansa were ladder spot and zonate leaf spot (*Gloeocercospora sorghi*) The cultivar SC146 had a moderate to high incidence of ladder spot at both the Mansa, Zambia and Panmure, Zimbabwe locations Cultivar vulnerability to minor foliar pathogens often goes unnoticed at these sites unless they have resistance to the major foliar pathogens

Virus Identification

Virus reactions were recorded in the International Sorghum Virus Nursery (ISVN) in an early and late planting at the Pandamatenga Research Station in Botswana In the early (normal) planting, red (and tan) leaf necrosis symptoms, including a concentric ring pattern sometimes called fingerprinting, were again observed in several entries of the ISVN and in the released variety Mahube (SDS2583) Although the later planting had very poor stands there was more evidence of mosaic symptoms and very little leaf necrosis compared to the early planting Populations of sugarcane aphid (probable vector of the virus) were very high throughout early planted material Characterization of these viruses previously collected at several sites in Zambia and Botswana is ongoing by S Jensen

Cultivar Evaluations for Drought and Insect Tolerance in Botswana

Several sorghum disease nurseries other nurseries selected sorghums and advanced generation breeding germplasm developed or introduced in conjunction with TAM-222 and TAM-223 were evaluated at Sebele, Botswana The objectives were to identify those with improved drought tolerance and resistance to sugarcane aphids and disease Several materials from the Drought Line Test again showed good response to the drought but only a few had corresponding agronomic desirability Advanced generation materials generated primarily by TAM-222 included cultivars previously demonstrating good adaptation to Botswana, plus a large number of new entries selected for evaluation based on drought response and agronomic characteristics at Corpus Christi in 1997 This nursery of 171 cultivars experienced severe but variable drought stress at the Sebele station Macia derivatives were predominantly the best throughout the test but, of individual crosses, the most consistently outstanding cultivars were those from Macia*Dorado and 87EO366*WSV387 (Kuyuma) (Table 1)

Survival of Claviceps africana in South Texas

Sorghum ergot caused by *Claviceps africana* spread to South Texas in March of 1997 and reached as far North as Nebraska by October 1997 Most occurrence of ergot in South Texas was at low levels on commercial grain sorghum or low to high levels on male-sterile forages There was also some incidence in male-steriles of a few hybrid seed production fields in the region with highest levels occurring in late season axillary tillers Winter survival of *C africana* in northern regions was questioned because of the extended exposure to freezing conditions and freeze thaw cycles Winter environments in South Texas are extremely mild and freezing conditions are either limited or absent Surveys were conducted to determine the presence of sorghum ergot throughout the winter months because cool and near freezing temperatures might actually increase likelihood of ergot through induced sterility in normally fertile

Table 1 Advanced generation cultivars with good agronomic desirability under severe drought stress at the Sebele Research Station in Botswana, 1998 season[1]

Entry number	Pedigree	Agronomic desirability[1]
205	Macia*Dorado	2 00
221	Macia*Dorado	2 25
149	87EO366/WSV387	2 25
204	Macia*Dorado	2 25
219	Macia*Dorado	2 25
247	EO361*Macia	2 25
145	87EO366/WSV387	2 50
141	87EO366/WSV387	2 50
147	87EO366/WSV387	2 75
236	Macia*Sureño	2 75
220	Macia*Dorado	2 75
201	Macia*TAM428	2 75
229	ICSV1089BF*Macia	2 75
223	ICSV1089BF*Macia	3 00
241	EO361*Macia	3 00
142	87EO366/WSV387	3 00
151	EO361*Macia	3 00
233	Macia*Sureño	3 00
239	EO361*Macia	3 00
101	Sureño*CE151	3 00
188	91CC371	3 00
206	Macia*Dorado	3 00
128	SRN39*87EO366	3 00

[1] Agronomic desirability ratings 1 to 5 1= most and 5= least desirable Rating included yield maturity (early rated higher) uniformity and drought response Value is average of two replicates

sorghums Cool temperatures during a November bloom period contributed to a high incidence of ergot in a few commercial grain sorghum fields near Corpus Christi Ratooned and feral sorghum in abandoned fields, along roadsides and near grain storage facilities developed relatively high levels of ergot under cool temperatures throughout South Texas This ergot persisted in an active phase until plants were killed by frost Some regions of the Rio Grande Valley and areas near Corpus Christi escaped frost damage and ergot continued to develop throughout the winter months as new tillers emerged Some ergot-infected plants had above ground foliage and stalks killed by frost but ergot later reoccurred on heads of new basal tillers In the Corpus Christi area ergot was not seen on johnsongrass until cool temperature sterility occurred in a manner similar to grain sorghum The persistence of ergot on feral sorghum and johnsongrass throughout the winter months was similar to the initial observations of ergot in the Lower Rio Grande Valley of Texas and portions of northern Mexico in early 1997 However, despite the presence of ergot until planting, March and earlier, dry conditions after planting and hot and dry conditions at anthesis and beyond prevented observable development of ergot in commercial grain sorghum fields or any other commercial production areas throughout northern Mexico and South Texas in 1998 except in experimental plot areas With the return of cooler, wetter conditions ergot is expected to again reoccur *Claviceps africana* is already an endemic pathogen and is likely to have ongoing active phases of the disease across northern Mexico and South Texas during the winter seasons

Hosts of C africana in Puerto Rico, Mexico and the U S

Several grasses including pearl millet have been observed with ergot in close association with ergot on sorghum in Mexico and South Texas All the ergot from grasses had spore and other morphologies that were distinct from *C africana* and of those tested none have infected sorghum Only *Sorghum* spp were observed to be naturally infected by *C africana* in surveys made in Puerto Rico, Mexico and the U S

Chemical Control of Ergot in the Field

In collaboration with B Rooney, TAM-222 and TAM-223, a group of commercial and public sorghum lines represented by 100 A-lines and 40 R-lines were planted in a replicated test at Corpus Christi, Texas in 1997 to evaluate phytotoxicity response to selected triazole fungicides effective against ergot Beginning at bloom initiation, heads in one-half of each replicate row were sprayed (until runoff) with Tilt (propiconazole) or Bayleton (triadimefon) at 500 or 1000 ppm Three total applications were done at 5-7 day intervals Ergot incidence was only noted because the diverse maturity of the cultivars made it too difficult to assess differences in control efficacy No visible phytotoxicity was observed on either the head or the leaves of any cultivar Seed of replicates sprayed at 1000 ppm were harvested to evaluate differences in seed weight and viability Across all A-lines there was a nonsignificant reduction in seed weight in response to three applications of 1000 ppm Tilt or Bayleton and no effect on seed viability

Ground applications of triazole fungicides like Tilt and Bayleton using a directed-spray application to the top and sides of blooming sorghum heads of male-sterile sorghums (ATX2752, ATX623) gave excellent control of sorghum ergot Single applications protected any emerged heads or exposed portions of heads Multiple applications were needed to protect subsequently emerging and blooming heads

A hand application CO_2 sprayer was used to apply several dilutions of systemic fungicides to the top and sides of blooming heads of a male-sterile cultivar (ATX2752) in a replicated field trial Conidia of *C africana* (1×10^6 conidia/ml) were sprayed onto the sorghum heads 24 hours after fungicide application After maximum expression of ergot, fifteen heads from each of four replicates were evaluated for the number of ergot florets per head Of the triazole fungicides, propiconazole (Tilt) and triadimefon (Bayleton) gave near 100% control of ergot when applied at concentrations of 125 ppm or greater but tebuconazole (Folicur) required 250 ppm or greater to give an equivalent level of control Benomyl provided some control of ergot when applied at 2000 ppm but efficacy was poor at lower concentrations Strobilurin fungicides, azoxystrobin (Quadris) and GA27922, the anilinopyrimidine fungicide cyprodinil (Vanguard), and thiabendazole (Mertect) provided little or no protection against sorghum ergot when applied at bloom in concentrations of 2000 ppm

Mechanized ground spray equipment was used in another field trial to apply Tilt at 4 oz/ac in 25 gallons of water (125 g a i /ha in 234 l of water) to blooming heads of the male-sterile sorghum line ATX2752 in three different spray patterns The treatments in three replicates, including a water control, were a three-nozzle application to the top and sides of heads, and cone nozzle applications at 15 cm (top-low) and 56 cm (top-high) above the sorghum heads Each replicate was a four-row plot approximately 37 m in length The sorghum heads were inoculated in the same manner as previously described

After full expression of sorghum ergot, 25 sorghum heads were randomly selected in each of two rows of each replicate and evaluated for the number of ergot florets per head The average number of ergot florets per head were 32 0 for the control, 2 1 for the top-high, 3 9 for the top-low, and 0 4 for the three-nozzle application Values for top-low and top-high were similar except for one collection row of the top-low whose much higher infection indicated poor spray coverage of that row The number of heads with no infection averaged 0 for the control, 5 7 for top-high, 8 5 for top-low, and 20 0 for the three-nozzle application The three-nozzle application performed as expected in giving the best control since it provides the best fungicide coverage However, the comparable level of control achieved by the top-low and top-high applications was surprising The low amount of drift in this test may have also contributed to the similar efficacy of these two applications

Host plant Resistance

TAM-228 assisted B Rooney, J Moran, R Bandyopadhyay, J Dahlberg, and T Isakeit in their studies of host plant resistance to *C africana* which included evaluations of lines (A/B and R-lines), commercial hybrids, and sorghum cultivars previously reported as resistant (see TAM-224 report)

Networking Activities

Sorghum Ergot Activities

In 1997 a collaborative research effort on sorghum ergot was initiated between Texas A&M and INIFAP of Mexico As part of this collaboration INIFAP provided post doctoral scientist Dr Rodolfo Velasquez-Valle who was employed by TAM-228 on funds provided by the USDA-ARS for sorghum ergot research During 1997-98, Dr Velasquez-Valle conducted research in the areas of chemical control, monitoring and assessment of the spread of ergot across Mexico and Texas, and evaluation of potential alternate hosts of *C africana*

Networking Activities

July 2, 1997 Presentations on the epidemiology and spread of sorghum ergot (R Velasquez) and Chemical Control of Sorghum Ergot (G Odvody) were made at the symposium "Ergot (Cornezuelo), Situacion Actual y Problematica en Sorgo" held during the 24th National Congress of the Mexican Society of Plant Pathology, Obregon, MX

August 26, 1997 Spread of Sorghum Ergot and Projected Research Areas (G Odvody) and Research Progress Chemical control and alternate hosts (R Velasquez) were presented at the II International INIFAP-TAMU-USDA/ARS Planning Conference on Sorghum Ergot Rio Bravo, MX

September 12, 1997 Presentation on biology and spread of sorghum ergot in the Western Hemisphere and the U S (G Odvody) at a Sorghum Ergot Review and Strategy meeting in Colwich, Kansas

November 20, 1997 Spread and Importance of Sorghum Ergot in the Western Hemisphere (G Odvody) presented at the Conference on Grain Sorghum for the 21st Century Working Together as an Industry at Corpus Christi, TX

December 9, 1997 Sorghum Ergot in the U S and Mexico (R Velasquez) presented at the 9th Annual Texas Plant Protection Conference in College Station TX

December 11 1997 Ergot - A New Threat to Commercial Sorghum Seed Production (G Odvody) presented at the 52nd Annual Corn & Sorghum Research Conference of the ASTA in Chicago, IL

January 27, 1998 Ergot of Sorghum - Update (G Odvody) presented at the Texas Seed Trade Association Production & Research Conference in Dallas, TX

February 5, 1998 Sorghum Ergot (G Odvody) presented to 1st Annual South Texas Crop Management Technical Seminar

June 23-24, 1998 Local arrangements chairman for the INTSORMIL Principal Investigators Meeting and Impact Assessment Workshop held in Corpus Christi, TX

June 24-26, 1998 Local arrangements chairman, member of conference organizing committee, and oral presentation made in the control session of the Conference on the Status of Sorghum Ergot in North America held in Corpus Christi, TX

June 26, 1998 Organizer for SICNA South Texas Sorghum Nursery Field Day and Tour held in conjunction with the Conference on the Status of Sorghum Ergot in North America

June 27-July 5, 1998 Hosted Medson Chisi, sorghum breeder from Zambia, to interact with other sorghum scientists in South Texas sorghum nurseries following INTSORMIL and Ergot conferences and to collaboratively evaluate sorghum cultivars in South Texas nurseries for future testing in Zambia

International Travel

TAM-228 PI traveled to Southern Africa April 1-24, 1998 to evaluate nurseries and determine future collaborative research activities in the region Locations visited include SMIP scientists and Zimbabwe national sorghum breeder in Bulawayo (Matopos), Zimbabwe, PPRI/RSS in Harare, Zimbabwe, sorghum program scientists in Mt Makulu, Golden Valley, Mansa, Zambia, and DAR in Sebele and Pandamatenga, Botswana

Germplasm Exchange

Over 600 lines and cultivars were evaluated for response to various diseases, adaptation, drought response, and sugarcane aphid resistance in the SADC region in 1997-98 (collaborative with TAM-222, B Rooney, TAM-223, and TAM-224)

Publications

Journal Articles

Bandyopadhyay R D E Frederickson N W McLaren G N Odvody and M J Ryley 1998 Ergot A New Disease Threat to Sorghum in the Americas and Australia. Plant Disease 82 356 367

Isakeit T G N Odvody and R A Shelby 1998 First report of sorghum ergot caused by *Claviceps africana* in the United States Plant Dis 82 592

Velasquez Valle R J Narro Sanchez R Mora Noasco and G N Odvody 1998 Spread of ergot of sorghum (*Claviceps africana*) in Central Mexico Plant Disease 82 447

Proceedings

Odvody G N 1997 Spread and Importance of Sorghum Ergot in the Western Hemisphere Pp 64 71 In Proceedings of the Conference on Grain Sorghum for the 21st Century Working Together as an Industry November 19 20 1997 Corpus Christi TX

Odvody G N and R A Frederiksen 1997 Ergot A New Threat to Commercial Sorghum Seed Production In Proceedings of the 52nd Annual Corn & Sorghum Research Conference of the ASTA December 10 12 1997 Chicago IL In Press

Velasquez Valle R G N Odvody H Torres Montalvo R A Frederiksen and T Isakeit 1997 Sorghum Ergot in the U S and Mexico p 6 In Proceedings of the 9th Annual Texas Plant Protection Conference December 9 10 1997 College Station TX

Miscellaneous Publications

Odvody G R Bandyopadhyay R Frederiksen T Isakeit D Frederickson H Kaufman J Dahlberg R Velasquez and H Torres 1998 Sorghum Ergot Goes Global in Less Than Three Years APSNET feature article for June 1998 published online at http //www scisoc org/feature/ergot/top html

Sustainable

Production Systems

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

Project PRF-205
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Summary

In the Sudan, output growth historically has been based upon area expansion in the mechanized rainfed regions Unfortunately, as the frontier has been disappearing, yields have declined The same phenomenon has been occurring in Sub-Saharan Africa, increasing production with area expansion while yields decline This strategy of continually pushing into more marginal areas and depleting the soils is not sustainable With the disappearance of sufficient land to restore soil fertility with the fallow system, higher input levels will be required In the countries that combined fertilizers, national or regional yields increased The yield effect of new cultivars alone is 0 and then the soil-mining process begins again There was no observed aggregate effect on yields from this cultivar-alone strategy Given the harshness of the semiarid regions, both increased water availability and higher principal soil-nutrient levels will be necessary To encourage higher expenditures on inputs, agriculture needs to be profitable

On consumption, the devaluations associated with structural adjustment in recent years were expected to increase the prices of imported cereals and to shift relative prices in favor of domestic cereals In our comparison of the before-after case for the CFA devaluation, the imported and domestic rice prices decreased and the prices of sorghum/millet increased Overall, cereals prices stayed constant and the consumption of all the major cereals, with the exception of imported rice, increased This substitution for imported rice is expected The declining prices of the two rices apparently resulted from continuing governmental intervention to maintain low food prices in urban areas

Objectives, Production and Utilization Constraints

The general objectives of our research are to estimate the potential effects of new technologies, to identify the constraints to their diffusion, and to recommend complementary policies to accelerate the introduction process Here we report on results from the Sudan on the shift from extensive to more intensive technologies in the dryland regions The main constraint of concern is the evolution of the input markets, especially for seeds and fertilizer Secondly, we report on the analysis of cereal consumption in Bamako, Mali, before and after the devaluation of the CFA The major constraint here is the profitability of the traditional cereal production (sorghum and millet), especially when various economic policies have historically favored imported cereals Finally, we compare and contrast two technology-introduction strategies observed with sorghum in Sub-Saharan Africa, the cultivar alone and the cultivar with increased utilization of inorganic fertilizers and water Again, a critical constraint is the improved functioning of the input and output markets

Research Approach and Project Output

Shifting from Extensive to Intensive Techniques in the Sudan

The basis of sorghum output expansion in Sub-Saharan Africa has been area expansion with much of the continent experiencing aggregate yield declines of millet and sorghum Economic policy has often resulted in decreasing profitability of staple crop production in Sub-Saharan Africa With low profitability, farmers push into more marginal areas to increase output rather than intensifying production with higher purchased input levels

In the Sudan, the area settlement process was promoted by the government in a large-farmer mechanized settlement program initiated after World War II The rapid area expansion, principally with mechanized production of monoculture sorghum, has been considered an outstanding success story Area expansion increased from 1 3 million ha in 1976 to 3 8 million in 1996, down from 5 million in 1993 and 1995 (Figure 1) During the '80s and '90s, the rainfed vertisols were responsible for 55 to 75% of Sudanese output of the principal staple, sorghum In the late '80s, approximately 5,000 entrepreneurs operated these farms with 100,000 wage-earning employees and up to a million seasonal laborers (Holdcroft, 1989)

To accelerate area expansion, the government provided land, machinery, fuel, and credit at subsidized prices Unfortunately, foreign exchange and price policy resulted in substantially reducing the sorghum price received by farmers thereby reducing the profitability of sorghum production The big surge in area expansion of sorghum occurred after 1980 as devaluations took place and the government became more concerned with profitability Average real sorghum prices were 50% higher in the '80s than in the '70s The recent critical instrument encouraging area expansion in the '80s and '90s appears to be the sorghum price with the input subsidies having little effect on cropping decisions, according to a programming simulation Moreover, those subsidies were eliminated in the '90s

Unfortunately, as the area expanded, yields declined Aggregate yields have been reduced from one t ha^{-1} to 500 kg ha^{-1} With yields varying substantially with rainfall and the area cultivated with the prices of the previous season, output variability has increased substantially after 1984 (Figure 2) Now that area expansion is becoming more difficult with falling yields and increasing transportation costs, the need to shift from extensive to intensive systems is becoming recognized by policymakers and researchers

With or without input subsidies, farmers on depleted soils would not intensify until they were no longer able to shift to other land areas Rather, they move to new areas even though they must continue to pay the land tax On the virgin soils, even doubling the costs of production by removing input subsidies did not encourage a shift to intensification Continuous cropping of either a traditional or a new cultivar without nitrogen addition results in the depletion of 48% of the available nitrogen in 16 years

With no more frontier land to rent on both the virgin land and in the depleted areas, nitrogen fertilizer is utilized and the system becomes more intensive, according to the modeling (Table 1) With the low-level use of nitrogen (47 kilos of urea/ha), yields on virgin soils are increased to 1 2 t ha^{-1} and stabilized there On the depleted soils, farmers double this fertilizer use in the modeling, and these nutrient depleted regions are recovered The risk averse farmers on both types of soil would then use inorganic fertilizers

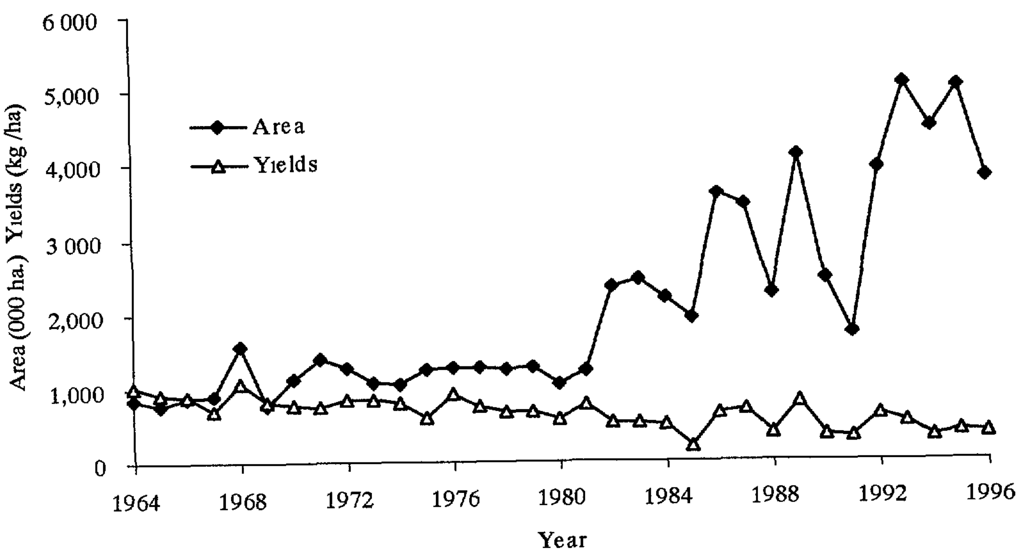

Figure 1 Area and yields of sorghum in the mechanized rainfed zone of Sudan, 1964-1996
Source Adapted from M Ahmed and Sanders, 1998

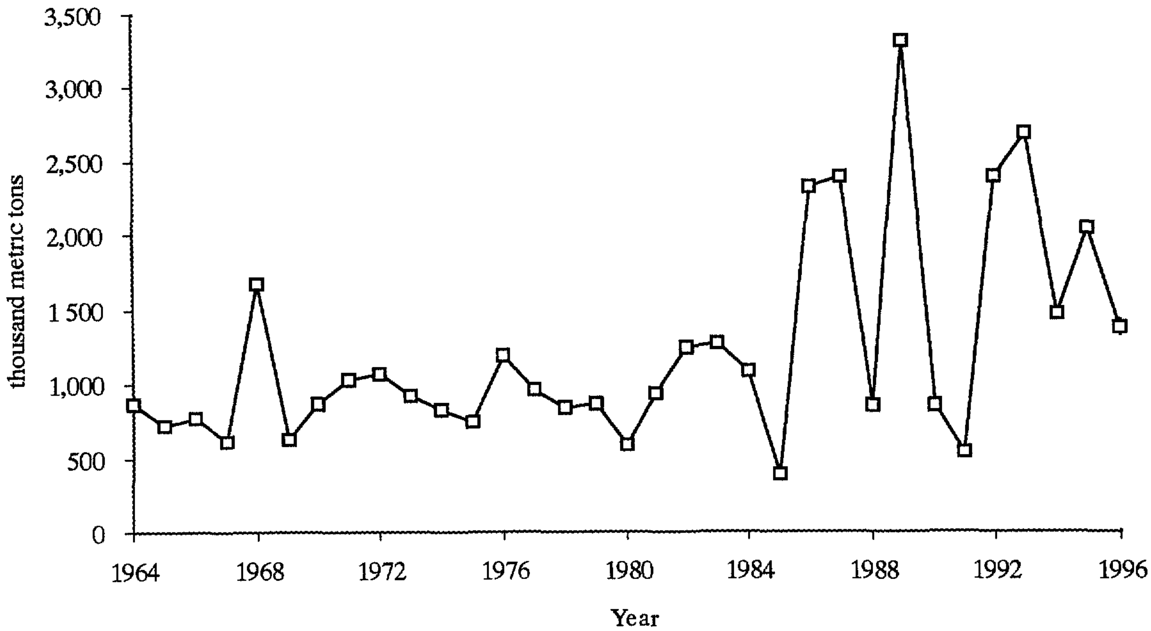

Figure 2 Sorghum output in the mechanized rainfed vertisols, 1964-1996

Table 1 Adoption of intensive technologies on the vertisols with and without land-suppy restriction and policy changes [a]

	Historic policy and unrestricted land supply	Restricted land supply	
Technology	Virgin land	Virgin land	Depleted soil
Improved sorghum	578 9	430 7	0 0
Improved sorghum + ½N[b]	0 0	126 6	0 0
Improved sorghum +½N + tied ridging	0 0	0 0	0 0
Improved sorghum +1N	0 0	0 0	402 0
Sesame	111 4	72 4	65 1
Total crop area	690 4	630 0	467 1
Rented area	60 4	N/A	N/A

[a] Risk aversion simuation is represented by a relative risk aversion coefficient of 2 at which the model approximates the observed cropping plan All area is in ha
[b] 1N denotes application of 94 kg ha^{-1} urea and ½N is 47 kg ha^{-1} urea
N/A Land is no longer available for expansion

What can be done before the rental market for land disappears? If expected yields can be moderately increased (20%) for either fertilizer level, the intensification option is chosen for both land types even with the possibility of renting land A 25% fertilizer price subsidy would have the same effect

Changes in Cereal Consumption After Devaluation in Bamako, Mali

In January 1994, the common currency in the French monetary union, the CFA, was devalued 50% with respect to foreign currencies One aspect of a devaluation is to restore the competitiveness of exports and of import substitutes The domestically produced cereals are expected to be substitutes for the imported cereals For the last two decades in a public policy environment in which one principal objective has been the maintenance of low food prices for urban consumers, the imports of rice and, to a lesser extent wheat have substantially increased

There has not been much concern with the profitability of the traditional food systems As a result, these systems retreat to subsistence Farmers produce a number of crops primarily for their own consumption and utilize few purchased inputs To break out of this subsistence, it is necessary for the production of the food crops to be profitable Then farmers will be prepared to purchase inputs and to make investments in agriculture

The prices of food imports normally increase with devaluation and to the extent that traditional cereals are substitutes, their consumption will go up and their prices also In practice, Sahelian governments often panic with higher food prices and acquire food aid or commercial food imports Note that in real terms, the price of imported rice declined 8 3% from 1993 to 1996 despite the devaluation With changes in domestic policy, the price of domestically produced rice also declined The real prices for domestic cereals and all cereals, weighted for the consumption shares, did not change with devaluation Obviously, there are many other factors operating on food prices besides devaluation Since many have argued that urban consumers have become worse off, this is a surprising result indicating apparently the degree of government intervention to protect urban consumers (Table 2) The important point here is that consumption of all cereals has increased, including the traditional cereals of sorghum and millet despite increases in their real prices

To understand the underlying factors behind consumption trends, the cereal consumption system was modeled Except for maize in both periods, own price elasticities had the correct signs Sorghum/millet was a substitute for imported rice in both periods and maize was a substitute for both imported and domestic rice As Asian rice imports become more expensive, not only will the domestic rice sector benefit from higher consumption but also the consumption of sorghum/millet will be increased, according to these results Cereal imports have been subsidized as food aid, further eroding the profitability of domestic cereal production Removal of the distortions on food prices from devaluation and other policies has potential for increasing the demand for the traditional cereals (sorghum/millet and maize) Unfortunately, governments frequently intervene with subsidized food imports when urban food prices increase

The expenditure elasticities indicate the percentage of expenditures on the item for a 1% increase in income These were reasonably high — around one — though often not significant The expenditure elasticities for maize and imported rice were substantially higher than those for sorghum/millet and domestically produced rice

New Sorghum/Millet Cultivar Introduction in Sub-Saharan Africa

In the last two decades 40 sorghum cultivars have been released in 23 countries and 16 millet cultivars in 12 countries So the process of new cultivar development is advancing in Sub-Saharan Africa We studied the returns to research for six introductions, most of which have been on farmers' fields for over a decade Then we looked at aggregate indicators of the success of these new cultivars, specifically at national yields From this sample and from comparison with other commodities, we identify two technology introduction patterns

Where hybrids were introduced with inorganic fertilizer and either irrigation or improved water retention, there were substantial yield increases and these were apparent in the aggregate yield data Where the new cultivars alone were introduced, yields remained stagnant This is illustrated for the Sudanese case comparing yield trends in the Gezira irrigated project with those in the mechanized rainfed region In both regions new cultivars have been introduced, but to increase aggregate yields over time apparently requires the complementary use of soil-fertility improvements and water (Fig 3) Similarly, comparing South African yields with national yields in three of the countries where new sorghum

Table 2 Average per-capita cereal consumption in Bamako, Mali, before (1993) and after (1996) devaluation

	1993		1996	
	Quantity (kg/person/month)	Price[a] (FCFA/kg)	Quantity (kg/person/month)	Price[a] (FCFA/kg)
Domestic rice	7 63	262	8 43	252
Imported rice	0 76 (14)(5 71)[b]	313	0 70 (13)(5 61)[b]	287
Sorghum/millet	9 71	130	10 26	136
Maize	1 34 (20)(7 05)[b]	118	2 32 (29)(8 41)[b]	145
Domestic cereals[c]	18 68	183	21 01	183
Major cereals[d]	19 44	188	21 71	186

[a] Prices are in real terms with 1996 as the base year The 1994 official exchange rate was 512 CFA/US$ (IMF Financial Statistics)
[b] Mean values for those households consuming this product Figures in the first parenthesis represent the number of households
[c] Domestic cereals include domestic rice sorghum/millet and maize
[d] Major cereals include domestic rice imported rice sorghum/millet and maize

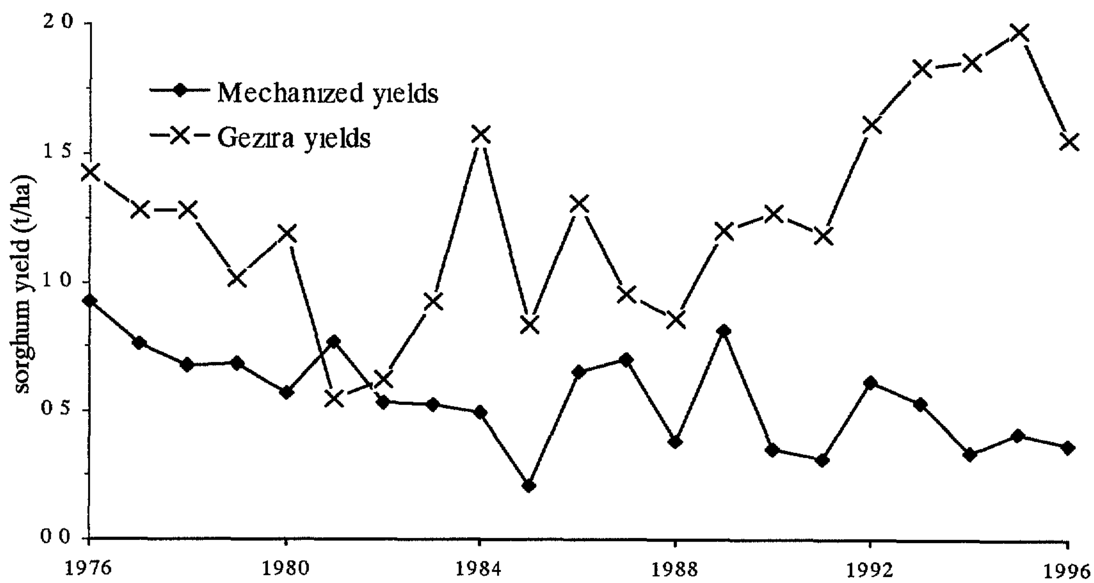

Figure 3 Sorghum yields in the irrigated Gezira and the mechanized sector of Sudan (1976-1996) Note From 1985 to 1996, the annual rate of growth of yield in the Gezira was 3% and in the mechanized zone -0 3% Source Sanders et al , 1996, Nichola and Sanders, 1996

cultivars were introduced but without moderate levels of inorganic fertilizer shows the same phenomenon (Fig 4)

Clearly, the breeding effort has been outstanding in developing new sorghum cultivars, but it is necessary to make things easier for breeders with more emphasis on improving the production environment The variety-alone strategy has been adequately tried and now a focus needs to be put on getting the input and output markets functioning better to increase the profitability of the basic cereals and to make substantial yield gains Everywhere in the world that yields have been successfully increased in semi-arid regions, more water and inorganic fertilizers have been required It is unlikely that Sub-Saharan Africa will be able to develop technology to bypass these fundamental input requirements

Networking Activities

Workshops

In August, Nina Lilja presented a selected paper on the impacts of technological change on women in Mali At this same international conference for agricultural economists in Sacramento, CA Sanders presented a paper and participated in a workshop on sustainability

In September, Jeff Vitale and Sanders gave a one-week workshop in Ghana to economists from Ghanian and other West African Anglophone countries on economic surplus methods for estimating impacts

Sanders presented a plenary paper on the introduction of technological change in Sub-Saharan Africa at the African Farm Management Association meeting in Stellenbosch, South Africa, in January 1988 Then he presented a variation of this talk at two universities in South Africa, the University of the Orange Free State in Bloemfontein and the University of Natal at Pietermaritzburg

In June INTSORMIL organized a one-day impact workshop for PIs and collaborators Sanders helped develop the program for the session gave a paper with Mohamed Ahmed reviewing the impact of new cultivars in Sub-Saharan Africa, and participated in the afternoon panel discussion

Jeff Vitale spent two months in Mali working with IER researchers in Sikasso, he participated in training programs for the IER and with INSAH courses and did fieldwork as part of the Impact project

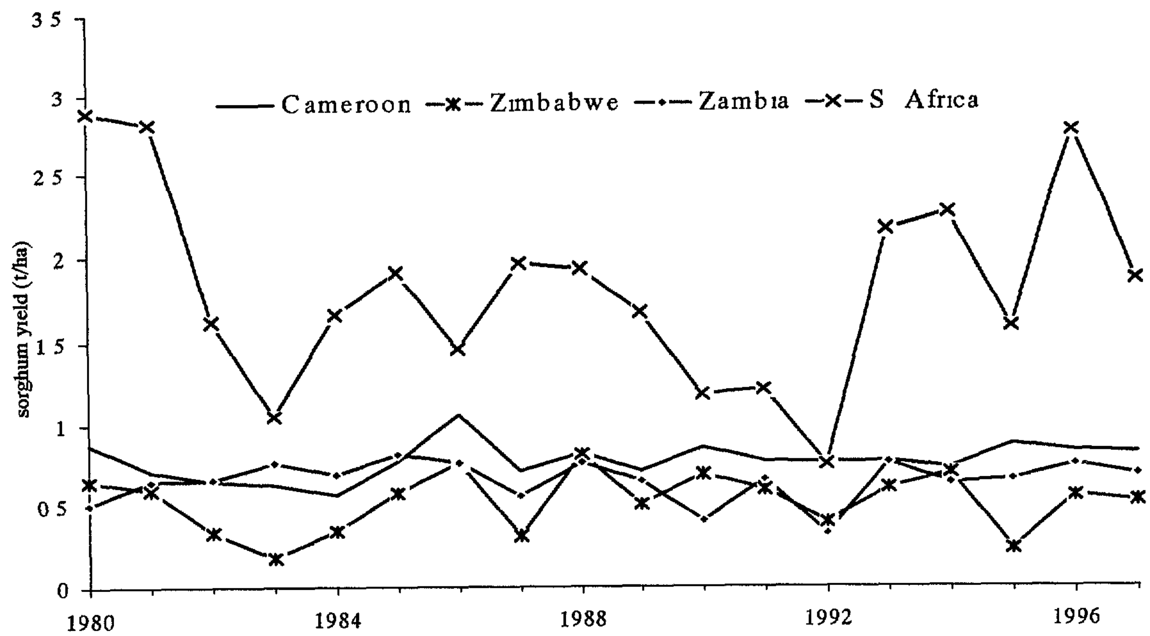

Figure 4 Sorghum yields in Cameroon, Zimbabwe, Zambia, and South Africa
Source FAO, 1998

Research Investigator Exchanges

On a three-week trip to Ethiopia in February to work on papers with Barry Shapiro, Sanders spent two days with Yeshi Chiche and her husband, Aberra Debella, both of the national sorghum program, visiting offices of government agencies and fertilizer distributors in preparation for our proposed trip in September to Ethiopia We will evaluate the introduction of new sorghum cultivars, especially those with *Striga* resistance

In April, Sanders spent ten days in Mozambique with World Vision and USAID preparing a report on the potential for INTSORMIL commodities and developing a proposal for future collaborative activities with the CRSPs

Also in April, Sanders spent ten days in Senegal working with ISRA to finish papers on the impacts of several commodity programs

Research Exchange

We have been making copies of our book available to developing country professionals As of June 1998, 176 professionals principally in Sub-Saharan Africa (but also in the drought area of Brazil) have received complimentary copies of the book, *The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa*

Publications and Presentations

Journal Articles

Coulibaly Ousmane N Jeffrey D Vitale and John H Sanders 1998 Expected effects of devaluation on cereal production in the Sudanian region of Mali Agricultural Systems accepted and forthcoming

M Ahmed Mohamed and John H Sanders 1998 Shifting from extensive to intensive agricultural systems A case study in the Sudan Agricultural Systems accepted and forthcoming

Lilja, Nina, and John H Sanders 1998 Welfare impacts of technological change on women in Mali Agricultural Economics accepted and forthcoming

Sanders John H Barry I Shapiro and Sunder Ramaswamy 1998 A strategy for technology development for semiarid Sub Saharan Africa Outlook on Agriculture accepted and forthcoming

Shapiro Barry I and John H Sanders 1998 Fertilizer use in semiarid West Africa Profitability and supporting policy Agricultural Systems 56(4) 467-482

McMillan D E J H Sanders Dolores Koenig Kofi Akwabi Ameyaw and Thomas Painter 1998 Agricultural performance of new lands settlement in West Africa World Development 26(2) 187 211

Nichola, Tennassie and John H Sanders 1997 The seed industry and the diffusion of a sorghum hybrid in Sudan Science Technology and Development 15 107 119

Published Proceedings

Sanders J and J Vitale 1998 Institutional and economic aspects of fertiliser use in West Africa Experiences and perspectives keynote address p 407 416 In Geneviève Renard Andreas Neef Klaus Becker and Matthias von Oppen (Eds) Soil Fertility Management in West African Land Use Systems proceedings of regional workshop Niamey Niger Mar 4 8 1997 sponsored by University of Hohenheim ICRISAT Sahelian Centre and INRAN Weikersheim Germany Margraf Verlag

Shapiro B I and J H Sanders 1998 Fertiliser use and supportive policy in semiarid West Africa Also in Geneviève Renard et al p 425 429
Sanders John H Sunder Ramaswamy and Barry I Shapiro 1997 Technology development for semiarid Sub Saharan Africa Theory performance and constraints In Roger Rose Carolyn Tanner and Margot A Bellamy (Eds) Issues in Agricultural Competitiveness Markets and Policies IAAE Occasional Paper No 7 p 415 424 Brookfield VT Ashgate Publishing Co
Sanders John H Sunder Ramaswamy and Barry I Shapiro 1997 Technology development for semiarid Sub Saharan Africa Theory performance and constraints In Taye Bezuneh A M Emechebe J Sedgo and M Ouedraogo (Eds) Technology Options for Sustainable Agriculture in Sub Saharan Africa, pp 19 27 Ouagadougou Burkina Faso OAU/STRC SAFGRAD Semiarid Food Grain Research and Development

Presentations

M Ahmed Mohamed and John H Sanders 1998 New sorghum and millet cultivar introduction in Sub Saharan Africa Impacts and policy implications Presented at a workshop on Impact given to the INTSORMIL PIs and collaborators in Corpus Christi TX June

Sanders John H 1998 Are women made worse off by the introduction of new technology in West African agriculture? Presentation to Dept of Agricultural Economics Purdue University May

Sanders John H 1998 Developing technology for agriculture in semiarid Sub Saharan Africa Plenary presentation at the African Farm Management conference Stellenbosch South Africa, Jan Variations of this talk were also presented at the University of the Orange Free State in Bloemfontein and the University of Natal at Pietermaritzburg Feb

Lilja, Nina and John H Sanders 1997 Welfare impacts of technological change on women in southern Mali Invited paper presented at 23rd conference of International Association of Agricultural Economists (IAAE) Sacramento CA Aug

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

Project UNL-213
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Summary

In studies on growth and nutrient uptake by diverse pearl millet genotypes in Nebraska and Niger, year (i e , environment) had the greatest effect on grain yield dry matter production and N uptake, management or N level had an intermediate effect, and genotype the least In Nebraska, applied N decreased NUE while in Niger the high management practices increased NUE in the drier 1996 growing season In both studies, genotype had minor effects on NUE except for the traditional variety Heini Kirei having lower NUE in 1996

Research indicates that ethylene is involved in germination and seedling vigor of grain sorghum Temperature and genotype influenced germination, seedling vigor in bioassays, and ethylene evolution in a similar manner across two years Bio-assays using the ethylene inhibitor 2,5-norbornadiene has potential as a screening tool for germination and seedling vigor of grain sorghum under stress temperatures

Rotation with cowpea in Mali increased grain and stover yield of pearl millet as reported in previous years Seven-year averages show the crop residue incorporation slightly increased pearl millet grain and stover yields, while crop residue removal adversely effected cowpea yields The increases in crop and stover yield over time, and the better maintenance of soil nutrient levels reported last year, suggest that leaving crop residue in the field and using crop rotation increases sustainability and productivity of pearl millet cropping systems

Technology adoption surveys in Mali indicate broad adoption of seed treatments, and in some communities, use of improved manure management techniques Improved variety adoption was only 17%, and suggests that future success in adoption would be promoted by proposing a technology package that includes improved cultivars appropriate production practices, and use of organic and/or inorganic fertilizers

Objectives, Production and Utilization Constraints

Objectives

- Conduct long-term studies to determine pearl millet/cowpea cropping systems (monoculture, intercropping, rotation) by nitrogen rate interaction effects on grain and stover yields, and nitrogen use efficiency at Cinzana and Koporo, 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, and the long-term effects on soil nutrient levels

- Conclude studies in Niger and Nebraska to determine dry matter production and partitioning, and nutrient uptake of pearl millet cultivars with different growth habits when grown under different management levels, and develop manuscripts for publication, and complete M S degree for Maman Nouri

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

- Determine the role of ethylene in grain sorghum emergence problems under stress inducing temperatures

- Convert long-term crop rotation study at Mead, NE from grain sorghum-soybean to pearl millet soybean with nodulating and non-nodulating isolines

- Publish research findings on the influence of row spacing and nitrogen application on pearl millet-grain sorghum competitiveness with velvetleaf and foxtail

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher pearl millet grain and stover yields This involves systems which increase 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 Future research efforts on manure management are planned 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 resource

Research Approach and Project Output

Pearl millet is usually grown in stressful environments with high temperatures lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length Lack of water is usually considered to be the most critical environmental factor controlling growth and limiting yield in Africa, but a source of nitrogen and/or phosphorus often is more critical This is especially true for intensive cropping systems using improved cultivars on degraded land Nutrient use and water use efficiencies are closely interwoven with higher yields possible with improved cropping systems utilizing improved cultivars Since human capital for research and extension activities are very limited for pearl millet producing areas in West Africa, the project conducts most activities either as graduate education programs for scientists from this region or mentoring collaborating activities upon return of former graduate students In the U S Great Plains, availability of high yielding, dwarf hybrids, markets, and production practices have limited it's adoption as a grain crop This complex interaction of water, nitrogen, phosphorus, cultivars and yield enhancing production practices is the focus of Project UNL-213's research efforts

Domestic (Nebraska)

Research Methods

A two-year study on growth and nutrient uptake of the pearl millet hybrids 59022A × 89-0083, 1011A × 0896R, and 1361 × 6RM having different growth habits grown at two nitrogen levels was completed by Nouri Maman as part of his M S thesis research Plots were sampled bi-weekly, plant parts separated, dried and weighed, and nutrient levels determined Data were analyzed by ANOVA and regression to determine hybrid and N level effects on grain and stover yield, dry matter production, nutrient concentrations and uptake, and nitrogen use efficiency (NUE) Bio-assays, ethylene evolution, ethylene inhibitors and seedling morphological methods have been used to study the role of ethylene in grain sorghum emergence under low and high temperatures Grain sorghum lines Naga White (Ghana), CE145-66 (Senegal), San Chi San (China) and 550590 (Russia) were chosen based on the percent germination at 14, 20, 28 and 35°C They were germinated and grown for 7 days in closed glass containers at 24°C The ethylene -action inhibitor 2 5-norbornadiene (NBD) was added at 47 7 to 95 4 mg/L at one day intervals Germination percentage seedling vigor and ethylene evolution were measured

Research Results

In 1995 and 1996 similar rainfall occurred, but July and August temperatures and evapotranspiration were much higher in 1995 In addition, poorer stands were obtained in 1995 due to soil conditions at planting and the lack of rainfall following planting Thus, grain yields were 2 7 to 3 2 Mg ha^{1} higher in 1996 than in 1995 dry matter production was 0 75 to 1 2 kg m^{2} higher and N uptake 10 to 14 4 g m^{2} greater The 1361M × 6RM hybrid produced the lowest grain yield and dry matter in both years (Table 1) Applied N of 78 kg ha^{1} increased grain yield by 0 5 Mg ha^{1} in both years, but had no effect on dry matter production in 1995 and increased dry matter production by only 0 3 Mg ha^{1} in 1996 Pearl millet dry matter accumulation increased cubically until physiological maturity with a 0 7 g m^{2} /Growing Degree Day(GDD) maximum growth rate in 1995, and quadratically with a 2 g m^{2} /GDD maximum in 1996 Nitrogen concentrations were higher during the vegetative stages and decreased with plant age Nitrogen uptake differences

Table 1 Grain yield, dry matter production, nitrogen uptake and use efficiency (NUE) of pearl millet hybrids at zero and 78 kg ha [1] N at Mead, NE in 1995 and 1996

	Grain yield Mg ha ^{1}		Dry matter kg m ^{2}		Nitrogen uptake g m ^{2}		Biomass NUE g DM/ g N		Grain NUE g Grain/ g N	
Treatments	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Hybrid (H)										
59022A × 0083 (H1)	1 4	4 6	0 31	1 5	3 6	18 0	90	82	54	48
1011A × 086R (H2)	1 5	4 4	0 32	1 3	4 1	15 0	81	89	56	50
1361M × 6RM (H3)	1 1	3 8	0 25	1 0	2 7	12 7	96	81	51	39
Nitrogen (kg ha ^{1})										
Zero	1 1	4 0	0 29	1 1	3 1	11 5	98	95	56	51
78	1 5	4 5	0 30	1 4	3 9	18 9	80	73	49	40
F test and contrast probabilities						P > F				
Hybrid (H)	NS	**	*	*	*	*	NS	NS	NS	**
H3 vs H1 + H2	*	**	NS	**	**	**	NS	NS	NS	**
H1 vs H2	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Nitrogen (N)	*	**	NS	*	NS	**	**	**	*	**
H × N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C V (%)	32	7	20	22	30	24	16	9	12	11

were largely the result of dry matter production rather than N concentration differences, and applied N decreased N use efficiency for biomass by 18 to 25 g DM/g N, and grain N use efficiency by 7 to 12 g grain/g N Environmental variability due to years had the greatest effect on yield, growth and N uptake, N rates had an intermediate effect, and hybrid the least effect

Research identified similar variation among genotypes (P = 0 03) and across temperatures (P = 0 01) for ethylene production during germination and early seedling vigor in 1996 and 1997 Germination was not affected, but normal growth of radicles and coleoptiles arrested within 24 hours of NBD treatment Radicles appeared dark and brittle, while coleoptiles prematurely ruptured to allow foliar leaf emergence When NBD was replaced at one day post imbibition with 1 3 x 10^3 mg/L ethylene, growth was restored These bio-assay and ethylene evolution results indicate that ethylene is necessary for normal grain sorghum seedling vigor Further, the NBD bio-assay appears to have potential as a screening tool

International

Niger

Research Methods

A two-year experiement to determine the dry matter accumulation and nutrient uptake of the pearl millet cultivars Heini Kirei (local), Zatib (improved tall), and 3/4 HK (Heini Kirei - improved short) grown under *Low Management* with no fertilizer application and plant population of 10,000 hills/ha, and *High Management* of 5 Mg ha ^{1} manure, 23 kg ha ^{1} nitrogen, 18 kg ha ^{1} phosphorus, and plant population of 20,000 hills/ha was completed, and was part of Nouri Maman's M S thesis Plots were sampled bi-weekly, plant parts separated, dried and weighed, and nutrient levels determined Data were analyzed to determine differences in grain yield, nutrient concentration, dry matter and nutrient uptake and partitioning, and crop growth and nutrient uptake rates

Research Results

Grain yield was 0 4 to 0 8 Mg ha ^{1} greater and dry matter production was 0 02 to 0 13 kg m ^{2} greater in 1995 than in 1996 largely due to rainfall differences (Table 2) The pearl millet cultivar 3/4 HK produced less dry matter than the other cultivars, and Heini Kirei produced the greater grain yield than other cultivars in 1995 Management level had a large impact on dry matter production in both years with high management increasing dry matter production 0 33 kg m ^{2} in 1995 and 0 25 kg m ^{2} in 1996, and increased grain yield 0 4 to 0 5 Mg ha ^{1} both years Nitrogen uptake and NUE was similar for varieties, except Heini Kirei took up less N and had lower NUE than other varieties in 1996 Management level had no effect on NUE in 1995, but in 1996 high management increased NUE Pearl millet cultivar differences, in spite of the large difference in genetic background, had much smaller impacts on grain yield, dry matter, N uptake and NUE than did the year (environment), and management level effects

Mali

Research Methods

Long-term cropping system and residue management studies were continued at Cinzana and Koporo Multi-year analyses was conducted to determine the seven-year effect of crop residue management and cropping system (continuous and rotational) on pearl millet grain and stover yields

Table 2 Grain yield, dry matter production, nitrogen uptake and use efficiency (NUE) of pearl millet varieties with high and low management at Kollo, Niger in 1995 and 1996

	Grain yield Mg ha^{1}		Dry matter kg m^{2}		Nitrogen uptake g m^{2}		Biomass NUE g DM/ g N		Grain NUE g Grain/ g N	
Treatments	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Variety (V)										
Heini Kirei (V1)	1 4	0 6	0 33	0 22	3 0	1 2	114	125	34	34
Zatib (V2)	1 1	0 6	0 35	0 22	3 2	1 7	110	93	34	29
3/4 HK	0 9	0 5	0 23	0 21	2 8	1 8	84	74	29	21
Management level										
Low	0 9	0 3	0 14	0 09	1 4	0 1	96	105	24	33
High	1 4	0 8	0 47	0 34	4 6	2 5	109	90	41	22
F test and contrast probabilities						P > F				
Variety (V)	**	NS	**	NS	NS	*	NS	**	NS	*
V1 vs V2 + V3	**	NS	NS	NS	NS	**	NS	**	NS	*
V2 vs V3	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Management level (ML)	**	**	**	**	**	**	NS	NS	*	**
V × ML	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
C V (%)	20	17	18	20	35	20	25	19	34	24

Table 3 Crop residue management effect on pearl millet grain and stover yield

Residue management	1991	1992	1993	1994	1995	1996	1997	Mean
Grain yield				kg ha^{1}				
Removed	1266	1472	1392	1327	1861	1820	1154	1469
Surface	1403	1687	1095	1424	1800	1896	1297	1515
Incorporated	1413	1750	1596	1429	1907	1981	1468	1649
LSD (0 05)	NS	NS	375	NS	NS	NS	NS	184
C V (%)	22	28	16	23	15	18	18	22
Stover yield								
Removed	3174	2604	3296	3825	4557	4150	1302	3273
Surface	3703	3066	2116	3845	4598	4028	1303	3237
Incorporated	2848	3662	3296	3805	4313	4354	2116	3484
LSD (0 05)	NS	NS	NS	NS	NS	NS	NS	NS
C V (%)	28	34	28	19	17	27	42	27

Research Results

Crop residue management treatments had no influence on pearl millet grain or stover yields from 1991-1997, except for grain yield in 1993 when plots with incorporated crop residues yielded more than those with residues left on the soil surface (Table 3) The seven-year average grain yields for plots with incorporated crop residues was180 kg ha ^{1}/year greater than plots with residue removed (significant at p = 0 07), and pearl millet stover yield in plots with crop residue incorporated was 247 to 211 kg ha ^{1} greater than plots with other crop residue management treatments (p = 0 19) These results confirm other studies that in sites with non-degraded soils and/or sites with adequate P levels crop residue management has only small effects on pearl millet yields In contrast, either surface crop residue application or incorporation increased cowpea grain yield by 186 to 240 kg ha ^{1}/year, and cowpea stover yield by 316 to 350 kg ha ^{1}/year Rotation with cowpea increased pearl millet grain yields by 228 kg ha ^{1}/year and stover yields by 628 kg ha ^{1}/year The increases in crop and stover yield over time, and the better maintenance of soil nutrient levels reported last year, suggest that leaving crop residues in the field and using crop rotation increases sustainability and productivity of pearl millet cropping systems

Technology Transfer in Mali

Technology Transfer Methods

During the past decade IER scientists collaborating with INTSORMIL Project UNL-213 have interacted with the Malien Agricultural Extension Service (PNVA) and Private Voluntary Organizations to extend improved technologies to producers in the Segou region In 1997, two farmer adoption surveys were conducted to determine adoption rates of improved technologies One survey was conducted by PNVA while the other was conducted by IER jointly with ICRISAT

Technology Transfer Results

In both surveys (Table 4), the technology adopted to the greatest extent was use of the seed treatment Apron® Plus which improves stand establishment and reduces downy mildew problems In the ICRISAT - IER survey, the communities surveyed were using improved techniques to pro-

Table 4 Adoption rates of improved pearl millet production technologies in the Segou region of Mali, 1997

Improved production technologies	Extension service (PNVA)	ICRISAT IER
	%	
Use of improved variety	17	16
Seed Treatment with Apron Plus	40	73
Improve pearl millet/cowpea intercropping	6	5
Animal traction Weed control	41	ND
Field preparation with single operator	ND	15
Manure application	40	ND
Composting of animal manure and crop residues	5	36
Animal corralling for manure production/collection	5	74

duce and collect quality animal manure for application to fields In both surveys, only 16 - 17 % of the farmers indicated use of improved pearl millet cultivars INTSORMIL Project UNL-213 personnel feel that greater future success in technology adoption would be promoted by proposing a technology package that includes improved cultivars, appropriate management practices, and use of organic and/inorganic fertilizers

Networking Activities

Workshops

American Society of Agronomy Meetings, 26 - 31 Oct 1997, Anaheim, CA

ROCAFREMI (West and Central Africa Pearl Millet Research Network) Meeting, 16 - 20, March 1998, Niamey, Niger

INTSORMIL Principal Investigator and Impact Conference, 23 - 24 June, 1998, Corpus Christi, TX

Research Investigator Exchange

Visited Nigerien and Malien research collaborators during 16 - 20 March trip to West Africa

Major Professor for M S degree for Nouri Maman (1996 - 98) and co-major professor for Ph D degree for Samba Traore (1995 - 98) Also have had frequent interactions with Minamba Bagayoko concerning Ph D thesis research conducted with the University of Hohenheim and ICRISAT Sahalien Center

Research Information Exchange

Presentation made to ROCAFREMI on research management and reporting during their meeting 16 -20 March 1998 in Niamey, Niger

Funds passed through to Mali to assist with collaborative research efforts

Computer was purchased to assist in research efforts in Niger

Publications and Presentations

Abstracts

Maman N S C Mason and S Sirifi 1997 Genotype and fertilizer influence on pearl millet growth and nutrient uptake in Niger Agron Absts p 96

Maman N S C Mason and T D Galusha 1997 Genotype and N influence on pearl millet growth and nutrient uptake Agron Absts p 96

Coulibaly A M Bagayoko S Traore and S C Mason 1998 Pearl millet yield and soil properties as influenced by crop residue management Agron Absts (In Press)

Maranville J W S C Mason and J H Sanders 1998 Improving crop production practices in Sub Saharan Africa INTSORMIL approaches and perspectives Agron Absts (In Press)

Stockton R D S C Mason S A Finlayson and P W Morgan 1998 Ethylene effect on grain sorghum germination and early seedling vigor Agron Absts (In Press)

Proceedings

Bagayoko M S C Mason and S Traore 1997 The role of cowpea on pearl millet yield N uptake and soil nutrient status in millet cowpea rotation in Mali p 109 114 In G Renard A Neff K Becker and M van Oppen (eds) Soil fertility management in West African land use systems Margraf Verlag Weikersheim Germany

Journal Articles

Limon Ortega A S C Mason and A R Martin 1998 Production practices improve grain sorghum and pearl millet competitiveness Agron J 90 227 232

Miscellaneous Publications

Andrew D J J F Rajewski and S C Mason 1998 Grain pearl millet A new crop being developed at UNL Extended Visions 2(1) 2

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-214
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Mr Seyni Serifi, Agronomy Division, INRAN, B P 60, Kollo, Niger
Dr R K Pandey, Agriculture Advisor, World Bank, Niamey, Niger

Summary

On-farm trials in Niger were conducted to study improved versus traditional cultural practices at three locations with eleven farms participating The improved culture consisted of use of manure plus inorganic nitrogen combined with tied ridges The results indicated that improved culture increased yields by 67% in the drier areas and that the new NAD-1 hybrid has excellent yield potential with better management In the wetter areas, yields were surprisingly low, i e , one t ha ^{1} or less at 700+ mm rainfall In these areas, the primary yield detriment is often factors other than fertility such as poor seedbed preparation and poor seed quality resulting in very poor stands

On-station fertility trials in Mali using inorganic nitrogen as urea and rock phosphate at Kolombada and N'Tarla stations showed that little yield enhancement occurred with use of fertility at Kolombada but a 59% increase was found at N Tarla Yields at the latter station however were less than one t ha ^{1} most likely due to poor stands The research established the yield enhancement effect of the previous crop At Kolombada, cotton was grown prior to sorghum and a 200 kg ha ^{1} dose of nitrogen was provided that crop which obviously carried over to sorghum

On-farm trials in Mali were conducted in or around three villages with six farmer participants and use of urea and rock phosphate Grain yields in these tests showed a 16% enhancement by fertilizer and a significant increase in the amount of stover produced Yields across farms ranged from 357 to 1095 kg ha ^{1} stover Stover is an important resource for producers in these regions for animal feed, fencing and shelter and increasing its production may be as necessary as increasing grain production

Studies were conducted at the University of Nebraska to determine the extent to which nitrate reductase activity (NRA) has on yield, N assimilation and N use efficiency Results showed that NRA was not correlated significantly to yield or N assimilation properties as often reported in the literature The study showed that tropical lines have high preanthesis biomass production and subsequent high biomass NUE Grain yields, however, and grain NUE are low compared to U S lines indicating the differences in dry matter distribution between these two groups Combining the superior preanthesis N accumulation capacity of the tropical types with better reproductive sinks and a sustained photosynthetic apparatus (stay green) may enhance grain yield of tropical sorghums

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
- Determine optimum nutrient (particularly nitrogen) management practices for arid and semi-arid environments
- Conduct on-farm trials to test improved management recommendations for sorghum production
- 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

International Research

On-farm Studies on the Use of Nutrients and Tied Ridges in Niger - Seyni Sirifi

On-farm studies were initiated in Niger to test improved genotypes using improved cultural practices versus traditional methods Three sites having different total seasonal rainfall averages were selected The dry location, Tillakaina, received 296 mm rainfall in 24 days with four farmers participating Konni, the medium rainfall location, received 369 mm rainfall over 28 days with three farmers participating The humid region, Bengou, received 741 mm precipitation over 53 days with four farmer participants Plots were 4m x 8m and farms were considered as replicates at each location Planting density was 0 80 m between rows and 0 40 m between hills within rows Genotypes were NAD-1, a new hybrid currently being introduced in Niger, 90SN7, an improved line, and a tall local type which is traditionally grown Improved cultural practice consisted of the application of 5 t ha^{-1} organic manure and 50 kg ha^{-1} urea combined with tied ridges to prevent water runoff Traditional culture was generally without fertility and hand weeding was used in both cultures

Grain yields presented in Table 1 are averaged over replicates (farms) per location For the dry location, Tillakaina, crop failures occurred on two farms and the data are averages of the remaining two farm participants Improved cultural practices resulted in an overall gain of 67% in grain yield although yields were generally very low, i e , below one t ha^{-1} The highest yield of 1516 kg ha^{-1} was obtained with NAD-1 using improved culture at the Tillakaina location This genotype was superior to the others when using improved culture, but did not yield well with traditional farming practices In the Bengou region, stands were very poor, especially for NAD-1 and 90SN7 with traditional culture There was also 22 0 mm of rain from July 10-29 resulting in drought during that critical period Thus, even though the Bengou region received 741 mm precipitation, yields were generally less than the two drier regions The local cultivar grown in traditional culture yielded comparatively well at Bengou

The yields for each genotype varied markedly between farms and locations For example at Konni, NAD-1 yields ranged from 563 to 1656 kg ha^{-1} with improved culture and from only 484 to 563 kg ha^{-1} with traditional culture

Table 1 Mean grain yields from on-farm sorghum trials at three locations in Niger in 1997 Treatments consisted of three genotypes grown with tied ridges plus manure and inorganic nitrogen (improved) versus the same genotypes grown with the traditional cropping practices

		Location			
Genotype	Treatment	Tillakaina[a]	Konni[b]	Bengou	Average[c]
			kg ha^{-1}		
NAD 1	Improved	1516	1078	975	1193
90SN7	Improved	778	1156	547	827
Local	Improved	765	872	973	870
	Average	1020	1035	831	962
NAD 1	Traditional	448	636	340	475
90SN7	Traditional	786	594	215	532
Local	Traditional	486	542	1060	713
	Average	573	591	538	573

[a] = average of two farms
[b] = average of three farms
[c] = average of four farms

These first year results indicate that generally, the new NAD-1 hybrid will respond to fertility inputs and that these plus water conservation culture will be required to maximize its grain yield However, sorghum yields at the farm level still remain well below what research stations have shown to be a potential Factors such as seed bed preparation and seed viability will need to be investigated

On-station Fertility Trials and On-farm Studies in Mali - Abdoul Toure

Interactions of sorghum variety, nitrogen and phosphorus were studies in dryland field tests at Kolombada and N'Tarla locations Varieties Temoin, CSM-388, Miksor-86-25-11, Miksor-86-25-20, and Miksor-86-30-42 were grown with four fertility combinations of N and P The variety Temoin is a local type, CSM-388 is an improved line, and the Miksor lines were derived from irradiation at the University of Katibougou The experimental design was a split plot with six replications Fertility treatments were 0 N, 0 P, 0 N, 46 P, and 41 N, 46 P designated F_1, F_2 and F_3, respectively Nitrogen was applied as urea and P as rock phosphate The variety was a local type grown with 0 7 to 0 8 m row spacing and 0 5 and 0 6 m between hills Fertility treatments were the same as those described in the first experiment

Yields were markedly higher at the Kolombada station than the N'Tarla station in experiment 1 (Table 2) There were no G*W*P, G*N, G*P or N*P interactions at either location At Kalombada, genotypes were significantly different for grain yield with Miksor-86-25-20 having the highest and Miksor-86-25-11 the lowest yield There was no fertility response at this location although there was a tendency for N and P additions to enhance yields

Nitrogen application significantly enhanced yields at the N'Tarla location by 59% although yields were well less than one t ha^{-1} There was no P effect or significant genotype difference although the Temoin variety (local) was numerically much less than the other varieties

The lack of response to N and the superior yield at Kolombada may have been due to the fact that the previous crop was cotton which received 200 kg ha^{-1} N the previous season

There was no significant fertility response in terms of grain and stover yields in the six on-farm trials although the N + P treatments resulted in a 16% numerical grain yield increase (Table 3) Grain yields across farms varied from an average of 357 to 1095 kg ha^{-1} grain and an average of 1123 to 3878 kg ha^{-1} stover Production on these farms using traditional culture and a local tall variety were typical in that only about 20% of the total biomass was put into grain Stover, however, serves as a significant resource for animal feed and construction material and may be as important as grain The extremely low grain yields on some farms however (Table 3), indicate that factors other than nutrients are limiting When traditional culture is used in on-farm trials, water conserving techniques are not always employed This will be critical if response to nutrients is to be maximized

Domestic Research and Research Related to Student Training

Nitrate Reductase Activity of Diverse Grain Sorghums and its Relationship to N Use Efficiency - Abdoulaye Traore

Field experiments were conducted using seven diverse grain sorghum genotypes (one hybrids, two U S adapted lines, and four tropical lines) to characterize and compare the seasonal trend in nitrate reductase activity (NRA) among these genotypes and to determine how NRA is related to total plant N, yield, and N use efficiency (NUE)

Table 2 Mean grain yields for five sorghum lines grown at different applied N and P levels at Kolombada and N'Tarla locations

	Grain yield (kg ha^{-1}) Kolombada						
	No P			+ P			Genotype
Variety	No N	+ N	Mean	No N	+ N	Mean	Mean
Temoin	1332	1531	1431	1372	1263	1317	1374
CSM 388	1530	1419	1475	1329	1258	1294	1384
Miksor 86 25 11	1048	990	1019	1018	1086	1052	1035
Miksor 86 25 20	1349	1183	1266	2001	2194	2098	1682
Miksor 86 30 42	1474	1465	1469	1443	1581	1572	1491
Mean	1346	1317	1332	1433	1476	1454	1393
	N Tarla						
Temoin	314	592	453	324	260	292	373
CSM 388	493	777	635	443	608	526	581
Miksor 86 25 11	509	823	666	400	850	625	646
Miksor 86 25 20	483	840	661	334	744	539	600
Miksor 86 30 42	509	728	618	450	556	503	561
Mean	462	753	607	390	604	497	552

Table 3 Grain and stover yields and harvest index yields from six on-farm trials in the Kangaba, Ouelessebougou and Banamba regions using applied N and P and traditional culture

Farmer	Fertility treatment	Grain yield	Stover yield	Harvest index
		kg ha-1		
Madou Samake	N P	933	3517	19
	+N P	1074	3788	20
	+N+P	1234	4328	29
Bakary Sacko	N P	811	2232	24
	+N P	1948	2976	24
	+N P	799	2381	23
Soumaila Samake	N P	1181	451	19
	+N P	885	43472	18
	+N+P	1219	2222	32
Issaba Samake	N P	1007	2674	25
	+N P	947	2274	27
	+N+P	1225	3344	24
Housseii Kante	N P	386	9011	24
	+N P	489	1190	26
	+N+P	383	1190	21
Sekou Samake	N P	303	1322	16
	+N P	251	991	16
	+N+P	516	1652	20
		Overall fertility means		
	N P	770	2542	21
	+N P	783	2449	22
	+N+P	896	2520	23

Two levels of N were used 0 and 100 kg ha ^{1} applied as ammonium nitrate in four replicated four row plots 7 0 m long and 0 75 m spacing NRA and total N were determined at the 10-leaf, flowering and physiological maturity stages

The results showed that applied N increased grain yield and that the hybrid produced greater yield (4767 Mg ha ^{1}) than the U S adapted (2958 Mg ha ^{1}) and tropical lines (3031 Mg ha ^{1}), the latter two being similar Kernel weight was not affected by N application Tropical lines had more rapid and greater shoot biomass production than the other genotypes, typical of this group of sorghums which are semi-tall (1 75 m to 2 m) This also resulted in the tropical lines accumulating more preanthesis N than the other groups Shoot N concentration, however, was greater in the U S group at maturity than the hybrid or tropical group

Nitrogen use efficiency (Table 4) differed among genotype groups and N treatments NUE for both biomass and grain production was significantly reduced by applied N, a common observation in sorghum At maturity, tropical lines had greater biomass NUE than U S adapted lines and the hybrid Grain NUE was greater for the hybrid (53 0 g g ^{1}) than U S adapted (46 5 g g ^{1}) or tropical (45 2 g g ^{1}) lines The higher biomass NUE and lower grain NUE for tropical lines indicates a major difference from U S lines in dry matter partitioning They have also been selected for centuries under low N supply and their forage production is important Masi observed that tropical lines selected in Africa had greater root branching, distribution and abundance (INTSORMIL Annual Report, 1995)

NRA was not significantly different between N levels (Table 4) which is in contrast to most observations There was also no difference in NRA among groups although M35-1 had less NRA than others at anthesis NRA decreased with plant age, but was not correlated with yield or N assimilating traits (Table 5) It was concluded that this enzyme was not the primary factor limiting yield, N accumulation or its efficient use The tropical lines had high N uptake capacity and rapid vegetative growth that led to greater biomass N use efficiency However, their lower reproductive sink capacity limits their grain yield potential and their grain NUE Combining N accumulation capacity of tropical lines with traits such as large reproductive sink capacity, N remobilization capacity during grain fill, postanthesis N accumulation capacity and sustainability of the photosynthesis apparatus (stay green character) should improve tropical sorghum yield potential

Networking Activities

Project UNL-214 has continued strong research collaboration with Dr R K Pandey of the World Bank We have followed through on our initial agreement that World Bank will support the operating budget for collaboration with Seyni Sirifi and UNL-214 will purchase equipment During 1997, UNL 214 supplied an Omega Model 0S86-LS infrared thermometer to INRAN at a cost of $1475 00

Table 4 Biomass N use efficiency (NUE_1), grain N use efficiency (NUE_2) and NRA at three growth stages for seven grain sorghum genotypes at 0 kg N ha^{1} (N 0) and 100 kg ha^{1} (N 100)

Treatments	Vegetative	Biomass NUE Anthesis	Maturity	Grain NUE	Vegetative	NRA Anthesis	Maturity
		g g^{1}				µmol NO_2 cm^{2} h^{1}	
N levels							
N0	46 4	94 1	96 7	49 6	1 06	0 70	0 26
N100	44 4	73 8	78 2	42 1	0 97	1 10	0 41
Hybrid							
HH 640	49 0	75 8	82 8	53 0	0 78	0 56	0 28
U S Adapted lines							
CK60	48 1	75 3	82 8	51 7	0 75	0 79	0 31
P720	39 9	65 1	66 9	35 6	1 22	1 08	0 34
Mean	44 9	78 5	81 7	46 5	0 99	0 94	0 33
Tropical lines							
M35 1	42 7	91 0	89 9	32 6	1 30	0 55	0 33
Malisor 84 7	43 2	78 2	83 5	48 1	1 27	1 33	0 40
S34	48 4	107 2	110 5	47 8	0 92	0 82	0 35
VG 146	46 7	95 1	95 4	52 1	0 87	1 19	0 32
Mean	45 3	92 9	94 8	45 2	1 09	0 97	0 35
Overall mean	46 4	82 4	86 4	48 2	0 95	0 82	0 32
LSD_{05} N level	5 8	18 8	12 4	5 2	0 88	0 83	0 35
LSD_{05} Genotype	5 6	17 8	11 3	4 4	0 86	0 76	0 32

Table 5 Pearson Correlation Coefficients of gra.r y e'd (YLD), shoot biomass (SBS), shoot N concentration (SNC), shoot N content (GSN), nitrate reductase activity (NRA), seasonal reduced N input (SNI), grain N concentration (GNC), grain N content (GGN), biomass N use efficiency (NUE_1), N utilization efficiency (NUE_2)

	YLD	SBS	SNC	GSN	NRA	SNI	GNC	GGN	NE_1	NE_2
YLD	1 00									
SBS	0 40	1 00								
SNC	0 63	0 38	1 00							
GSN	0 67	0 92*	0 01	1 00						
NRS	0 48	0 02	0 40	0 13	1 00					
SNI	0 26	0 01	0 16	0 02	0 45	1 00				
GNC	0 60	0 27	0 86*	0 01	0 52	0 22	1 00			
GGN	0 70	0 10	0 40	0 23	0 15	0 65	0 34	1 00		
NE_1	0 29	0 67	0 92*	0 32	0 26	0 04	0 72*	0 16	1 00	
NE_2	0 96*	0 39	0 64	0 65	0 24	0 42	0 66	0 72*	0 30	1 00

* ** significant at 0 05 and 0 01 probability levels respectively

Participated in a three week trip to four countries in Africa (Ghana, Senegal, Mali and Niger) to review and establish links to the InterCRSP activity with Bean/Cowpea CRSP and World Vision International (WVI) As a result of this trip, project UNL 214 anticipates a new collaborative project in Ghana with the Savanah Agricultural Research Institute (SARI) beginning sometime in 1999 with an agronomist, Samuel Buah, who is currently finishing his Ph D at Iowa State University Research proposals are being formulated for this collaborative implementation

Publications

Traore A 1998 Physiological contributions to nitrogen use efficiency in grain sorghum Ph D diss Univ of Nebraska 132 p

Masi C E A and J W Maranville 1998 Evaluation of sorghum root branching using fractals J Agric Sci (Cambridge) (In press)

Buah S S J J W Maranville A Traore and P J Bramel Cox 1998 Response of nitrogen use efficient sorghums to nitrogen fertilizer J Plant Nut (In press)

Germplasm Enhancement

and Conservation

Breeding Sorghum for Increased Nutritional Value

Project PRF-203
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Summary

Two major achievements of this project will be cited

Seed Production of NAD-1 in Niger

The sorghum hybrid, NAD-1, was released in Niger in 1992 The hybrid was developed from collaborative research between the Nigerien sorghum breeders and INTSORMIL breeders at Purdue University In Niger, the hybrid was involved in on-farm demonstrations where it raised excitement among farmers In 1995, INRAN (Institut National de Recherches Agronomiques du Niger) and INTSORMIL-Purdue (International Sorghum and Millet CRSP) expressed interest in using this hybrid to launch a seed production and marketing activity in the private sector That seed production in the private sector is now widely accepted in Niger

Testing indicated a 40 to 65% increase in yield compared to the best local varieties Yield results from on-farm demonstrations have ranged from 3000 to 4500 kg ha^{-1} with adequate moisture to 1200-1500 kg ha^{-1} on dryland (the national average is around 270 kg ha^{-1}) Farmer enthusiasm and interest is strong

Production and marketing of seed in the private sector is not new in Niger Rice seed used in the country is produced by a coop Seed of onions is privately produced and marketed A company, Agrimex, markets vegetable seed through a well organized marketing program, and their seed comes from Holland ICRISAT expects to have hybrid pearl millet ready for seed production in 1999 They currently are involved with experimental seed production There is some use of hybrid maize seed coming from Nigeria, but hybrid maize is currently being developed in Niger, some of this being done privately Pearl millet is grown on over 3 million hectares and sorghum on over 1 5 million hectares in the country, providing ample marketing opportunity The successful establishment of a seed industry in Niger would stimulate the establishment of industries in other West African countries, particularly Mali and Burkina Faso

A Hybrid Seed Workshop for W Africa will be held in Niamey, Niger on September 28 through October 2, 1998 The purpose of the workshop is to acquaint W African sorghum and millet research scientists about the benefits of hybrid seed for W Africa Several speakers will discuss relevant hybrid seed experiences in their own developing countries, including India, Zambia, Sudan, and Brazil The goal is to explore opportunities for development of sorghum and pearl millet hybrids for W Africa and to assist the development of a private sector seed industry which brings many benefits to farmers in W Africa

Brown Midrib (BMR) Sorghum-Sudangrass

Several years ago Purdue/INTSORMIL produced several brown midrib mutants in sorghum by chemical mutagenesis These mutants were evaluated for their reduction in lignin content and for improved dry matter digestibility Three of these mutants were fully characterized and released to the seed industry for incorporation into commercial forage varieties Several companies have backcrossed the low lignin genes into sudangrass so that sorghum-sudan hybrids can be produced Sorghum sudangrass hybrids are a very high yielding forage grown on several million acres in the United States alone The forage yields are very high, but the forage quality is generally lower than other forage grass species This can now be remedied by the incorporation of the brown midrib gene in sorghum-sudan hybrids They are also extensively utilized in Asian countries as a forage crop

Several seed companies are now producing seed of brown midrib sorghum sudangrass commercially Response of livestock producers has been excellent due to improved digestibility and significantly improved palatability Dairy farmers are the first to see the benefits of the improved nutritional quality in increased milk production There are approximately five million acres of sorghum sudangrass in the United States at the present time, compared with nine million acres of hybrid sorghum for grain production The potential of brown midrib sorghum sudangrass in W Africa is being explored through collaboration with Dr Issoufou Kapran The value of forage in W Africa is high and there is a chronic shortage of good quality forage which we believe can be partially alleviated by brown midrib sorghum sudangrass hybrids

Objectives, Production and Utilization Constraints

Objectives

- Collaboration with Issoufou Kapran to develop the hybrid seed production potential in Niger so that this well adapted and well accepted sorghum hybrid NAD-1 can be produced for utilization in Niger
- Collaborate with Bruce Hamaker to develop rapid screening techniques for breeders to assess the new high digestibility trait recently discovered by Dr Hamaker in germplasm from our program
- To determine the inheritance of the recently discovered sorghum cultivars with very high digestibility and to incorporate this trait into improved African and U S sorghum germplasm
- Improve forage quality of sorghum stover for better ruminant animal nutrition
- Train LDC and U S scientists in plant breeding and genetics with special emphasis on exposure of graduate students to the U S seed industry All graduate training at Purdue involves active involvement for every graduate student in plant breeding with hands-on experience with new technologies including sorghum transformation and molecular marker studies through collaboration of PRF-203 with other Purdue University scientists

Constraints

Sorghum and millet production in W Africa is limited by the lack of high yielding cultivars with superior grain quality for utilization as a subsistence cereal by people in West Africa This project addresses improvement of sorghum yield potential through utilization of elite sorghum lines and hybrids with good food grain quality An additional constraint addressed is the lack of a viable private seed industry in West Africa which would allow the exploitation of heterosis or hybrid vigor for the benefit of agriculture in West Africa Experience in the rest of the world has shown that pure lines have a significant role to play, but also that there are opportunities for utilization of hybrid cultivars of sorghum and millet with benefits for both increased stress tolerance and high yield potential under appropriate management

Both sorghum and pearl millet are usually grown under stress conditions (particularly moisture and temperature) in semi-arid environments Most cereal breeders acknowledge the benefits of heterosis in providing superior performance of hybrids when grown under stress conditions The evidence for this superior stress tolerance of hybrids, however, is not always readily available, and is frequently anecdotal Seed producers in Indiana, for example, frequently credit a drought in the mid 1930s for demonstrating the superiority of maize hybrids over open-pollinated maize varieties Maize breeders in Wisconsin frequently would say that hybrid maize was more quickly adopted in the peripheral areas of the cornbelt than in the central cornbelt, presumably because of the better tolerance of hybrids to cold stress

Dwight Tomes, at Pioneer, used the frequency of corn acres planted that were harvested as a measure of the superior yield stability of hybrids During the ‘normal’ years in the 1920s and 1930s when open-pollinated varieties predominated, about 85% of the corn planted was harvested During the drought stress years of 1934 and 1936 harvest rates dipped to only 61% and 67% After widespread adoption of hybrids (1940 and beyond), the proportion of harvested hectares has fluctuated from 85 to 92%, regardless of the environment of any particular year However, the yield in each of these high stress years was lower than that recorded in more normal years

Superiority of sorghum hybrids over inbred lines in stress environments was reported by Quinby in 1958 They found that the hybrid yield increase was 58 percent over the best parent under dry-land conditions, but only 22 percent under irrigation conditions in Texas, U S The actual mean yield increases were 612 kg ha^{-1} under dry-land conditions, and 790 kg ha^{-1} under irrigation From the results of 391 trials carried out in four countries Doggett concluded that the yield increases of the sorghum hybrids relative to the open pollinated varieties are constant over a wide range of growing conditions and management levels Under conditions of low varietal yield levels, hybrids can give more than double the variety yield In Sudan, Dr Ejeta identified three elite hybrids with a combined mean yield of 50% over the best open-pollinated local varieties in a total of 27 yield trails over four seasons One of these hybrids was released (HD-1) as the first sorghum hybrid in Sahelian Africa

A recent experiment by Yahia Ibrahim in Gebisa Ejeta's laboratory confirms the superiority of sorghum hybrids across a wide range of environments Extensive resources from both public and private sector institutions were utilized to conduct this experiment A total of 126 different sorghum genotypes were tested in an international yield trial over 15 different environments in the U S , Africa, and South America Genotypes tested include 30 inbred lines and their hybrids on each of three A-lines, commercial hybrids, and B-lines

The results showed that genotypic × environmental (G × E) interaction did not alter the relative rank of cultivar types than inbred lines in all environments Differences between mean yield of hybrids and their parental inbred lines were greater in stress environments than in favorable environments They concluded that hybrid varieties were superior to inbred lines in all environments and sorghum hybrids appeared to be more reliable than inbred varieties in erratic environments typical of sorghum growing regions in the semi-arid tropics

Research Approach and Project Output

Sorghum Hybrids in Niger

A case history of the development of the sorghum hybrid NAD-1 in Niger was presented in last years annual report The report this year will focus on recent experience of the production of hybrid seed in Niger and under conditions prevalent in the Sahel The focus will be on a West African hybrid sorghum and hybrid millet seed workshop which will be held in Niamey, Niger, September 28 through October 2, 1998

Experimental seed production NAD-1 seed production by INRAN grew from a 200 m_2 plot in 1989 to several hectares today Under good management, the equivalent of 1 5 t ha ^{1} of hybrid seed has been obtained The repeatability of hybrid seed production is now in progress by Kapran and House with INTSORMIL, INRAN, McKnight Foundation, ICRISAT and World Bank support

Seed Business Activity

Having a hybrid that appeals to farmers and can be produced are key elements for seed marketing For the first time in Niger, eight tons of hybrid seed was sold in 1996 at a price eight times that of sorghum grain However, INRAN, as a public research organization, has no mandate for commercial seed activity We are actively approaching extension, farmer coops, and individuals that potentially could turn into commercial seed producers

It is concluded that heterosis can be used to improve agricultural productivity in Niger and similar Sahelian countries Sorghum hybrid NAD-1 also demonstrates the value of heterosis in other important crops like millet The momentum created by this hybrid is today being used by INRAN, INTSORMIL, and the Sahelian Center of ICRISAT, to educate policy makers and private producers on the need for, and the advantages of launching a seed industry in Niger The role of the private sector will be paramount, but the involvement of the public sector in appropriate activities is also essential

Seed Industry

The paradox is that in spite of the fact that sorghum and pearl millet are usually grown under stress conditions, agricultural policy makers and sorghum researchers in many developing countries have been reluctant to adopt sorghum hybrids They believe that hybrids are adapted to, and therefore profitable only under high-yielding favorable environments, where modern production practices are widely employed and production inputs are available

The lack of a viable private-sector seed industry in many countries is the major impediment to the utilization of hybrids in sorghum and pearl millet There are many reasons for this predicament It seems clear that the availability of well adapted hybrids can be used as a tool to foster the development of a successful seed industry in the private sector with all of the accompanying benefits

The best example of this is the Indian experience of the last 40 years A Rockefeller team of 14 scientists laid the groundwork for the development of hybrid maize and sorghum in India An indigenous seed industry which now numbers over 35 companies has emerged with significant impact on food production in India This is an aspect of the "green revolution" in India which is not well known outside India, but has important implications for other newly developing countries, especially in Africa We all need to know more about this experience, and the individual scientists, government policies, and entrepreneurial businessmen who made it happen At times it seems the world has forgotten the importance of seeds and seed technology in delivering agricultural research to the farmers

Develop Rapid Screening Techniques for Breeders to Assess the New High Digestibility Trait Recently Discovered by Dr Hamaker in Germplasm from our Program.

A new rapid screening technique, which measures disappearance of alpha kafirin in sorghum grain has been developed by Bruce Hamaker The test is rapid and readily distinguishes between normal sorghum and the highly digestible sorghum cultivars Details of the assay can be found in this report in the section by Bruce Hamaker It is significant that we now have a screening technique that is rapid and accurate and can be applied to large populations of breeding materials so that progress can be made in improving the agronomic value of lines with high protein digestibility This has been a severe limitation in the past and we are now in a position to screen breeding populations and world collection lines of sorghum at a rate of approximately 60 samples per day This should allow significant progress in breeding for this important trait for both human and animal populations We are currently in the process of confirming in vivo the results from in vitro laboratory tests Test with chicks have verified the in vivo value of highly digestible sorghum Tests with swine and ruminant animals is in progress at the current time

Identification of Molecular Markers Linked to High Protein Digestibility and or High Lysine in High Lysine Sorghum Lines

Lexington Nduulu is a graduate student from the Machakos Dryland Station in Kenya currently studying at Purdue The identification of molecular markers which can be used to tag the high digestibility trait in sorghum will comprise the bulk of his Ph D thesis research He is now evaluating breeding materials and characterizing them for protein digestibility, lysine content, and identification of linked molecular markers The most favorable makers for this study will be SSRs (Single Sequence Repeats) Data from Gary Hart, in Texas, has been used in these studies along with molecular markers, which he kindly provided to Purdue for these studies

Improve Forage Quality of Sorghum Stover for Better Ruminant Animal Nutrition

Chemically induced brown midrib (bmr) mutants of sorghum [*Sorghum bicolor* (L) Moench] were characterized with regard to phenotype, fiber composition, and in vitro dry matter disappearance (IVDMD) several years ago The recessive bmr genes produced brown pigmentation in the leaf midrib and stem of mature plants Pigmentation varied among mutants in intensity, time of appearance, and degree of fading as plants matured Ten of the 13 mutants had significantly less stem lignin than their normal counterparts Reductions in lignin ranged from 5 to 51% in stems and from 5 to 25% in leaves In the case of other fiber components, only occasional differences were observed between normal and mutant plants Increases in IVDMD and IVCWCD of as much as 33 and 43%, respectively, were associated with the presence of bmr genes Seed company researchers have now incorporated one of our low lignin brown midrib genes into both parents of a sorghum × sudangrass hybrid Results on improved palatability and performance of the brown midrib cultivar have been excellent and commercial studies have shown the brown midrib hybrid seed is producible on a commercial scale Currently, in vivo studies confirm the higher digestibility for dairy and beef animals that were seen in our earlier studies using in vitro tests In 1996, approximately one million pounds of seed of the brown midrib sorghum-sudan hybrid was produced by just one company This company will produce seed to plant 750 thousand acres in 1999 Other companies are in the process of converting their sorghum-sudan hybrids to brown midrib types

Train LDC and U S Scientists in Plant Breeding and Genetics with Special Emphasis on Exposure of Graduate Students to the U S Seed Industry

Graduate student education continues to be an important and vital activity of our INTSORMIL program A partial listing of graduate students who have completed degrees with Purdue INTSORMIL support (Axtell, Ejeta, and Hamaker) was presented in last years annual report Students can be divided into roughly four categories according to their current employment activities

Academic Appointments	7
National Program Scientists	17
Seed Industry Scientists	13
International Center Scientists	9

A wide variety of employment opportunities are available to INTSORMIL graduates and the above list reflects the range of opportunities for our students Many of these students are now in key positions in the private sector, national research programs, international centers, and academia It is noteworthy that Dr Ronald Cantrell, an INTSORMIL collaborator at Purdue, has recently been named Director General of the International Rice Research Institute (IRRI) The training at Purdue provides basic research skills and applied practical plant breeding experience For example, one of our current graduate students, Mr Carlos Carvalho, from Brazil, has recently reported the first successful experiment on sorghum transformation using the *agrobacterium* system A report of his activities is a good example of the depth of research training at Purdue which accompanies the practical field experience in sorghum breeding His research was reported in June 1998 at the Third Latin-American Plant Biotechnology Symposium in Havana, Cuba The report is as follows

"Sorghum transgenic plants were produced from immature embryos co-cultivated with *Agrobacterium tumefaciens* LBA 4404 (pTOK233) Stable integration, expression and inheritance of the transgenes were demonstrated by molecular analysis of transformants in R_0 and R_1 generations Among various factors that affected transient expression the use of Pluronic F-68 significantly increased transient expression after co-cultivation Transient GUS expression was useful during protocol optimization, though its pattern was not uniform in transgenic tissues Histochemical GUS activity was higher in younger leaf tissue than in older leaf tissue, and it was not detected in roots Overall, floral tissues had higher GUS activity than the other tissues "

A second example of significant research results achieved by this project was presented and a Ph D thesis awarded to Dr Issoufou Kapran in January 1998 This also reflects the quality of training received by INTSORMIL students at Purdue His abstract follows

"Maturity is a critical trait for better adaptation and productivity of sorghum [*Sorghum bicolor* (L) Moench] in stress environments where this crop is usually grown Despite accrued knowledge of how genotypes with different maturity respond to environments, breeding efficiency is still limited by poor characterization of individual quantitative trait loci (QTL) affecting this trait The objective of this research was to identify factors of sorghum maturity through DNA marker association, and to determine their relationships with other important agronomic traits The 10% earliest and 10% latest maturing sorghum lines were identified in FGxM90812 (Cross 1) and MMxSEPON72 (Cross 2) Parents and progeny were evaluated at one temperate location in the US and six semi-arid tropical locations in Niger For each cross, maturity (days to anthesis), plant height, and grain yield data were statistically analyzed considering six alternative groupings of locations Genetic variability for maturity and plant height was high For grain yield however there was significant genetic variability only in Cross 2 under rainfed conditions of Niger Seventy-three random amplified polymorphic DNA (RAPD) and six simple sequence repeat (SSR) markers in Cross 1, and 62 RAPD markers in Cross 2, were used in single marker analyses In Cross 1, 17 of the 79 markers (22%) detected maturity loci with stable expression across environments Most of these markers also identified plant height factors in all environments, but grain yield and maturity were related only when the temperate location was included In Cross 2 four markers out of 62 (6%) detected maturity factors in all environmental settings In this cross, maturity influenced plant height and grain yield especially under rainfed conditions in Niger A set of 121 recombinant inbred lines (RIL) independently developed from Cross 1 was used to confirm association of six of the above DNA markers with maturity factors Four RAPD and two SSR collectively explained 47% of the phenotypic variation for maturity in the RIL They mapped to one genomic segment defining the position of a putative QTL for maturity in sorghum "

Networking Activities

Workshops

The West African Hybrid Sorghum and Millet Workshop will be held September 27 -October 2, 1998 A steering committee met in January 1998 to develop the program and identify potential speakers and attendees A steering committee in W Africa has been assembled by INRAN to react to and to modify the program according to the needs of W African National Research Program Scientists The focus of the workshop will be to build on a successful seed production effort of sorghum hybrid NAD-1 during 1997 A total of eight tons of seed was sold in Niger in 1998 NAD-1 and several new hybrids were produced in Mexico last winter for demonstration plots at the Workshop Dr Kumar, from ICRISAT, will also demonstrate some pearl millet hybrids developed by his ICRISAT Program at the ICRISAT Sahelian Center (ISC) The seed production effort in 1998 involved a major effort by Dr Lee House, with McKnight Foundation and World Bank support, under the auspices of the Purdue INTSORMIL Project (PRF-203 and PRF-209) Dr House made three extended trips to Niger in 1998 and has documented progress on hybrid seed production in trip reports on file at the INTSORMIL/Niger Office at Purdue (Katy Ibrahim)

A second workshop activity during 1998 was a training program conducted at the ICRISAT Sahelian Center in the Spring 1998 by Lee House and Issoufou Kapran Training was on elements of hybrid seed production for INRAN and World Bank technicians in Niger This activity was very useful and productive during the growing season and will definitely be repeated in the Spring of 1999 A practical training manual on hybrid seed production in Niger was prepared in English and French

Research Investigator Exchange

A number of sorghum scientists from the U S and throughout the world were involved in exchanges during 1997-98 Dr Robert Schaffert from the EMBRAPA program in Brazil is spending a one year sabbatical leave as a visiting professor at Purdue University Support is provided by EMBRAPA One of our main activities has been to host a conference on the development of sorghum hybrids which are tolerant to the acid high aluminum savannas in Brazil (CERRADO), held during the Spring 1998 A major topic of discussion was how to transfer the very successful experience in Brazil to many problem soil areas in Africa This workshop was supported by the Rockefeller Foundation

Germplasm and Research Information Exchange

Numerous requests for germplasm and information were received and distributed to collaborators in Africa, South Asia, and Latin America This includes sorghum genetic stocks and breeding lines, and reprints from INTSORMIL research at Purdue An important "HOW TO" manual on the elements of hybrid seed production for Niger was produced in both English and French

Inter-CRSP support provided significant research equipment for the cereal chemistry lab in Niger This includes a pilot couscous apparatus and funds for Dr Adam Aboubacar to attend training in France and installation of the equipment with French technicians in Niamey, Niger

Publications and Presentations

A very useful practical training manual on hybrid seed production was published in French and English for use in training activities in Niamey, Niger Other publications include the following

Axtell, J D I Kapran Y Ibrahim G Ejeta, and D Andrews 1998 Heterosis in sorghum and pearl millet Coors J (ed) The Genetics and Exploitation of Heterosis in Crops CIMMYT Press Mexico City Mexico

Kapran I J Axtell G Ejeta, and T Tyler 1998 Expression of Heterosis and Prospects for Marketing of Sorghum Hybrids in Niger Coors, J (ed) The Genetics and Exploitation of Heterosis in Crops CIMMYT Press Mexico City, Mexico

Oria, M P , B R Hamaker and J D Axtell 1998 A highly digestible sorghum cultivar exhibits a unique folded structure of endosperm protein bodies Proc National Academy of Sciences USA (In Press 1998)

Weaver C B Hamaker, and J D Axtell 1998 Discovery of grain sorghum germplasm with high uncooked and cooked in vitro protein digestibility Cereal Chem (In Press)

Carvalho C H S U B Zehr N Gunaratna T K Hodges and J D Axtell 1998 Genetic transformation of sorghum via *Agrobacterium tumefaciens* Third International Plant Biotechnology Symposium Havana, Cuba

Kapran Issoufou 1998 Quantitative trait loci for sorghum maturity and their influence on agronomic traits in diverse growing environments Ph D thesis Purdue University W Lafayette IN

Hamaker B M P Oria C A Weaver and J D Axtell 1997 Improved sorghum nutritional quality In Proceedings International Symposium on Quality Protein Maize 1964 1994 Sete Lagoas Brazil

Hamaker B R J D Axtell, and J D Hancock 1997 Nutritional quality of sorghum and pearl millet Proc International Conference on Genetic Improvement of Sorghum and Pearl Millet Lubbock TX Sept 1996

Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Drought, *Striga*, and Grain Mold

Project PRF-207
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Summary

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limiting production, knowledge of germplasm, and an 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-207 attempt to address these essential requirements

PRF-207 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 19, we report on the results of two major studies conducted under PRF-207 that were recently published The first study involves an evaluation of near-isogenic sorghum lines contrasting for quantitative trait loci (QTL) markers associated with drought tolerance Following our earlier findings of several QTL markers associated with drought tolerance, we developed isogenic lines to test the phenotypic effects of three genomic regions associated with various measures of agronomic performance in drought and non-drought environments In most cases near-isogenic lines (NILs) contrasting for a specific locus differed in phenotypes as predicted based on earlier QTL analysis Further analysis indicated that differences in agronomic performance may be associated with a drought tolerance mechanism that also influences heat tolerance

In the second study we tested the use of molecular markers to assess genetic diversity and taxonomic relationships in collections of sorghum germplasm Traditionally, sorghum germplasm are classified into taxonomic groups based mainly on morphology of the inflorescence (grain shape, glume, and panicle shape) Considering that the panicle of sorghum is only a small portion of the total genome of the species, it is perhaps unwise to base total differentiation of the species on such a limited component of the genome In an evaluation of 190 entries, we detected a high level of genetic variation among genotypes Partitioning the genetic

variation in cultivated sorghum revealed that 86% of the total genetic variation occurred among accessions and 14% among races Examining the degree of association among accessions with their geographic areas of origin, we found that, contrary to our expectation, only 13% of the total genetic variation was attributable to divergence among regions This is perhaps due to our global sampling that lacked sharp differentiation of areas of special adaptation for the crop Despite such limited differentiation among races or regions, Random Amplified Polymorphic DNA (RAPD) markers successfully identified races and regions with maximum genetic diversity We believe that molecular markers may optimize sampling of genetically divergent accessions for introgression into breeding pools

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

Research Approach and Project Output

Research Methods

The research efforts of PRF-207 are entirely interdisciplinary The on-campus research at Purdue is in close collaboration with colleagues in several departments We undertake basic research in the areas of biotic and abiotic stresses 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 where field evaluation of joint experiments are conducted

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 pests and 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, in a winter nursery at Puerto Vallarta, Mexico, as well as the University of Arizona Dryland Station at Yuma, Arizona Over the years, 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-207 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

Research Findings

Development and Analysis of Near-Isogenic Sorghum Lines Contrasting for QTL Markers Associated with Drought Tolerance

We have been conducting a genetic research program directed at developing a better understanding of drought tolerance in sorghum We have identified several QTL associated with drought tolerance in a recombinant inbred population specifically developed for this purpose Nevertheless, detailed analysis of QTL in such segregating populations is hindered by two problems First, the mapping of quantitative trait loci in segregating population has limited resolution Loci associated with the expression of a QTL can be mapped with a precision of some 10-20 cM, but additional experiments are required to obtain more precise map information Second, phenotypic evaluation of a trait conditioned by a QTL is often confounded by variability resulting from segregation of other loci that influence the same trait Both of these problems can be addressed by utilizing NILs The location of a QTL can be narrowed to a smaller interval by evaluating a series of NILs that differ for overlapping regions of the genome indicated by QTL analysis A comparison of these NILs can be used to map a QTL to a smaller genomic interval NILs can also be used for phenotypic analysis of specific QTL, offering a common genetic background in which direct comparison of two lines can be used to evaluate the phenotype conditioned by a QTL In this study, we report on the development and evaluation of near isogenic lines with the objective of assessing specific effects of QTL associated with pre- and post-flowering drought tolerance in sorghum

In a series of experiments, we identified loci associated with drought tolerance in sorghum by QTL analysis in a set of 98 recombinant inbred (RI) lines derived from a cross between two sorghum inbred lines with contrasting reactions to drought stress RAPD and restriction fragment length polymorphism (RFLP) markers were scored for segregation according to standard procedures and the markers ordered into a linkage map using the MapMaker program The RI lines were evaluated for phenotypic differences in drought tolerance in pre-flowering and post-flowering drought environments in Mexico and Yuma, Arizona QTL associated with drought tolerance during the pre-and/or post-flowering stages were identified by single factor analysis Several genomic regions associated with pre and post-flowering drought tolerance were identified We developed a set of 98 heterogenous inbred family (HIFs) from the original RI lines and were screened with RAPD markers to identify families segregating at marker loci associated with drought tolerance A RAPD marker associated with each target QTL was used to test eight progeny lines from each of the HIFs Three HIFs with segregating progeny were identified for each of the three RAPD markers tested Four NILs were selected from the progeny of each segregating HIF so that both parental alleles of the segregating marker were represented by two lines These NILs were further evaluated for the segregation of molecular markers flanking the target marker to determine the extent of the genomic region differentiating each set of NILs

QTL analysis indicated several genomic regions associated with pre-flowering and post-flowering drought tolerance Phenotypic evaluation of NILs indicated large differences in yield and seed weight associated with each QTL marker (Table 1)

Table 1 Mean yield and seed weight of NILs contrasting at three marker loci

Marker	Genotype[1]	Yield kg ha^{1}	Seed weight g (100 seed)^{1}
tM5/75	0	4382	2 71
tH19/50	1	3258	2 81
t329/132	0	3747	2 61
	0	3948	2 67
	1	3651	2 41

[1] 0 = B35 1 = TX7078

NILs contrasting at marker tM5/75 differed in average yield by more than 1100kg per ha NILs contrasting at tH19/50 differed by more than 700kg per ha over the seven environments in this study NILs contrasting for t329/132 also differed in yield but differences associated with this marker were not as large NILs contrasting for marker t329/132 differed in seed weight by more than 0 25g per 100 seed These effects were consistent with results predicted from earlier QTL analysis As expected, environments and environmental interactions were important and significant sources of variability We were particularly interested in the significant genotype × environment interaction observed for yield and seed weight in NILs contrasting at tM5/75 For a QTL associated with drought tolerance, a genotype × marker interaction should be expected Lines and HIFs were also significant sources of variability, particularly in NILs contrasting at markers tH19/50 and t329/132 The marker genotype effect was of interest in this study and was quite large for most markers, although the test for significance of the genotype main effect was not statistically significant perhaps because of the single degree of freedom in our experiment

An analysis of individual sets of NILs was more effective for evaluating marker effects because a pooled error could be used to test the significance of the genotype main effects NILs contrasting for markers tM5/75 and tH19/50 differed consistently and significantly in yield In each set of NILs, the B35 marker allele was associated with higher yield One set of NILs each contrasting at tH19/50 or tM5/75 also differed in seed weight These differences were consistent with marker associations observed previously in our earlier QTL analysis Phenotypic differences associated with each marker were generally consistent across drought and non-drought environments (Table 2) NILs contrasting at tM5/75 differed significantly in grain yield across environments In each case, the marker allele derived from the B35 parental line was associated with higher grain yield Differences in plant water status were evaluated in pre-flowering drought environments One set of NILs contrasting at the tM5/75 marker differed in xylem pressure potential (XPP) under pre-flowering drought Similar differences in XPP were also noted in other sets of NILs contrasting at tM5/75, but these were not significant In each case, a more favorable plant water status was associated with lower grain yield This suggests that the mechanism contributing to in creased grain yield results in a less favorable water status Each set of NILs contrasting for this marker differed for a genomic region including tM5/75 and tE8/102 Consistent differences in phenotype across NILs clearly indicate that a major QTL influencing yield and XPP is contained in this genomic region NILs contrasting at tH19/50 expressed differences in yield, seed weight, stay green, and xylem water potential (Table 2) In each case, the B35 parental allele was again associated with higher grain yield NILs contrasting at t329/132 differed consistently in seed weight As expected, the largest differences in seed weight were observed in the post-flowering drought experiments and in each case the B35 parental allele was associated with higher seed weight These differences were consistent with the results of our previous QTL mapping study

Physiological changes involved in respiration and synthesis of ethylene during conditioning were compared in seeds that differ in basal moisture content before conditioning The evolution of CO_2, ACC oxidase activity (penultimate enzyme in the ethylene synthetic pathway) and germination decreased for seeds when pre-conditioning seed moisture content was high The activity of ACC oxidase decreased when seeds were soaked in water for long periods (3-5 months) The germination percentage of *Striga* seeds also decreased proportionately

This study is one of the first examples in which QTL associated with the expression of grain yield and agronomic performance under drought have been studied in near-isogenic lines The expression of drought tolerance QTL was found to be strongly influenced by the environment and the genetic background in which they were evaluated Nevertheless, we believe that focusing research efforts on specific genomic regions associated with drought tolerance holds promise for developing a clear understanding of the physiology and biochemistry associated with this complex trait

Assessment of Genetic Diversity in Sorghum Using Molecular Markers

Analyses of the extent of and distribution of genetic variation in a crop are essential in understanding the evolutionary relationships between accessions and to sample genetic resources in a more systematic fashion for breeding

Table 2 Analysis of yield, seed weight, stay green, and leaf water potential in NILs tested in non-drought, post-flowering drought, or pre-flowering drought environments

			Non drought[2]		Post flowering drought			Pre flowering drought	
Marker	HIF	Genotype[1]	Yield kg ha[1]	Seed weight g (100 seeds)[1]	Yield kg ha[1]	Seed weight g (100 seeds)[1]	Staygreen 1 to 5	Yield kg ha[1]	XPP MPa
tM5/75	1	0	4417***	2 83	3982**	2 77	2 66**	2826**	1 37
		1	2851	2 71	3064	2 88	3 09	2186	1 30
	2	0	3649**	2 58	3522*	2 58	3 06	2367*	1 56*
		1	2402	2 52	2549	2 68	3 03	1491	1 45
	3	0	5805***	2 78*	4600	2 66***	2 75	3625	1 47
		1	4554	2 93	4287	3 30	2 69	3102	1 45
tH19/50	1	0	3830***	2 76***	4172**	2 94*	3 34*	2814**	1 55
		1	2533	3 15	2644	3 25	3 81	1360	1 55
	2	0	2938	2 42*	2575	2 32***	2 25**	1934	1 47**
		1	2664	2 54	2503	2 68	2 72	1828	1 59
	3	0	4392	2 56	4176	2 72	2 75	3133	1 54
		1	4152	2 54	3735	2 56	2 75	2567	1 59
t329/132	1	0	4351***	2 68***	3348*	2 56	2 84	2781**	1 63
		1	3409	2 42	2636	2 42	2 56	2073	1 53
	2	0	3842	2 62	3606	2 81**	3 41	2696*	1 55
		1	3612	2 44	3166	2 37	3 59	2386	1 55
	3	0	3192**	2 64***	2940**	2 71***	2 75*	2052*	
		1	3792	2 39	3737	2 41	3 03	2456	1 57

* ** *** Significant at 0 05 0 01 and 0 001 level respectively
[1] 0 = B35 1 + TX7078
[2] Non drought = Irrigated Mexico and Arizona Indiana

and conservation purposes Traditionally, genetic resources in sorghum are classified by taxonomists based on morphological markers However, these morphological traits used in classification of sorghum to different races are conditioned by a relatively small number of genes On the other hand, important traits which are related to habitat adaptation and exhibit enormous variability among sorghum germplasm are complex and quantitatively inherited Hence, classifying germplasm accessions based solely on a few discrete morphological characters may not provide an accurate indication of the genetic divergence among the cultivated genotypes of sorghum In this study, we used molecular markers to analyze genetic diversity in cultivated races of sorghum We hypothesize that both natural and human selection efforts have contributed to current genetic differences in sorghum, and hence landraces of the same race grown in different habitats may have greater genetic dissimilarity than those of different races from the same habitat

We sampled 190 sorghum accessions from five major cultivated races of sorghum, namely bicolor, guinea, caudatum, kafir, and durra Thirty eight accessions representing each race were randomly selected from the world collection of sorghum maintained at the International Crop Institute of the Semi-Arid Tropics (ICRISAT) Accessions from *bicolor caudatum durra guinea and kafir* represented 30, 32, 31, 28, and 13 countries, respectively The 190 accessions were divided into 38 sets, in each of which five randomly selected accession from all five main cultivated races of sorghum were included to ensure parallel comparison of races on gels and minimize biases while scoring marker products A total of 82 primers were used for DNA amplification but only 53 primers produced clearly scorable bands generating 220 bands across all sorghum accessions

A high level of genetic variation was detected among sorghum accessions The results also indicated that genetic diversity within a race was high for race *bicolor* and *guinea* and low for race *kafir* (Table 3) Partitioning the genetic variation further revealed that 86% of the total genetic variation occurred among accessions and 14% among races We also examined the degree of association of accessions with their geographic areas of origin (Table 4) The results indicated that only 13% of the total genetic variation was attributable to divergence among regions In spite of the limited differentiation among regions, the extent of genetic diversity within and among regions showed some trends Though represented by a large number of accessions, Southern African germplasm exhibited the least amount of genetic diversity, suggesting a narrow genetic base of accessions from this region By contrast, West Africa exhibited a high level of genetic diversity with a least number of accessions Genetic diversity in Central and Eastern Africa as well as accessions from the Middle East was as high as that observed in accessions from West Africa In conclusion, our data suggest that molecular markers are suitable to assess genetic diversity and to identify diverse sources in crop germplasm collections In particular, genetic distance estimates determined by molecular markers help identify suitable germplasm for introgression into breeding stocks Selecting the most divergent accessions for introgression may increase the chances for extracting suitable inbred lines from backcross populations Such inbred lines may, in turn, become useful sources of favorable alleles to improve the productivity of varieties and hybrids

Table 3 Mean genetic distance estimates calculated from 162 polymorphic RAPD bands for all pairs of accessions from either one or two cultivated races of sorghum

Races	Bicolor	Caudatum	Durra	Guinea	Kafir
Bicolor	0 363b[1]	0 355b	0 349c	0 381c	0 358c
Caudatum	0 355ab	0 330a	0 337b	0 362ab	0 339b
Durra	0 349a	0 337a	0 315a	0 367b	0 365c
Guinea	0 381c	0 362b	0 367d	0 354a	0 381d
Kafir	0 358ab	0 339a	0 365d	0 381c	0 254a

[1] Means within a column followed by the same letter did not differ from each other at $a = 0\ 05$ level based on Tukey s honest significant difference test Symmetrical distance estimates were presented to facilitate comparison within a column

Table 4 Mean genetic distance estimates calculated from 162 polymorphic RAPD bands for all pairs of accessions from either one or two geographic regions of origin

Regions	Far and Middle East	Central and Eastern Africa	Southern Africa	Western Africa
Far and Middle East	0 350a[1]	0 357bc	0 356c	0 375b
Central and Eastern Africa	0 357a	0 353ab	0 348b	0 365aq
Southern Africa	0 356a	03458a	0 305a	0 374b
Western Africa	0 375b	0 365c	0 374d	0 358a

[1] Means within a column followed by the same letter did not differ from each other at $a = 0\ 05$ level based on Tukey s honest significant difference test Symmetrical distance estimates were presented to facilitate comparison within a column

Networkıng Actıvıtıes

Workshop and Program Revıews

Traveled to Eastern Afrıca to vısıt NARS ın the regıon wıth INTSORMIL Dırector, Dr John Yohe and held dıscussıons leadıng to the establıshment of an INTSORMIL Regıonal Collaboratıve Research Program ın the Horn of Afrıca, June, 1997

Served as chaır of the organızıng commıttee of an INTSORMIL/ Horn of Afrıca Travelıng workshop The week long travelıng workshop was attended by three scıentısts from Kenya, two from Erıtrea, one from Uganda, scıentısts from the Ethıopıan Instıtute of Agrıcultural Research, four INTSORMIL prıncıpal ınvestıgators, and an assocıate program dırector

Attended and partıcıpated ın the 1997 World Food Prıze Symposıum, 16-17 October, 1997, Des Moınes, Iowa

Served as Vısıtıng Faculty, Unıversıty of Wısconsın, Summer Instıtute for Afrıcan Agrıcultural Research, June 1998

Partıcıpated ın Afrıcan Dıssertatıon Internshıp Awards Selectıon, Rockefeller Foundatıon, November 1997, and Aprıl 1998

Attended the Amerıcan Socıety of Agronomy Natıonal Meetıngs, Anaheım, Calıfornıa, October, 1997

Partıcıpated ın Pıoneer HI-Bred In-house Revıew of Publıc/Prıvate Plant Breedıng Programs, Aprıl 1997, Des Moınes, Iowa

Research Investıgator Exchange

Interactıons wıth publıc, prıvate, and ınternatıonal sorghum research scıentısts contınues to be an ımportant functıon of PRF-207 The followıng ındıvıduals vısıted our program or worked ın our laboratory durıng the project year

A large number of sorghum scıentısts from the U S and around the world vısıted our sorghum research program, field and laboratory facılıtıes, on the way to and from the Internatıonal Sorghum and Mıllet Genetıc Conference ın September, 1997

We were also vısıted by the new Dırector General of ICRISAT, Dr Shawkı Barghoutı, where current state of ICRISAT and future collaboratıve possıbılıtıes wıth Purdue were dıscussed

Germplasm Exchange

We contınue to provıde an array of sorghum germplasm from our breedıng program to natıonal research programs ın developıng countrıes Our germplasm ıs provıded ın eıther a formally organızed nursery that ıs unıformly dıstrıbuted to all collaborators that show ınterest or upon request by a natıonal program of specıfic germplasm entrıes or groups from or germplasm pool Germplasm was dıstrıbuted to cooperators ın over 15 countrıes ın 1997

Publıcatıons

Refereed Papers

Menkır A P B Goldsbrough and G Ejeta 1997 RAPD based assessment of genetıc dıversıty ın cultıvated races of sorghum Crop Scı 37 564 569

Tuınstra, M G Ejeta and P Goldsbrough 1997 Heterogenous Inbred Famıly (HIF) Analysıs A Method for Developıng Near Isogenıc Lınes that Dıffer at Quantıtatıve Traıt Locı Theor Appl Genet 95 1005 1011

Tuınstra, M E Grote P Goldsbrough and G Ejeta 1997 Genetıc Analysıs of Post flowerıng Drought Tolerance and Components of Graın Development ın Sorghum Mol Breedıng 3 439 448

Mohammed A H G Ejeta, L G Butler and T L Housley 1997 Moısture Content and Dormancy ın *Strıga* asıatıca seeds Weed research (In Press)

Tuınstra, M G Ejeta, and P Goldsbrough 1997 Evaluatıon of Near Isogenıc Sorghum Lınes Contrastıng for QTL Markers Assocıated wıth Drought Tolerance Crop Scı (In Press)

Conference Proceedıngs

Rosenow D T G Ejeta, L E Clark M I Gılbert R G Henzell A K Borrell and R E Muchow 1997 Breedıng for Pre and Post flowerıng drought Stress Resıstance ın Sorghum p 400 411 InRosenow et al (eds) Proc Internatıonal Conference on Genetıc Improvement of Sorghum and Mıllet, 22 27 September Lubbock Texas

Andrews D J G Ejeta M Gılbert, P Goswamy A Kumar A B Maunder K Porter K N Raı J F Rajewskı B V Reddy W Stegmeıer and B S Talukdar 1997 Breedıng Hybrıd Parents p 173 187 *In* Rosenow et al (eds) Proc Internatıonal Conference on Genetıc Improvement of Sorghum and Mıllet, 22 27 September Lubbock Texas

Tuınstra, M R P Goldsbrough and G Ejeta 1997 Analysıs of Drought Tolerance ın Sorghum Mappıng of Quantıtatıve Traıt Locı and Theır Evaluatıon ın Near Isogenıc Lınes p 425 428 In Rosenow et al (eds) Proc Internatıonal Conference on Genetıc Improvement of Sorghum and Mıllet 22 27 September Lubbock Texas

House L R B N Verma, G Ejeta B S Rana, I Kapran A B Obılana, and B V S Reddy 1997 Developıng Countrıes Breedıng and Potentıal of Hybrıd Sorghum p 84 96 *In* Rosenow et al (eds) Proc Internatıonal Conference on Genetıc Improvement of Sorghum and Mıllet 22 27 September Lubbock Texas

Ejeta G L G Butler D E Hess T Obılana, and B V S Reddy 1997 Breedıng for *Strıga* Resıstance ın Sorghum p 504 516 In Rosenow et al (eds) Proc Improvement of Sorghum and Pearl Mıllet 22 27 September Lubbock Texas

Butler L G G Ejeta, A G Babıker and D E Hess 1997 *Strıga* Host Relatıonshıps and Theır Role ın Defınıng Resıstance p 490 504 In Rosenow et al (eds) Proc Improvement of Sorghum and Pearl Mıllet, 22 27 September Lubbock Texas

Axtell J D I Kapran Y Ibrahım G Ejeta, L House B Maunder and D Andrews 1997 Heterosıs ın Sorghum and Pearl Mıllet Paper presented at the Internatıonal Conference on the Genetıcs and Exploıtatıon of Heterosıs ın Crops CIMMYT Mexıco

Published Abstracts

Kapran I J Axtell G Ejeta, and T Tyler 1997 Expression of Heterosis and Prospects for Marketing of Sorghum Hybrids in Niger Presented at the International Conference on the Exploitation of Heterosis and in Crops CIMMYT Mexico

Invited Research Lectures

Ejeta, G 1997 Strategies in breeding sorghum for stress tolerance Presented at the Summer Institute for Agricultural Research June 8 14 Univ of Wisconsin Madison

Ejeta, G 1997 Interdisciplinary collaborative research in sorghum and millets Presented at the Greater Horn of Africa INTSORMIL Traveling Workshop Sept 22 Oct 5 Nazret Ethiopia

Ejeta G 1997 Response to the Sasakawa Global 2000 Program Presentation Presented at the 1997 World Food Prize Symposium Food Security and the Future of Sub Saharan Africa Oct 17 18 Des Moines Iowa

Ejeta, G 1997 Agricultural Research Population and Global Food Production Presented at the HOBY World Leadership Congress July 21 Purdue University West Lafayette Indiana

Ejeta, G 1997 Breeding for *Striga* Resistance in Sorghum Special Seminar Purdue University Dec 11 Purdue University West Lafayette Indiana

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-222
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Summary

The principal objectives of TAM-222 are to identify and develop disease resistant and drought resistant sorghum germplasm in genetically diverse backgrounds for use by host country and U S scientists, to identify, evaluate, and utilize new elite exotic germplasm, and to collaborate with host country scientists in all aspects of their crop improvement programs The disease and drought resistance breeding program continued to develop germplasm for use in the U S and host countries New cultivars were introduced into the U S and evaluated for useful traits Thirty new fully converted exotic lines and partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released in June 1998

The Mali Sorghum Collection growout in Mali was successful with characterization completed on all but the late-maturing entries Selfed seed was obtained on essentially all entries, and seed of most entries (over 2,000) has been sent to the NPGS in the U S Candidates for a small Working Group representative of the diversity were identified There was considerably more diversity in the Collection than expected

Performance of stay green vs non-stay green hybrids under severe post-flowering moisture stress showed that the stay green trait dramatically reduced lodging and the stay green hybrids produced an average of 1500 lb/acre more than the non-stay green hybrids Performance data of these

same hybrids under non-stress high yield conditions showed that the stay green hybrids have a yield potential equal to that of non-stay green hybrids

The white-seeded, tan-plant, guinea type breeding cultivar named N'tenimissa continued to look promising for yield and adaptation in on-farm trials in Mali Grain quality evaluations indicate that the grain has good food quality traits for various products It should be 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 Several new white, tan true Guinea type breeding lines were identified, including 96CZF4-98 and -99 and looked promising in yield trials

Objectives, Production and Utilization Constraints

Objectives

U S

- Develop agronomically improved disease and drought resistant lines and germplasm and identify new genetic sources of desirable traits Select for drought resistance with molecular markers Evaluate new germplasm and introgress useful traits into useable lines or germplasm

Mali

- Assist breeders in developing agronomically acceptable white seeded, tan plant Guinea type sorghum cultivars
- Characterize and describe the indigenous Mali origin sorghum collection and evaluate for useful traits and breeding potential
- Identify and assist in developing new germplasm with resistance to grain mold, drought, head bug, anthracnose, and *Striga*
- Identify molecular markers for head bug resistance to develop improved sorghums for West Africa

Honduras

- Enhance germplasm base with sources of resistance to grain mold, foliar diseases and drought, and food type sorghums and lines for adapted commercial hybrids

Horn and SADC

- Enhance drought resistance and disease resistance with improved germplasm and elite lines

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 semi-arid environment 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 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 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 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 difficult to handle in a breeding program Their unique grain quality 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 compound 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 with both pre- and post-flowering drought tolerance important Foliage diseases such as anthracnose and sooty stripe are important in the central and southern parts of Mali In Sudan, and much of East Africa, the major constraint is drought, and related production problems Moisture-stress related charcoal rot and subsequent lodging are serious problems *Striga* is a major constraint in Mali, Niger, and Sudan

In Central America, 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 the drier portions of the 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 utilizing new diverse germplasm sources with resistance to pests, diseases, and environmental stress 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 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 primarily in large disease screening nurseries utilizing natural infection in South Texas 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 assembled or collected as opportunities exist, 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 Growouts of entire collections are sometimes grown in their country of origin for characterization, seed increase and evaluation prior to introduction into the U S Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs

Research Findings

Thirty fully converted exotic lines and 30 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released in late June 1998 (Table of lines on page 91, 1997 INTSORMIL Annual Report) The male sterile (A-line) of 5 new female parental lines, (A1, A2-2(B), A35, A803, A807) were distributed to private companies through a pre-release materials transfer agreement Two, A807 and A1 were selected for pilot increase in 1998 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

Breeding, selection, and screening for drought resistance and disease resistance continued using disease screening field nurseries in South Texas and field drought screening nurseries at Lubbock, Halfway, and Chillicothe Late summer rains precluded post-flowering stress at some locations but a dry early season allowed good pre-flowering stress on dryland plots at Lubbock Breeding derivatives of the stay-green line, B35, and B1, showed good stay-green and outstanding lodging resistance Sterilization of new B lines continued or was initiated Progeny from drought tolerant breeding lines were backcrossed and intercrossed with agronomically elite lines Major diseases involved in the disease resistance breeding 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, continued to show outstanding resistance to head smut in South Texas

The grain yield in 1997 under high yield, essentially non-stressed conditions of stay green versus non-stay green hybrids indicates that the yield potential of stay green hybrids is equal to that of non-stay green hybrids The stay green trait is an extremely useful drought resistant trait under severe post-flowering moisture stress and results in significantly higher grain yield, while also yielding well when under non-stressed conditions

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) Five QTLs were identified for the stay green trait in the cross (B35*Tx7000) with two appearing to be the most important In the cross (B35*Tx430), the same QTLs were identified for stay green along with two others Two hundred different RILs, each from two populations, B35*Tx7000 and SC56*Tx7000, were evaluated for drought and lodging and DNA analyzed to attempt marker assisted selection for the stay green trait using the identified QTLs New crosses and backcrosses were made for molecular analysis involving stay green and greenbug resistance (combining resistance using MAS), new sources of drought resistance with disease resistance, and crosses involving converted exotic lines to identify QTLs for yield and heterosis

Several breeding progeny from crosses generated for Host County and U S use looked very good agronomically in Southern Africa in 1997-98 Various progenies showed excellent drought resistance, grain quality, and sugarcane aphid resistance, combined with excellent yield potential The cross, Macia*Dorado, was especially outstanding Many Macia derivatives look excellent Other lines giving good progeny included 87EO366, WSV387, TAM428, SRN39, and ICSV1079

The Mali Sorghum Collection Growout in Mali was very successful Only a few plots of the indigenous cultivars were blank, even though for some of the entries, original seed from collections in 1982 was planted All lines except the late maturing entries were characterized (most by Dr J A Dahlberg) Selfed seed was obtained on essentially all entries, was threshed, packaged, and a set carried to the U S for the NPGS at NSSL in Fort Collins, Colorado It is processed for a quarantine growout in St Croix There was much more diversity in the Collection than expected especially among the Durra derivative cultivars Several potential new candidates for the Sorghum Conversion Program were identified

The guinea-type, white-seeded, tan-plant breeding progeny names "N'tenimissa" (means 'no regrets' in Bambara) from the cross (Bimbiri Soumale - a late maturing southern Mali guinea *87CZ-Zerazera) continued to look good in IER and World Vision InterCRSP on-farm trials in Mali It was also included in the ROCARS (Sorghum Regional Network) regional trials Its head bug resistance is slightly inferior to the local guinea cultivars, but appears to have an acceptable level under on-farm conditions Farmers seemed happy with it grain quality wise, and also for yield, even though it exhibits some peduncle breakage

Approximately two tons of N'tenimissa grain was produced in increase plantings for use in various food quality and food product trials Grain quality evaluations consistently show N'tenimissa as being superior to non-guinea breeding materials, but not quite as good as local guinea cultivars in decortication yield (a measure of hardness of endosperm) The food products quality, however, is excellent Selection continued in efforts to purify the line and select the best of several sister lines

Two outstanding F_4 progeny rows (96CZF4-98 and 96C2F4-99) of the cross (N'tenimissa*Tiemarfing) were identified at Cinzana in 1996, and were tested extensively in 1997 Their performance compared well with local guineas They are tan-plant lines with excellent guinea traits, and are free of the peduncle breakage problem Selection and evaluation continued within other tan-plant guinea type breeding materials, and among non-guinea type, tan-plant breeding lines with improved levels of head bug tolerance

Excellent segregation for head bug resistance was apparent in the F_3 progenies of the cross (Malisor 84-7*S34) evaluated in Mali in 1996 and again in 1997 This cross is being utilized by Dr Aboubacar Toure in his Post-Doc research to identify markers for head bug resistance, which could be used to improve the efficiency of screening for head bug resistance This program is cooperative with CIRAD (A Ratnadass) and ICRISAT

Networking Activities

Workshops/Conferences

Organized a Workshop on Sorghum Germplasm and Characterization held November 10-12, 1997, at the Cinzana Station, Cinzana, Mali The Workshop was held in conjunction with the working, harvest, etc of the Mali Sorghum Collection growout at Cinzana The Workshop was cosponsored by INTSORMIL, IER, ICRISAT, USDA-ARS, WCASRN (ROCARS), ORSTOM, and CIRAD Presented a talk on Germplasm Utilization at the Workshop It was attended by over 40 sorghum scientists, mostly from West Africa Dr Jeff Dahlberg, USDA-ARS Sorghum Curator, was a major contributor to the Workshop, and provided training on classification and descriptors

Participated in the INTSORMIL PI Conference (June 23) the Impact Assessment Workshop (June 24), and the International Ergot Conference, June 25-26, 1998 at Corpus Christi, Texas Also helped lead the field tour of research plots on June 26

Research Investigator Exchanges

Coordinated the procuring, assembly and planting of the Mali Sorghum Collection of indigenous cultivars in Mali, in cooperation with IER, INTSORMIL, ICRISAT, ORSTOM (France), CIRAD (France), and USDA-ARS Seed was procured from ICRISAT (India), ORSTOM (France), U S , CIRAD (France), and IER The entire growout of 2,543 plots was planted at Cinzana with a duplicate planting at the ICRISAT site at Samanko, near Bamako Coordinated the characterization, harvest threshing, and seed packaging at Cinzana, November 3-21, 1997 I also provided assistance to ICRISAT team in harvesting the Collection at their site

Participated in the Sorghum Germplasm and Characterization Workshop, Cinzana, Mali, November 10-12, 1997, presented talk on Germplasm Utilization, assisted with field tours, and interacted with key sorghum scientists from West Africa

Traveled to Mali Nov 3-21, 1997 to evaluate the INTSORMIL/IER collaborative research program, harvest and characterize the Mali Sorghum Collection, and participate in the Sorghum Germplasm and Characterization Workshop

Interacted with Host Country PIs, INTSORMIL PIs, U S public and private sorghum researchers, and international scientists at the INTSORMIL PI conference (June 23), INTSORMIL Impact Assessment Workshop (June 24) the International Ergot Conference (June 25-26) and the SICNA Field Tours, June 26, 1997 at Corpus Christi, Texas

Participated in the Sorghum Crop Germplasm Committee (SGC) as Ad Hoc member October 27, 1997, Anaheim, California, and on June 24, 1998, Corpus Christi, Texas

Participated in INTSORMIL Technical Committee (TC) meetings, October 20-21, 1997, and April 27-28, 1998 at Kansas City, Missouri

Interacted with other U S sorghum scientists during travel to Puerto Rico to harvest Sorghum Conversion materials and winter nurseries September 15-18, 1997 and March 23-April 5, 1998

Toured nurseries and discussed breeding germplasm and procedures with Dr R G Henzell, QDPI, Australia and Dr Medson Chisi, Golden Valley, Zambia, June, 1998

Participated in Sorghum Biotech Partnership meeting (Cargill, Novartis, NC+, Crosbyton), March 2, 1998, TAES Center, Lubbock, TX

Coordinated the training (B S and eventually M S) for Mr Niaba Temé (sorghum breeding technician) from Mali at Texas Tech University and TAES at Lubbock, beginning August, 1995

Served as local coordinator for Dr Aboubacar Toure, Malian sorghum breeder, during a Rockefeller Foundation Post Doctoral Fellowship through Texas A&M University, working on molecular markers for head bug resistance in Mali, in Dr Henry Nguyen's lab at Texas Tech University, Lubbock, TX

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Arrangements were made to assemble all sorghums of known Malian origin from the ICRISAT Center/India, ORSTROM/France, CIRAD/France, U S introductions, and those currently stored or in use in Mali These were planted at the Cinzana Station in Mali in July, 1997, to evaluate, classify, describe, and increase seed A duplicate planting was made at the ICRISAT Center near Bamako for insurance purposes The increased seed will be made available to all parties, and put into long term storage at ICRISAT, NSSL, and ORSTROM Working Collection candidates were identified and will be evaluated further for maintenance and active use in Mali It was a joint effort among INTSORMIL, IER, ICRISAT, ORSTROM, USDA-ARS and CIRAD Some of the collections in the past never were received at ICRISAT and their only known source was ORSTROM in France There are approximately 1,800 accessions with some duplicates from ICRISAT and ORSTOM making a total of 2,543 plots in the Collection Growout Seed of most Mali indigenous cultivars was carried to the U S and given to the USDA's NPGS at NSSL for processing prior to a quarantine growout in St Croix, USVI

Thirty new exotic sorghums were selected for entry into the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program in 1997-98 These included several cold tolerant lines (potentially ergot resistant?) from East Africa, along with selected elite introductions from Ethiopia, Zambia, Zimbabwe and Mali Marker assisted selection using maturity and height molecular markers is being tried on selected items in the Conversion Program to attempt to improve efficiency and shorten the conversion time

Several recent introductions from Southern Africa (Botswana, Zimbabwe, Zambia) Ethiopia, Mali and ICRISAT were grown and evaluated in Puerto Rico and seed increased Several new introductions were made, and planted in the quarantine greenhouse Approximately 700 photoperiod insensitive sorghums from the Sudan Collection were evaluated for response to drought (Lubbock and Chillicothe)

Thirty fully converted exotic lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were approved for release in June, 1998 and seed placed in permanent storage at the NSSL at Ft Collins, Colorado Thirty partially converted bulks from the Conversion Program also were released in June

Seed Production and Distribution

Several sets of previously released fully converted lines and partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were distributed The male sterile version (A-lines) of five new female parental lines containing drought resistance and lodging resistance were distributed via a pre-release distribution agreement Arrangements were made for pilot increases of two of those A lines, A807 and A1, in 1998 A large number of sorghum breeding and germplasm lines, including F_2 to advanced generation breeding progeny, A, B, and R lines, converted lines, and experimental hybrids were increased and distributed to international and domestic col laborators 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, Ethiopia, Guatemala Honduras, Nicaragua, Mexico, and Egypt

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 breeding method ology, as well as information on sources of new useful germplasm and sources of desirable traits, was provided to several visitors Pollinating bags, coin envelopes, and breeding supplies were provided to the Mali breeding program

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-222

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 Jeff Dahlberg, Sorghum Curator, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico

Dr L E Claflin, Pathologist, KSU-210, 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-218, University of Nebraska, Lincoln, NE

Dr J D Eastin, Physiologist, University of Nebraska, Lincoln, NE

Dr Bob Klein, Geneticist, USDA/ARS - Texas A&M University, College Station, TX

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 P K Subudhi, Molecular Biology, Texas Tech University, Lubbock, TX

Dr Medson Chisi, Sorghum Breeder, Golden Valley, Zambia

Dr Fred Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali

Dr Inoussa Akintayo, WCASRN Coordinator, WCASRN, ICRISAT, Bamako, Mali

Dr Osman Ibrahim Sorghum Breeder, ARC, Wad Medani Sudan

Publications and Presentations

Abstracts

Rosenow D T C A Woodfin K Schaefer and L E Clark 1997 Performance of stay green sorghum hybrids under post flowering soil moisture stress Agronomy Abs p 88

Wiltse C C W L Rooney R A Frederiksen and D T Rosenow 1997 Survey of anthracnose resistance sorghum germplasm lines to identify additional resistance genes Agronomy Abs p 72

Journal Artıcles

Dahlberg J A D T Rosenow G C Peterson L E Clark F R Mıller A Sotomayor Rıos A J Hamburger P Madera Torres A Quıles Belen and C A Woodfin 1998 Regıstratıon of 40 converted sorghum germplasm Crop Scı 38 564 565

Toure A K Traore A Bengaly J F Scheurıng D T Rosenow and L W Rooney 1998 The potentıal of local cultıvars ın sorghum ımprovement ın Malı Afrıcan Crop Scıence Journal 6 1 7

Mıscellaneous Publıcatıons

Pıetsch D L Synatschk W L Rooney D T Rosenow and G C Peterson 1997 1997 Graın Sorghum Performance Tests ın Texas Dept of Soıl and Crop Scıences Department Technıcal Report, DTR 97 12 120 p

Dahlberg, J A D T Rosenow, G C Peterson and L E Clark 1997 Release of 50 partıally converted sorghum bulks from the Sorghum Conversıon Program Internatıonal Sorghum and Mıllets Newsletter ISMN 38 38-41

Rosenow D T J A Dahlberg G C Peterson L E Clark A J Hamburger P Madera Torres and C A Woodfin 1997 Release of 30 converted sorghum lınes Internatıonal Sorghum and Mıllets Newsletter ISMN 38 41 43

Rosenow D T 1997 Sorghum germplasm utılızatıon Presentatıon at the Sorghum Germplasm and Characterızatıon Workshop November 11 1997 Cınzana, Malı

Germplasm Enhancement for Resistance to Insects and Improved Efficiency for Sustainable Agriculture Systems

Project TAM-223
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Collaborating Scientists

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Ing Rafael Mateo, Sorghum Breeding, Escuela Agricola Panamericana, P O Box 93, Tegucigalpa, Honduras
Dr Aboubacar Toure, Sorghum Breeding, IER, Sotuba, B P 438, Bamako, Mali (Currently Rockefeller Post-Doctoral Fellow, Texas Tech University/Texas A&M University)
Mr Sidi B Coulibaly, Agronomy/Physiology, IER, Sotuba, B P 438, Bamako, Mali
Dr M D Doumbia, Soil Chemistry, IER, Sotuba, B P 438, Bamako, Mali
Dr Y Doumbia, Entomology, IER, Sotuba, B P 438, Bamako, Mali
Dr G L Teetes, Department of Entomology, Texas A&M University, College Station, TX 77843-2475 (TAM-225)
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Dr A H Paterson, Molecular Biology, 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 Project 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 stresses Research is conducted to determine the genetic factors responsible for resistance and their associated mechanisms Insect pests receiving major emphasis include sorghum midge (*Stenodiplosis sorghicola*), biotype E and I greenbug (*Schizaphis graminum*), yellow sugarcane aphid (*Sipha flava*), and sugarcane aphid (*Melanaphis sacchari*) Breeding and selection activities are done using conventional methodology Collaborative molecular biology research projects are mapping and characterizing insect resistance traits of economic importance including resistance to greenbug biotypes Another molecular biology project is using molecular markers to concurrently select for greenbug and post-flowering drought resistance

Extensive research to develop lines resistant to sorghum midge that are suitable for hybrid production has been done In addition to pest resistance the lines and hybrids should possess excellent yield potential under high pest density, acceptable yield in the absence of the pest, and other needed traits for grain yield, adaptation, foliar quality, etc This project, in collaboration with entomologists (TAM-225), released three A/B-line pairs (A/BTx639, A/BTx640, A/BTx641) which will be used as hybrid sorghum midge resistant seed parents In four years of trials each line produced hybrids with grain yield significantly greater under high or moderate 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 susceptible hybrids in late plantings Sets of the lines were distributed under a pre-release memorandum to private seed companies (7 U S and 1 Guatemalan) for evaluation in 1997, and the lines were available for general distribution in October 1997 These are the first sorghum midge resistant A/B-line pairs with the traits needed for acceptable commercial resistant hybrids Private companies are evaluating the lines as seed parents using proprietary lines as pollen parents to determine their use in commercial hybrids

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
- Utilize molecular biology 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 production and yield stability is constrained by many biotic and abiotic stresses including diseases and drought in addition to insects 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 Cultivars are exposed to stress sequentially and 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 changing and insect damage becoming increasingly severe

Genetic resistance may be utilized at no additional cost to the producer to meet the demands of increased food production in an economically profitable, environmentally sustainable production system This requires a multi-disciplinary research program to integrate resistant hybrids into the management system Cultivars resistant to insects 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

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 with less photoperiod sensitivity 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

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 resulting Solutions to these problems must meet site specific needs of soil, rainfall, resources, labor and capital

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 Mali for resistance to headbugs and identification of sorghum genotypes resistant/tolerant to soil toxicity A project located in Southern Africa to incorporate resistance to sugarcane aphid into adapted cultivars is in development Establishment of a collaborative research program with Nicaragua will provide the opportunity for additional research on sorghum midge (the most important production constraint in Nicaragua), drought, disease, and adaptation For the United States, sorghum midge, biotype E, I, and K greenbug and yellow sugarcane aphid resistant sources have been identified and used in developing elite resistant sorghums Through collaborative ties with other projects, genetic inheritance and resistance mechanisms are determined Molecular biology is used to map genes for greenbug resistance and conduct marker assisted selection

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 introductions from other programs (including ICRISAT), exotic lines, and partially or fully converted exotic genotypes from the sorghum conversion program New resistance sources are crossed to elite resistant germplasm, and to other germplasm lines with superior trait(s) Primary selection criteria is for insect resistance Studies to determine the genetics of resistance and resistance mechanism(s) are conducted when possible The geographical diversity of Texas allows for growing and evaluating breeding lines at diverse locations for adaptation, stability of insect resistance, and resistance to other stresses (disease and drought) Based on data analysis and phenotypic evaluation, crosses are made among elite lines to produce additional germplasm for subsequent evaluation The overall objective is to combine as many stress resistance genes into a single high yielding genotype as possible

For insects important in LDCs but not in the U S , germplasm is provided to the LDC cooperator The germplasm is evaluated for resistance to the specific insect under the local production system (fertilizer, tillage, plant population, etc) and agronomic and yield data collected Based upon experimental results crosses are made to produce populations for inheritance and entomological studies These populations are provided to the cooperator for evaluation Molecular biology is used to study headbug resistance in Mali and the U S Resistance ratings are collected in replicated field trials in at least two Mali locations A duplicate trial is grown in the U S and tissue samples collected for analysis

For soil toxicity research, diverse cultivars from the U S and other countries are evaluated in field nurseries at Cinzana, Mali Lines which show promise are selected for further evaluation Research on soil toxicity is hindered by the site specific nature of the problem and poor germination of experimental entries in nurseries planted for screening and evaluation

Research Findings

Research to broaden the genetic base of the sorghum midge resistance breeding program, to incorporate additional sources of resistance into elite lines, and to identify new superior A- or R-lines continued Significant progress to improve agronomic traits and grain yield potential of sorghum midge resistant germplasm has been achieved

Breeding lines and hybrids were evaluated for sorghum midge resistance at three locations under high (Corpus Christi), moderate (College Station) and low (Tifton, GA) population density The converted exotic sorghum collection was evaluated for resistance at Corpus Christi and College Station Diverse locations to screen for sorghum midge resistance are needed since lines and hybrids that perform well under moderate/low midge density may not perform as well under high sorghum midge density

Sixty-three lines were evaluated for resistance to sorghum midge and agronomic desirability in the Midge Line Test (Table 1) Included in the test were three susceptible and six resistant checks, and 54 experimental breeding lines All resistant checks and most experimental lines were significantly less damaged than the susceptible checks The most resistant checks, Tx2880 and Tx2883 [midge damage rating (MDR) of 2 0 and 2 3, respectively], were not significantly less damaged than several experimental entries The three newly released B-lines Tx639 (MDR=3 7), Tx640 (MDR=3 2), and Tx641 (MDR=4 5), were not significantly more damaged than any resistant check This confirmed data from the previous four years that each of the lines had excellent seed set under high and moderate sorghum midge population density Most experimental entries were not significantly more damaged than resistant checks Tx2782, Tx2880, Tx2882 or Tx2883 Sorghum midge density was greater at Corpus Christi (MDR=4 1) than at College Station (MDR=3 2) Thirty-eight experimental entries with resistance over locations and acceptable agronomic traits were selected for evaluation in 1998

The primary sorghum midge resistance source is TAM2566 (SC175-9) a partially converted zerazera (IS12666) from Ethiopia Major research emphasis for several years has been to use other resistance sources to 1) diversity the genetic base of the program for resistance and 2) attempt to improve the level of resistance Several midge line test entries derive resistance from two or three different sources These resistance sources include IS3390C (SC572-14E), IS12572C (SC62-14E), IS2579C (SC423-14E), IS2549C (SC228-14E), and three lines from ICRISAT (PM11344, PM12713, and (IS12573C*PHYR)) Utilization of these lines is allowing selections to broaden the resistance genetic base and select for other useful traits like tan plant, improved foliar quality (resistance to disease and insecticide phytotoxicity), and larger kernel size Most of these lines have excellent resistance and agronomic traits Several were selected to test in hybrids

The converted exotic sorghum collection has formed the basis for the sorghum midge resistance breeding program in the United States However, the total collection has not been evaluated in one test and location The converted collection was evaluated in a non-replicated trial at Corpus Christi and College Station to evaluate for additional sources of resistance Based on resistance ratings and agronomic desirability, 47 converted lines were selected for more extensive evaluation

Combining ability for yield potential and sorghum midge resistance was studied to evaluate advanced germplasm for use as hybrid parents 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 Release of A/BTx639, A/BTx640, and A/BTx641 represent significant progress in development of sorghum midge resistant hybrids Improvement is now needed in R-lines to provide additional heterosis and superior agronomic traits

Grain yield and midge damage rating selected entries in the Midge Hybrid Test are shown in Table 2 The standard resistant check is ATx2755*Tx2767 (MDR=3 3 grain yield=4566 kg ha^{-1}) and the standard susceptible check is ATx2752*RTx430 (MDR=8 0, grain yield=1363 kg ha^{-1}) Most experimental hybrids produced significantly more grain than the susceptible checks Three experimental hybrids produced significantly more grain than ATx2755*Tx2767 Additionally many experimental hybrids produced significantly more grain than the resistant checks although the differences were not significant High pest density at Corpus Christi resulted in more damage (5 1) and lower grain yield (1492 kg ha^{-1}) and revealed greater differences between hybrids While the differences were not as large under moderate density (at College Station) the

Table 1 Mean midge damage rating and agronomic desirability of entries in the Midge Line Test at Corpus Christi and College Station, TX, 1997

Pedigree	Midge Damage Rating[1] Mean	CC[3]	CS	Days to 50% Anthesis CC	Desirability[2] Mean	CC	CS
(PM11344*Tx2767) BM7 LMBK CMA CMBK CM2 CMBK	1 7	2 0	1 3	78	2 6	2 6	2 6
((SC228 14*Tx2767) 2 B2 BM2 LM2*Tx2876) CM4 CM2 CMBK ML4 SM2	1 7	2 0	1 3	75	2 7	2 8	2 5
((SC62 14*Tx2782) B12 CC1 CC1*Tx2878) SM18 LMBK CM2 CM2 SM1 CMBK	1 8	2 0	1 7	75	2 3	2 2	2 3
Tx2883	2 0	2 0	2 0	75	2 5	2 7	2 4
94ML69/(PM12713*Tx2866) CM2 CM1 CMBK ML1 CM5	2 0	2 0	2 0	79	2 7	2 8	2 6
(Tx2880*Tx2882) BM1 CM1 CM1 SM2 SMBK	2 0	2 7	1 3	69	2 6	2 7	2 4
(MR118 3 R2 CC2 CS1 CS1 SM1*Tx2882) SM15 SM1 CM2 SM2	2 0	2 7	1 3	69	2 6	2 7	2 5
((SC228 14*Tx2767) 2 B2 BM2 LM2*Tx2876) CM4 CM2 CMBK ML5 SM1	2 0	2 0	2 0	77	2 7	2 9	2 5
Tx2880	2 2	3 0	1 3	67	2 5	2 6	2 4
(PM11344*Tx2782) CS24 LMBK CM2 CM1 CM1 CMBK	2 2	2 0	2 3	84	3 0	2 9	3 2
94ML33/(Tx2877*86PL2119 20) BM22 LMBK CM2 CM1 SMBK ML1 SMBK	2 3	2 3	2 3	79	2 7	2 9	2 5
94ML31/MR126 BM5 BM2 LMBK CM2 LMBK SMBK ML2	2 3	2 0	2 7	78	3 2	2 9	3 4
((SC228 14*Tx2767) 2 B2 BM2 LM2*Tx2876) CM4 CM2 CMBK ML5 SM1	2 3	2 3	2 3	76	2 7	2 7	2 7
(Tx2767*((SC572 14*SC62 14) B5 11 BM1 CM1)) SM5 SM1 CM2 CMBK	2 3	2 0	2 7	72	2 6	2 5	2 6
(Tx2882*86EO374) CM9 SM1 CM1 CM1	2 3	2 0	2 7	77	2 5	2 5	2 4
(PM12713*Tx2882) CM3 CM2 CM2 CM3	2 3	2 3	2 3	78	2 4	2 5	2 4
Tx2882	2 5	2 4	2 3	77	2 3	2 2	2 3
(PM12713*Tx2880) CM5 SM1 CM1 CM2	2 5	2 4	2 3	71	2 5	2 5	2 5
(Tx2882*7eo366) CM7 SM1 CM1 CM3	2 6	2 5	2 7	78	2 7	2 9	2 5
Tx2782	2 7	2 7	2 7	71	3 2	3 1	3 3
MR114 90M11	2 7	2 7	2 7	69	2 7	2 8	2 5
((SC62 14*Tx2782) B12 C11 C11*Tx2878) SM17 SM2 CM1 CM2 SM1 CM1	2 7	3 0	2 3	71	2 4	2 5	2 3
(Tx2872*Tx2880) SM10 SM2 SM1 SMBK	2 7	2 7	2 7	73	2 4	2 5	2 4
(MR114 90M11*Tx2880) SM5 LMBK SM2 CM2 CM1	2 7	2 3	3 0	79	2 6	2 4	2 7
(MR118 3 R2 CC2 CS1 CS1 SM1*Tx2882) SM15 SM1 CM2 CM3	2 7	2 0	3 3	78	2 8	2 7	3 0
(PM12713*Tx2882) CM3 CM3 CM1 SM2	2 7	2 3	3 0	76	2 7	2 6	2 7
(Tx2782*Tx2878) BM40 CM2 CM1 CM2 CMBK	2 8	2 7	3 0	73	2 4	2 4	2 3
94ML68/((SC228 14*Tx2767) 2 B2 BM2 LM2*Tx2876) CM4 CM2 CMBK ML4	3 0	3 0	3 0	74	2 8	3 0	2 6
Tx640/892 3	3 2	4 3	2 0	72	2 5	2 5	2 4
(MR112 90M5*87EO366) CM4 CM3 CM1 SM2	3 2	4 0	2 3	77	2 3	2 4	2 2
(PM12713*Tx2880) CM5 CM1 CM1 CM2	3 2	2 7	3 7	72	2 5	2 4	2 6
Tx2767	3 3	3 3	3 3	79	2 7	2 4	2 7
(Tx2872*Tx2880) CM5 CM1 CM1 CM2	3 3	4 3	2 3	72	2 4	2 4	2 4
(Tx2882*86EO374) CM8 SM1 CM3 SMBK	3 3	3 4	3 0	76	2 5	2 5	2 5
(MB108B/P G *MB110 49 B2 CC2 CC1 LMBK) BM10 CM1 CM2 SM3 SMBK	3 5	3 4	3 3	77	2 5	2 5	2 6
Tx639/B91 6	3 7	4 7	2 7	70	2 7	2 8	2 6
B94 3	3 7	4 0	3 3	65	2 69	2 9	3 0
B94 7	3 7	4 3	3 0	71	2 5	2 6	2 5
(Tx2882*89CC132) CM53 CM3 SM1 CM1	3 7	4 0	3 3	79	2 6	2 6	2 5
MB108B/P G	3 8	4 3	3 3	76	2 0	2 1	2 0
(MB108B/P G *MB110 49 B2 CC2 CC1 LMBK) BM10 CM1 CM2 CM1 CMBK	3 8	5 0	2 7	74	2 5	2 5	2 5
B94 14	4 0	6 0	2 0	71	2 4	2 4	2 3
(MB110 21 L1 BM2 CC1*Tx623) CM8 CM1 SM2 PR1 PRBK	4 0	4 3	3 7	75	2 4	2 4	2 4
B94 6	4 2	5 3	3 0	70	2 5	2 5	2 4
(Tx2872*Tx2782) SM2=CM3 SM1 SM3 SMBK	4 3	4 7	4 0	74	2 5	2 5	2 5
Tx641/B93 6	4 5	6 0	3 0	69	2 4	2 4	2 4
B94 17	4 7	6 0	3 3	68	2 4	2 4	2 3
B95PR1017/MB126E	4 7	5 3	4 0	75	2 4	2 3	2 4
(MB110 21 L1 BM2 CC1*Tx623) CM8 CM1 SM2 PR2 PRBK	4 7	5 3	4 0	77	2 5	2 5	2 5
(IS12573C*PHYR) *Tx2766) CM2 LMBK CM1 CM2 SMBK	4 7	6 0	3 3	65	2 8	2 7	2 8

Table 1 Continued

Pedigree	Midge Damage Rating[1] Mean	CC[3]	CS	Days to 50% Anthesis CC	Desirability[2] Mean	CC	CS
B94 15	4 8	5 3	4 3	68	2 4	2 4	2 3
(Tx2782*Tx2876) BM13 CM2 SMBK ML1 CMBK	5 0	3 3	6 7	77	2 4	2 3	2 5
B94 16	5 2	5 7	4 7	70	2 4	2 5	2 3
BQL41	5 7	7 3	4 0	73	2 7	2 8	2 6
94M2/(Tx2877*86PL2119 20) BM22 LMBK CM1 CM2 CMBK CM2	5 7	8 0	3 3	77	2 5	2 4	2 6
TAM2566	6 0	7 0	5 0	72	3 4	3 5	3 9
B94 13	6 3	6 3		71	2 6	2 6	0 0
Tx378	7 8	8 3	7 3	73	1 7	0 0	3 3
Tx430	8 3	9 0	7 7	74	1 3	0 0	2 6
Tx3042	8 7	9 0	8 3	64	1 5	0 0	3 0
Average	3 7	4 1	3 2	73 0	2 5	2 5	2 6
LSD 05	1 0	1 1	1 0	4 0	0 4	0 3	0 2

[1] Rated on a scale of 1=0 10% 2=11 20% 9=81 100% of kernels that failed to develop
[2] Rated on a scale of 1=most desirable to 5=least desirable
[3] CC=Corpus Christi CS=College Station

Table 2 Grain yield and midge damage rating of selected entries in the Midge Hybrid Test at Corpus Christi and College Station, TX, 1997

Hybrid	Class[2]	Grain yield kg ha [1] Corpus Christi	College Station	Mean	Midge damage rating[1] Corpus Christi	College Station	Mean
A94 6*Tx2767	RxR	2410	9155	5783	3 0	1 0	2 0
ATx640*94M2	RxR	2944	8428	5686	3 0	1 0	2 0
ATx640*94M3	RxR	2345	8801	5573	4 0	1 3	2 7
ATx641*94M3	RxR	2503	7698	5101	4 3	2 0	3 2
A94 10*Tx2880	RxR	2567	7634	5100	3 0	1 7	2 3
A94 15*Tx2880	RxR	2765	7374	5070	2 3	1 7	2 0
A94 10*Tx2767	RxR	1791	8311	5051	4 0	1 3	2 7
A94 6*Tx2880	RxR	2702	7209	4956	2 0	1 0	1 5
ATx639*Tx2880	RxR	2430	7469	4950	3 7	1 7	2 7
ATx641*94ML33	RxR	2364	7259	4812	4 7	1 7	3 2
A94 16*Tx2880	RxR	2787	6736	4761	2 7	1 7	2 2
ATx640*94ML33	RxR	2213	7165	4689	4 7	1 7	3 2
A94 7*Tx2880	RxR	2352	7012	4682	4 7	1 3	3 0
ATx2755*94M3	RxR	1292	8053	4673	6 3	2 7	4 5
ATx639*Tx2880	RxR	2101	7041	4571	4 7	2 3	3 5
ATx2755*Tx2767	RxR CK	1459	7673	4566	5 3	1 3	3 3
ATx641*Tx2882	RxR	2508	6572	4540	3 7	2 3	3 0
A94 16*Tx2882	RxR	2154	6716	4435	4 0	2 3	3 2
ATx641*Tx2880	RxR	2495	6292	4394	3 3	1 7	2 5
A94 17*Tx2882	RxR	2374	6192	4283	4 0	2 7	3 3
ATx640*Tx2883	RxR	1648	6895	4271	4 3	2 3	3 3
A94 13*Tx2880	RxR	2389	6134	4262	3 0	1 3	2 2
ATx2755*94ML31	RxR	1543	6802	4173	6 3	2 0	4 2
A94 3*Tx2767	RxR	1435	6812	4124	4 7	1 7	3 2
ATx640*Tx2882	RxR	2110	6093	4102	4 3	2 7	3 5
A94 3*Tx2880	RxR	2315	5870	4092	4 0	3 0	3 5
A94 10*Tx2882	RxR	1632	6545	4088	4 3	2 0	3 2
ATx640*Tx2880	RxR	1591	6453	4022	4 0	2 0	3 0
A94 13*Tx2767	RxR	1453	6540	3997	4 0	2 0	3 0
ATx641*Tx2767	RxR	1429	6545	3987	4 3	1 7	3 0
ATx639*Tx2767	RxR	2060	5779	3920	4 3	2 0	3 2
A94 7*Tx2882	RxR	2258	5348	3803	3 7	2 0	2 8
A94 13*Tx2882	RxR	1713	5633	3673	4 3	3 0	3 7
A94 7*Tx2767	RxR	1600	5647	3624	4 7	1 3	3 0
ATx2755*Tx2882	RxR CK	1694	5552	3623	5 3	2 3	3 8

Table 2 Continued

Hybrid	Class[2]	Grain yield kg ha 1[1] Corpus Christi	College Station	Mean	Midge damage rating[1] Corpus Christi	College Station	Mean
A94 14*Tx2882	RxR	1737	5345	3541	3 7	3 0	3 3
ATx2755*94ML33	RxR	719	6051	3385	7 3	2 3	4 8
A94 6*Tx2882	RxR	1626	5087	3357	3 0	2 7	2 8
A94 3*Tx2882	RxR	1592	4747	3169	4 7	2 7	3 7
ATx641*RTx430	RxR	791	5429	3108	8 0	6 0	7 0
ATx2755*94ML69	RxR	998	5146	3072	6 3	4 0	5 2
A94 15*Tx2882	RxR	1546	4342	2944	4 0	2 7	3 3
ATx640*ATx430	RxR	881	4784	2833	7 7	4 0	5 8
ATx2755*RTx430	RxS CK	588	4843	2716	8 3	5 0	6 7
ATx640*Tx2767	RxR	726	4268	2497	7 3	4 3	5 8
ATx2755*Tx2883	RxR CK	286	3439	1863	9 0	6 0	7 5
A35*Tx2864	SxS CK	142	3050	1596	9 0	5 3	7 2
ATx2752*RTx430	SxS CK	203	2524	1363	9 0	7 0	8 0
ATx641*94ML38	RxR	168	2527	1348	8 3	6 7	7 5
ATx2752*Tx2864	SxS CK	232	2271	1252	9 0	5 0	7 0
A1*Tx2783	SxS CK	171	2025	1098	9 0	6 7	7 8
ATx399*RTx430	SxS CK	180	1044	612	9 0	8 3	8 7
	$\bar{x}$	1492	5563	3528	4 1	5 2	3 0
	LSD_{05}	512	1363	945	1 3	1 1	1 0

[1] Rated on a scale of 1=0 10% 2=11 20% 9=81 100% of kernels that failed to develop
[2] R=Resistant S=Susceptible CK=Check

experimental hybrids expressed better yield potential and resistance than previously available resistant hybrids or susceptible checks Differences at College Station (average grain yield of 5563kg ha 1) under moderate pest density represent grain yield potential under conditions more likely to be encountered in producers fields

Selections were made to continue the development of germplasm resistant to biotype E I, and K greenbug New R-lines resistant to biotype E continued to produce high yielding hybrids The lines represent a range of plant types including tan plant, white pericarp and tan plant, red pericarp Other favorable traits include wide adaptation and resistance to several diseases Several lines could be used to develop food type sorghums with improved biotic stress resistance

The primary sources of resistance to biotype I and K are PI550607 and PI550610 Both sources are used in developing R-lines, and PI550610 is used in B-line development Selections to develop biotype I/K resistant lines were made in many populations Screening against biotypes I and K greenbugs identified several genotypes that contain moderate resistance to both biotypes Resistance to biotype I and K is controlled by different genes and a moderate level of resistance to both biotypes is emphasized in the selection criteria Many crosses to introgress resistance gene(s) into an array of elite germplasm were made

Molecular biology research has identified markers resistant to biotype C, E, I, and greenbug This research was the dissertation study of C S Katsar For this study TAM-223, TAM-225, and the molecular biology laboratory of Dr A H Paterson, interacted to provide unique training Significant new understanding of the nature of greenbug resistance resulted from this research Nine molecular markers on eight linkage groups were identified for resistance to greenbug Two markers on different linkage groups were identified for biotype C resistance derived from SA7536-1 For biotype C resistance derived from Capbam two markers on different linkage groups were identified One marker for biotype C resistance was common to both SA7536-1 and Capbam For biotype E resistance derived from Capbam three markers on two linkage groups were identified For resistance genes in PI550607 one marker for biotype C, three markers for biotype E, and three markers for biotype K were identified For PI550607 the markers for each biotype were on different linkage groups Additionally, a low level of resistance to greenbug was identified in a susceptible cross with BTx623 as a parent This could lead to identification of additional resistance genes with small effects that could eventually enhance to useable level of greenbug resistance The study concluded that resistance to greenbug is not simply inherited Resistance to greenbug is multigenic and mostly quantitative, the number of resistance loci found ranging from one to five (depending on the population) The relationship between greenbug resistance in sorghum, wheat, and barley was also studied It was concluded that some correspondence exists between greenbug resistance in the different species This could lead to strategies of gene management or deployment to improve durability of resistance Additional populations are in development to conduct fine mapping activities as a prelude to cloning

Crosses and backcrosses were made to incorporate greenbug resistance and post-flowering drought tolerance into a single genotype Three sources of resistance to greenbug are used Capbam through Tx2783, PI550607, and PI550610 The source of post-flowering drought tolerance is the cross B35*Tx7000 Molecular analysis using RFLP markers will be used to identify genotypes that contain greenbug resistance genes and QTLs for drought resistance The research is a collaborative project between TAM-223, TAM-222, and the molecular biology laboratory of Dr Henry Nguyen (Texas Tech University) Mr Sidi Bekaye Coulibaly (Mali) will conduct Ph D research in this project

For soil toxicity research at Cinzana a 17 entry paired plot experiment was developed and sent to Mali All entries in the test were specifically requested by Dr Mamadou Doumbia, IER soil chemist The experiment was planted in the soil toxicity site on the Cinzana station and in a farmers field adjacent to the Cinzana station Research in soil toxicity continued to be hindered by poor germination in the sites selected for the study

Head bug damage was rated at Sotuba and Samanko in the population Malisor 84-7*S34 The populations were developed in Texas and Puerto Rico and sent to Mali for evaluation Dr A Toure, IER sorghum breeder, is conducting this research for a Rockefeller Foundation post-doctoral fellowship For 1997, the study was expanded to include progeny from the same cross that was developed by the ICRISAT West African sorghum program

Work with Malian collaborators to develop improved guinea type varieties with higher yield potential, superior grain traits, tan plant, and other needed plant traits continued One tan plant, white seeded line named "N'Tenimissa" has consistently shown excellent grain yield and agronomic traits It is currently being tested on-farm and is being released

Sugarcane aphid resistant breeding materials are in development to establish a research project with entomologists and breeders in Southern Africa Resistance sources including TAM428, CE151 WM#177, Sima (IS 23250) SDSL89426, and FGYQ336 were intercrossed or crossed to locally adapted cultivars to develop a range of populations for study Exotic cultivars used include Segaolane, Marupantse, Macia, Town, SV1, and A964 The lines were also crossed to elite TAM-223 germplasm to introduce additional favorable traits including foliar disease resistance Backcrosses of selected F_1s to adapted cultivars were made Initial selections will be made at Texas nursery locations Selections provided to collaborators will contain wide adaptation and potential resistance to several diseases

Networking Activities

Workshops

Participated in the Sorghum Characterization Workshop, November 10-11, 1997, Cinzana, Mali Participated in instructing participants in the use of sorghum descriptors and moderated a discussion section

Research Investigator Exchanges

Honduras - August 25-28, 1997 Participated in discussions with representatives of the Escuela Agricola Panamericana (EAP), Zamorano, concerning future direction of the collaborative sorghum research program Planned research for 1997-98

Mali - November 3-21, 1997 Participated in the Sorghum Characterization Workshop at Cinzana Participated in characterization of the Mali Sorghum Collection planted at Cinzana Worked with IER breeding collaborators in use of computer software for breeding program management Evaluated cooperative IER/INTSORMIL research at Sotuba and Cinzana Rated plots at Sotuba and Samanko (ICRISAT/WASIP) for damage to headbugs for the molecular biology research conducted by Dr A Toure (currently Rockefeller Foundation Post-Doctoral Fellow) Met with ICRISAT/WASIP scientists at Samanko to discuss future collaborative research on use of molecular biology for resistance to headbugs Developed future collaborative research plan for research on soil toxicity and resistance to insects

Honduras - February 1-4, 1998 Participated in discussions with representatives of the Escuela Agricola Panamericana (EAP), Zamorano, and the Direccion de Ciencia y Tecnologia Agropecuaria (DICTA)/Recursos Naturales concerning future direction of the collaborative sorghum research program Planned research for 1998-99

Honduras/Nicaragua - May 2-9, 1998 Honduras - Participated in discussions with representatives of the EAP, DICTA, and USAID concerning future direction of the collaborative sorghum research program Planned 1998-99 research with EAP Discussed organization of the December, 1998 review by the External Evaluation Panel Nicaragua - Participated in discussions with representatives of the Instituto Nicaragunese de Technologia Agropecuria (INTA) and USAID/Nicaragua to establish a collaborative research relationship between INTA and INTSORMIL Planned research to be conducted in Nicaragua during 1998-99 Met with representatives of the Union of Agricultural Producers of Nicaragua (UPANIC) to discuss possible collaborative activities

Participated in meeting of the Sorghum Improvement Conference of North America (SICNA)Board of Directors to plan the February, 1999, Biennial Sorghum Research and

Utlization Conference Currently serving as SICNA Board Chair

Participated in the INTSORMIL Principal Investigators Conference, June 23, 1998, Corpus Christi, TX

Participated in the INTSORMIL Impact Assessment Workshop, June 24, 1998, Corpus Christi, TX

Participated in Sorghum Crop Germplasm Committee (CGC) meeting, June 24, 1998, Corpus Christi, TX

Participated in U S Ergot Conference, June 25-26, 1998, Corpus Christi, TX Led field tour discussion on breeding for insect resistance

Dr A Touré, IER, Bamako, Mali

Mr Antonio J Cristiani, President of Cristiani Burkard, Guatemala, October, 1997

Dr Bob Henzell, Queensland Dep of Primary Industries, Australia, June 1998

Mr Tim Lust, National Grain Sorghum Producers Research Director, and Mr Travis Taylor, Texas Grain Sorghum Board Executive Director, several occasions

Germplasm and Research Information Exchange

Germplasm Conservation Use

Accessions from the sorghum conversion program were grown for increase and evaluation Releases from the sorghum conversion program were 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 A/BTx639, A/BTx640, and A/BTx641 was distributed following release Seed was previously distributed to seven U S and one Guatemalan seed company under a pre-release memorandum to allow evaluation prior to official release

Cooperator in the release of forty 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 production Biotype E greenbug resistant R-lines from this project are widely used in the production of greenbug resistant hybrids

Provided miscellaneous computer supplies to Malian breeding collaborators Trained Malian IER breeding collaborators in the use of computer software

Other Cooperators

Collaboration with the following scientists was important in the activities of TAM-223

Dr R A Frederiksen, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843 (TAM-224)

Dr L W Rooney, Cereal Chemistry, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (TAM-226)

Dr G N Odvody, Plant Pathology, Texas Agricultural Experiment Station, Texas A&M University Agricultural Research and Extension Center, Route 2 Box 589, Corpus Christi, TX 78406-9704 (TAM-228)

Dr R D Waniska Cereal Chemistry, 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

Dr T L Archer, Entomology, Texas A&M University Agricultural Research and Extension Center, Route 3 Box 219, Lubbock, TX 79401-9757

Dr B R Wiseman, Entomology, 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, USDA-ARS, Tropical Agriculture Research Station, 2200 Avr Pedro Albizu-Campos, Suite 201, Mayaguez, PR 00680-5470

Dr C S Manthe, Ministry of Agriculture, Department of Agricultural Research, Private Bag 033, Gaborone, Botswana

Ing Laureano Pineda, Instituto Nicaragense de Technologia, Edificio Mar, Apdo 1247 Managua, Nicaragua

Dr R G Henzell, Sorghum Breeding, Hermitage Research Station, via Warwick, QLD 4370, Australia

Dr Henry T Nguyen, Molecular Biology, Texas Tech University, Lubbock, TX

Publications and Presentations

Abstracts

Katsar C S A H Paterson G C Peterson and G L Teetes 1998 Molecular analysis of resistance to greenbug in sorghum In Proc of the International Conference on the Genetic Improvement of Sorghum and Pearl Millet Lubbock TX Sep 22 27 1996 p 654 655

Rosenow D T J A Dahlberg L E Clark and G C Peterson 1998 Sorghum conversion program In Proc of the International Conference on the Genetic Improvement of Sorghum and Pearl Millet Lubbock TX Sep 22 27 1996 p 671 672

Teetes G L G C Peterson R M Anderson K Schaefer and J W Jones 1998 Sorghum midge resistant hybrids for the 21st century In Proc of the International Conference on the Genetic Improvement of Sorghum and Pearl Millet Lubbock TX Sep 22 27 1996 p 677

Diarisso N Y B B Pendleton G L Teetes G C Peterson and R M Anderson 1997 Relationship between sorghum glume closure and resistance to sorghum midge International Sorghum and Millets Newsletter 38 87 88

Katsar C S A H Paterson G C Peterson and G L Teetes 1997 RFLP analysis of greenbug resistant sorghum germplasm Annual Plant Resistance to Insects Newsletter 23 39 40

Peterson G C G L Teetes J W Jones R M Anderson B B Pendleton and K Schaefer 1997 Release of sorghum inbred lines resistant to sorghum midge International Sorghum and Millets Newsletter 38 37 38

Peterson G C G L Teetes J W Jones R M Anderson B B Pendleton and K Schaefer 1997 Sorghum inbred lines resistant to sorghum midge Annual Plant Resistance to Insects Newsletter 23 36 37

Peterson G C J W Jones G L Teetes B B Pendleton and R M Anderson 1998 Grain yield of sorghum midge resistant sorghum hybrids 1997 Arthropod Management Tests (in press)

Presentations

Teetes G L B B Pendleton R M Anderson C S Katsar and G C Peterson Hybridization of sorghum midge resistant and susceptible sorghums International Plant Resistance to Insects 13th Biennial Workshop 15 18 March 1998 Memphis TN

Teetes G L B B Pendleton R M Anderson C S Katsar and G C Peterson Hybridization of sorghum midge resistant and susceptible sorghums 46th Annual Meeting of the Southwestern Branch of the Entomological Society of America 9 12 February 1998 Corpus Christi TX

Katsar C S G L Teetes A H Paterson and G C Peterson Comparative analysis of greenbug resistance genes among the Poaceae 1997 Annual Meeting of the Entomological Society of America 14 18 December 1997 Nashville TN

Refereed Journal

Rosenow D T J A Dahlberg G C Peterson L E Clark F R Miller A Sotomayor Ríos A J Hamburger P Madera Torres A Quiles Belen and C A Woodfin 1997 Registration of fifty converted sorghums from the sorghum conversion program Crop Sci 37 1387 1398

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 63 converted sorghum germplasm lines from the sorghum conversion program Crop Sci 37 1399 1400

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Diarisso N Y B B Pendleton G L Teetes G C Peterson and R M Anderson 1998 Floret morphology of sorghum midge resistant sorghum Southwestern Entomol 23 67 75

Teetes G L C S Manthe G C Peterson K Leuschner and B B Pendleton 1995 (published in 1997) Sorghum resistant to the sugarcane aphid *Melanaphis sacchari* (Homoptera Aphididae) in Botswana and Zimbabwe Insect Sci Applic 16 63 71

Diarisso N Y B B Pendleton G L Teetes G C Peterson and R M Anderson 1998 Spikelet flowering time cause of sorghum resistance to sorghum midge (Diptera Cecidomyiidae) J Econ Entomol (in press)

Peterson G C G L Teetes B R Wiseman J W Jones R M Anderson K Schaefer and B B Pendleton 1998 Registration of Tx639 Tx640 and Tx641 sorghum midge resistant sorghum inbred lines Crop Sci (in press)

Books, Book Chapters and Proceedings

Henzell R G G C Peterson G L Teetes B A Franzmann H C Sharma, O Youm A Ratnadass A Toure J Raab and O Ajai 1997 Breeding for Resistance to Panicle Pests of Sorghum and Pearl Millet p 255 280 In Proc of the Genetic Improvement of Sorghum and Pearl Millet International Conference Lubbock TX Sep 23 27 1996

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Teetes G L G C Peterson and K F Nwanze 1999 Genetic Diversity of Sorghum *Sorghum bicolor* (L) Moench a Source of Insect Resistant Germplasm p 63 82 In Global Plant Genetic Resources for Insect Resistant Crops Edited by Stephen L Clement and Sharron S Quisenberry CRC Press Boca Raton FL

Miscellaneous Publications

Pietsch D L Synatschk W L Rooney D T Rosenow and G C Peterson 1998 1997 Grain sorghum performance tests in Texas Dep of Soil and Crop Sci Technical Report No 97 12 120p

Breeding Pearl Millet and Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-218

David J Andrews
University of Nebraska

Principal Investigator

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Dr Chris Manthe, Cereals Coordinator, and Mr Peter Setimela, Sorghum Breeder, Department of Agricultural Research, P O Box 0033, Sebele, Botswana
Mr Issoufou Kapran, INRAN, B P 429, Niamey, Niger
Mr Adama Coulibaly, Agronomist and Modi Diagouraga, Millet Breeder, Cinzana, BP 214, Segou, Mali
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, and Dr Paula Bramel-Cox, Genetic Resources, ICRISAT, Patancheru P O AP 502 325, India
Dr Anand Kumar, Millet Breeder, ICRISAT, Sahelien Center, BP 12 404, Niamey, Niger
Dr J D Axtell, Sorghum Breeder, PRF-203, Department of Agronomy, Purdue University, West Lafayette, IN 47907
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Mr W M Stegmeier, Millet Breeder, Department of Agronomy, Kansas State University, Hays, KS 67601
Drs J W Maranville, Cereal Physiologist, UNL-214, and S C Mason, Cereal Agronomist, UNL-213, Department of Agronomy, University of Nebraska, Lincoln, NE 68583
Dr D T Rosenow, Sorghum Breeder, TAM-222, Texas A&M University, Lubbock, TX 79401

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 still too high for most low resource 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 5 tons of grain/ha in 3 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, to identify sources of useful traits and to develop methods to consistently select for them, 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 Mali 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/SMIP 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, and recently, in collaboration with ICRISAT, the A_5 system which appear to offer significant 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 In April, 1998, 29 sorghum seed parent lines, N250A to N278A, and 33 seed parent germplasms, N279A-N311A, were released principally for use in the U S Two very early maturing male parent lines N248R and N249R were also released These provide new genetic diversity for producing early and full season grain hybrids including white grain-tan plant food quality hybrids In May, 1998 five grain pearl millet seed parents and two male parents were released for the production of early maturing pearl millet hybrids suitable for combine harvesting in the midwest/high plains region of the U S Each of the seed parents was released both in the A_1 and A_4 cytoplasmic male sterile systems, thus enabling a greater range of hybrids to be made Both male parents released were restorers (R_1) for the A_1 system (the project released R_4 germplasm earlier) The project collaborates 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 Work has commenced on using sources of genetic resistance to low and high temperatures at germination and initial stages of seedling growth and on the development of screening techniques that will provide effective selection for these traits

Objectives, Production and Utilization Constraints

Objectives

The objectives of the breeding programs with slight changes in emphasis, 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 release to make grain 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 and visiting scientist projects

For Pearl Millet

- Because of its significant advantages compared to the A_1 cytoplasmic male sterile (CMS) system, emphasis is being given to development of both seed parents and restorers in the A_4 CMS system, and to investigating its various attributes Some work on the newer A_5 CMS system recently discovered at ICRISAT, has commenced

- Selection for Atrazine/Propachlor herbicide tolerance, since pearl millet is sensitive to most sorghum and maize herbicides

- Assessing the adaptation of experimental millet hybrids in the U S with sorghum checks through the coordination of a regional testing program

For Sorghum

- Increased emphasis is being given to food quality male parent development, using introgression of productive tropical germplasm

- A major constraint to sorghum in the Midwest/High Plains of the U S is its late planting date compared to maize Earlier planting requires germination and seedling cool tolerance Work has commenced in identifying tolerant sources and the transfer of these traits

- Because seedling heat tolerance is often needed in the tropics, the inheritance of known sources is being studied and simplified screening methodology developed

Constraints

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 under non-stress conditions) 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 also 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 the several pests and diseases in their locality, 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 broaden the genetic diversity in parental lines

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 in topcross hybrids Increased yields at the small farmer level, often at low productivity levels 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 top cross hybrid development and production with conventional CMS or protogyny seed parents 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) system in sorghum but both A_1 (Tift 23A_1 cytoplasm) and increasingly A_4 CMS (monodii cytoplasm) is being used in pearl millet A_4 male sterility has been transferred into lines derived from a Senegalese long headed dwarf pearl millet variety, IBMV 8401 These can be used then to detect A_4 genes in adapted varieties in Senegal with the eventual aim of being able to produce top cross hybrids made with R_4 derivatives or R_4 versions of the best varieties as male parents on IBMV 8401A_4 seed 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 herbicide is being obtained through repeated screenings and recurrent selection under high rates of herbicide application

In sorghum sources of germination and seedling cold tolerance and their cross performance are being evaluated by Iskender Teriyaki for his M S thesis, through growth chamber and early season field plantings The inheritance of seedling heat tolerance, using a simplified lab screening technique is being studied by Peter Setimela for his Ph D dissertation A food quality B-line population based on ms$_7$ is being produced by random mating

Research Findings

Pearl Millet

Five seed parent lines (NM-1 through NM-5) and two male parent lines (NM-6R and NM-7R) for the production of grain pearl millet hybrids adapted to the Midwest/High plains region of the U S were released Each seed parent was made available in two CMS systems, A$_1$ and A$_4$ This greatly increases hybrid opportunities, and the capability of identifying more elite R$_4$ pollen parents Both the male parents have improved lodging resistance, an essential trait for midwest fall conditions

Some twenty farmers, in Nebraska, Kansas, Colorado, Texas, Oklahoma and South and North Dakota, requested and received hybrid seed of 68A × NM-6R to make test plantings of 0 5 to 2 ha in May or June 1998 Arrangements were made with two seed companies for the 1998 pilot production of several hybrids each with NM-6R and NM-7R Independent research results confirm that pearl millet is an excellent substitute in part or whole for maize in poultry diets, however, market channels will need development

The production of new seed parents in both cytoplasms and particularly R$_4$ restorers in A$_4$ cytoplasm continued The results of two locations of the advanced pearl millet grain hybrid yield test are shown in Table 1 Exceptionally severe lodging conditions occurred in mid-October (15 cm of wet snow and wind Sorghum hybrids in the same field also lodged 8-70%) However, the highest yielding millet hybrid NM-5A × NM-6R, showed excellent lodging resistance

A research grant was obtained from the Maharastra Hybrid Seed Company, Jalna, India, to compare the attributes of different cytoplasmic male sterility systems which will now include A$_5$ CMS recently obtained from ICRISAT Though only one replicated test was conducted in 1997, it is clear that the time between stigma emergence and anthesis is reduced by 15% in hybrids with A$_4$ cytoplasm, compared to the same hybrids in A$_1$ × R or B × R form, while pollen quantity is at least double that of the A$_1$ versions There was no difference, as expected, in open pollinated seed set (since all have the same pollen environment), and selfed seed set on A$_4$ hybrids was good (80 + %, equalling the B × R hybrids), but A$_1$ hybrids averaged only 11% seed set under bags In ordinary conditions such A$_1$ hybrids might show normal seed set, but where stress on pollination occurs, such as with cold or wet conditions, seed set may be easily affected

The development and testing of white grain hybrids also continued White grain provides the opportunity to produce attractive flour based and parboiled products, also milling recovery rates can be higher White grain hybrids have been found as shown in Table 2, which gave yields as good as the normal grain colored (grey) check hybrid A larger planting of the best white grain hybrids will be made to produce enough grain for product testing

Mean location grain yields in the 1997 Regional Pearl Millet Hybrid Test grown at seven sites in five states ranged from 2770 to 5290 kg ha^{1} with yields of individual hybrids reaching 6800 kg ha^{1} at Walsh, Colorado

Table 1 Pearl Millet Advanced Grain Hybrid Trial 1997 Mean of two locations at UNL, Mead, Nebraska (Results of 11 of 25 entries)

Hybrid	Yield[1] kg ha^{1}	Bloom days	Height cm	Lodge %
NM 5A x NM 6R	5220	78	106	9
1021A x 58057R	5160	72	119	31
59068A x NM 6R	5020	68	116	40
2068A x 89 0083R[2]	4860	69	135	38
57135A x NM 7R	4800	80	111	12
NM 5A x NM 7R	4800	72	111	8
59043A$_4$ x 68A$_4$R$_1$R$_4$	4630	72	116	30
57135A x NM 6R	4600	72	115	28
NM 5A x 60007R	4560	81	104	12
NM 1A x NM 7R	4440	71	113	42
57139A x 58068R	4310	73	98	15
Mean (25 entries)	4320	71 9	108 6	23 7
LSD P = 0 05	1240	6 0	7 6	15 6

1 Yield includes grain from lodged heads
2 Check hybrid

Table 2 Pearl Millet White Grain Hybrid Trial 1997 UNL, Mead, Nebraska (Results of 10 of 42 entries)

Hybrid[1]	Yield[3] kg ha^{1}	Bloom days	Height cm	Lodge %
59041A x 54025R	6142	63	129	32
59043A$_4$ x 1163A$_4$R$_4$	5590	56	121	14
2068A x 89 0083R[2]	5456	57	152	14
59043A x 89 0083R	5407	61	123	16
59037A x 57028R	5374	61	127	25
59039 1A$_4$ x 68A$_4$R$_4$	5281	63	125	17
59043A$_4$ x 68A$_4$R$_4$	5249	62	124	16
1163A x 0183R	5095	57	125	38
1163A x 89 0083R	5081	62	117	13
59039 1A x 57028R	4904	63	122	42
Trial Mean 42 entries	4363	60 7	119	23 5
LSD P = 0 05	900	3 0	8 8	14 6

1 All parents are white grained versions except check
2 Check hybrid
3 Yield includes grain from lodged heads

Sorghum

A total of 29 seed parent lines (N250-N278), 2 early restorer parent lines, (N248R, N249R) and a further 33 seed parent germplasms (N278-N311) were released These provide new genetic diversity for producing hybrids in the U S , and since many of the parents were white grain tan plant, numerous food quality combinations can be made

These parental lines originated from the program, described in previous reports, to introgress tropical breeders food quality germplasm into widely used U S seed parents Germplasm from ICRISAT/India (originally derived from world wide sources, especially Ethiopia, Sudan, and Nigeria), Botswana, Nigeria, Senegal, Zambia, and Zimbabwe was involved in the breeding of the released parents The characterization of their combining abilities [leading to the seed parent line (excellent) and seed parent germplasm (good) classification] through multilocation hybrid testing was supported by a three year grant from the Nebraska Grain Sorghum Board Early in the development of these seed parents, segregating families were sent to Botswana, which through collaboration with SADC/ICRISAT/SMIP, resulted in the identification and pending release of 37 seed parents for Botswana and similar ecologies

The development of further seed parents from subsequent introductions and intercrosses, continued in the report year Table 3 shows the yields of some of these parents in hybrid combination Increased emphasis started several years ago, has been given to producing food quality male parents, through a similar program of introgression of tropical breeders germplasm from India, Botswana, Zambia, Congo, and South Africa Yields involving some of the new male parents (R-lines) are shown in Table 4

The screening technique for seedling heat tolerance developed by Peter Setimela in work for his Ph D involves measuring the recovery growth of three day old seedlings returned to 28°C in the dark after receiving a heat shock of 50°C for 10 minutes The seedlings are held between perspex plates to permit photocopying them every eight hours for two days Shoot recovery growth response varied from 40% reduction in the most tolerant genotypes, to no further growth in the most susceptible In one genotype shoot growth resumed but not root growth, in others secondary root branching was halted Crosses and backcrosses between the most and least tolerant will be used to estimate heritabilities

In the germination and seedling cold tolerance research conducted by Iskender Tiryaki for his M S degree, large differences in rate of emergence in cold soil conditions (10-15°C) were found both between genotypes and also in tester effect Tester N123A, though a very early line, generally showed negative combining ability, but tester 144-3A showed good heterosis for cold tolerance with poor lines

Table 3 Initial Grain Sorghum Hybrid Yield Trial 1997 UNL, Mead, Nebraska Data of selected entries

Hybrid Parentage	Yield[1] kg ha[1]	Plant Height cm	Bloom days	Lodge %
9044A x 316R	8990	117	82	35
026A x RTX9032	8930	130	76	76
315A x RTX9032	8930	135	78	47
N122A x RTX430 (Check 2)	8900	125	74	75
699A x RTX9032	8790	132	80	68
026A x RTX9032	8750	130	75	73
23/4NA x 317R	8700	117	78	60
N148A x (WSV x 430)	8410	135	76	71
599A x 320R	8370	120	77	69
N122A x [PL1 (KS_4 x NPC_3)]	7990	135	78	80
N122A x (DOR x 8503)	7990	120	79	68
P8500 (Check 1)	7950	120	72	53
Mean 44 entries	7250	123	73	64
SE±	715	4	1 2	9

[1]Yield includes grain from lodged heads

Table 4 Advanced Grain Sorghum Hybrid Trial 1997 UNL, Mead, Nebraska Data of selected entries

Hybrid Parentage	Yield[1] kg ha[1]	Plant Height cm	Bloom days	Lodge %
618A x (DOR x 348)	7940	125	75	46
311A x 290R	7880	115	75	14
026A x RTX2737	7850	125	77	74
P8500 (Check 1)	7680	125	71	37
N122A x 290R	7590	120	75	32
N148A x 316R	7400	122	76	49
618A x RTX9032	7310	115	73	46
23/4NA x 290R	7290	125	74	42
N122A x RTX430 (Check 2)	7260	125	74	42
599A x 1226R	6910	117	72	62
N122A x 317R	6910	130	77	63
N122A x 337R	6850	117	72	43
N122A x (WSV x 430)	6730	110	73	14
311A x 316R	6060	117	77	31
N122A x 320R	5980	122	77	52
026A x 1226R	5640	107	72	47
901A x 1226R	5190	95	77	8
Mean of 17 entries	5969	118	75	41
SE±	573	5	1	6

[1]Yield includes grain from lodged heads

For example, PI550-666, Figure 1A, however it did not improve the hybrids with lines that already possessed good tolerance, for example PI550 586, Figure 1B Both these PI lines are of Russian origin The chance of seed parent lines is therefore very important for early seedling emergence in cool conditions

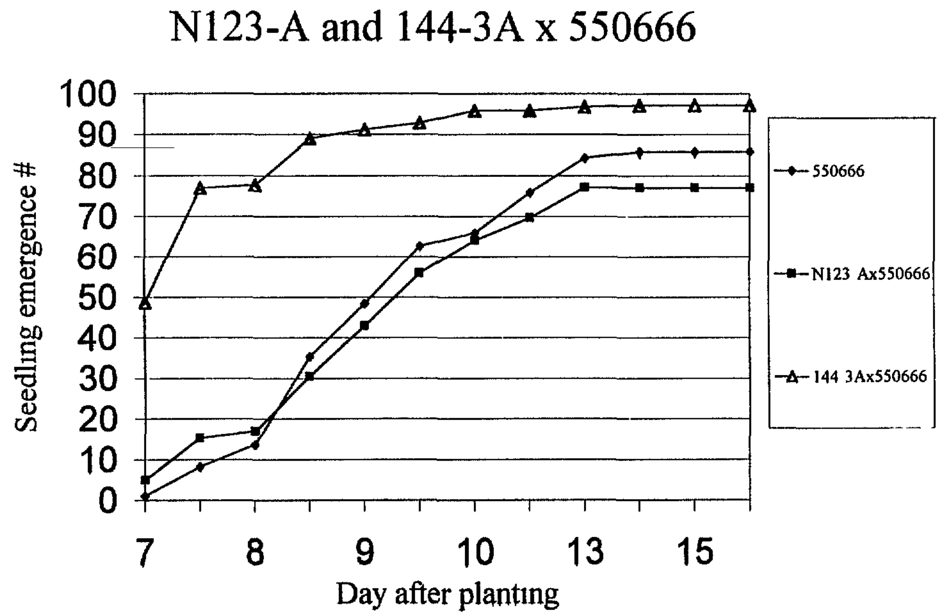

Fıgure 1A **Sorghum germınatıon cold tolerance Rate of emergence of relatıvely susceptıble lıne PI 550666 and test crosses wıth N123-A and 144-3A**

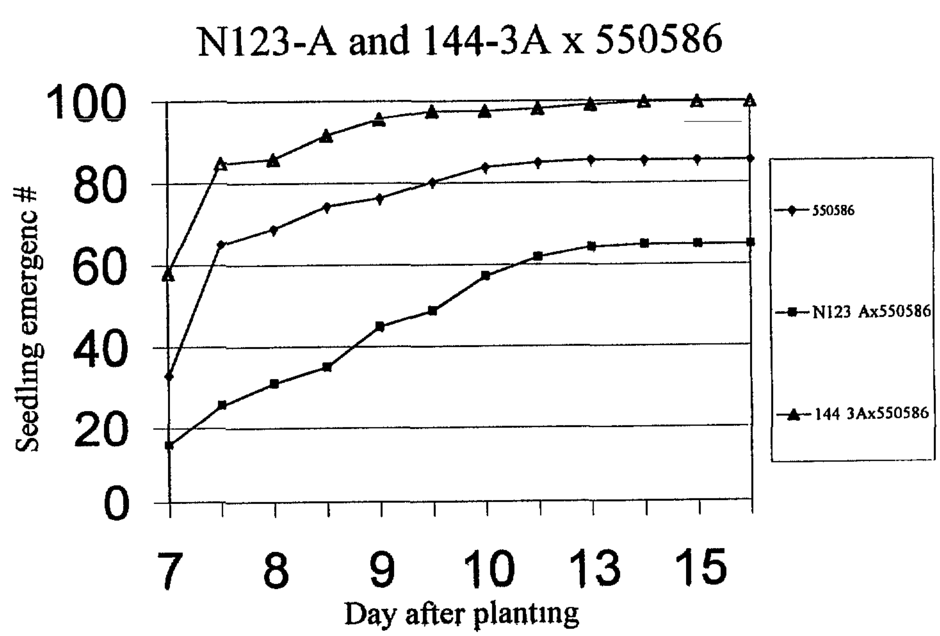

Fıgure 1B **Sorghum germınatıon cold tolerance Rate of seedlıng emergence of relatıvely tolerant lıne PI 550586 and test crosses wıth N123-A and 144-3A**

Networking Activities

Workshops

Contributing author of "Heterosis in sorghum and pearl millet", Presentation given in The Genetics and Exploitation of Heterosis in Crops, August 1997, CIMMYT, Mexico

Participant in Use of Molecular Markers in the Improvement of Pearl Millet in Developing Countries Workshop, November 23-27, 1997, ICRISAT, Patancheru

Participant in workshop in Seed Production and Farmer Participatory Breeding, March 26-29, 1998, Oshakati/Mahenene, Namibia

Participant in INTSORMIL PI and Sorghum Ergot Workshop, Corpus Christi, Texas, June 22-26, 1998

Research Investigator Exchanges

Dr K N Rai, Senior Millet Breeder, ICRISAT, Patancheru Visiting scientist at UNL Nebraska, January-December, 1998, primarily working on pearl millet CMS systems

Mr S A Ipinge, Senior Millet Breeder, MAWRD, Okashsana, Namibia Visiting research scholar, May-October, 1998, hybrid breeding techniques

Principal Investigator made trips in support of INTSORMIL collaborative research (and jointly where indicated(*), as Scientific Liason Officer for USAID to ICRISAT),

October 7-12, 1997 - SADC/ICRISAT/SMIP, Zimbabwe*

November 23-27, 1997 - ICRISAT Center, Patancheru, India*

September 4-12, 1997 - IER Mali, and ICRISAT, Mali, Samanko*

March 26 - April 4, 1998 - Namibia, SADC/ICRISAT/SMIP, Zimbabwe*, and Botswana

Germplasm and Information Exchange

Acquired 60 pearl millet breeder lines from ICRISAT, India and 20 pearl millet breeder lines from ICRISAT ISC, Niger

Release of 62 sorghum parent lines/germplasms for U S

Release of 7 grain pearl millet parent lines for U S

Protogyny based hybrid seed production method developed by UNL-218 research in pilot project use to produce pearl millet topcross hybrids by IER, Mali PI visited seed production plots to advise on management techniques

Production of R_4 restorer versions of popular varieties, by use of the backcrossing in male sterile cytoplasm method, in Namibian breeding program (In collaboration with SADC/ICRISAT/SMIP) PI made visit

Provided A_4R_4 donor parent to Zambian millet program to commence development of R_4 versions of Zambian varieties

Breeding supplies (pollinating bags) provided to Botswana sorghum and Namibia millet breeding programs

Publications and Presentations

Presentations

Axtell J D I Kapran Y Ibrahim G Ejeta, L Hovie B Maunder Heterosis in sorghuum and pearl millet The Genetics and Exploitation of Heterosis in Crops August, 1997 CIMMYT Mexico

Journal Articles

Gupta, S C F R Musa and D J Andrews 1997 Registration of INFM 95001 Finger Millet Genetic Male Sterile Line Crop Sci 37 1409

Proceedings

Andrews D J G Ejeta, M Gilbert P Goswami K Anand Kumar A B Maunder K Porter K N Rai J F Rajewski V S Belum Reddy W Stegmeier and B S Talukdar 1998 Breeding hybrid parents In D Rosenow et al (eds) Proc of International Conference on the Genetic Improvement of Sorghum and Pearl Millet Lubbock Texas September 23 27 1996 INTSORMIL University of Nebraska Lincoln Nebraska

Miscellaneous

Rajewski J F and D J Andrews 1998 Summary of 1997 Pearl Millet Regional Trials 8 p Dept of Agronomy University of Nebraska Lincoln

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF-212
Bruce R Hamaker
Purdue University

Principal Investigator

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Collaborating Scientists

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Dr John Axtell, Sorghum Breeder, Dr Gebisa Ejeta, Sorghum Breeder, Dr Robert Elkin, Poultry Nutritionist, Purdue University, West Lafayette, IN 47907

Dr Brian Larkins, Plant Molecular Biologist, University of Arizona, Tucson, AZ

Summary

Our work this year covered couscous processing, development of a screening assay for high protein digestibility sorghum, porridge pasting properties of sorghum, and the effect of a sorghum grain fungal protease on analytical assays The major achievement was the successful development of a rapid screening assay for identification of sorghum lines with high protein digestibility The need for such an assay originates from our previous discovery of a sorghum mutant with high protein digestibility The screening assay will allow breeders to use this material in their breeding programs

Sorghum protein and starch digestibilities in livestock animals have been shown to be slightly lower than for other feed cereals, and are substantially lower in cooked porridges fed to children Previous work done in this laboratory (Kirleis' and Hamaker's groups) showed that the protein bodies of sorghum, that encapsulate about 70% of total grain protein, are difficult to digest and become even more resistant to digestion following cooking The high protein digestibility sorghum found in this laboratory has dramatically different, irregularly-shaped protein bodies resulting in easy access of proteases to the storage protein called kafirins The screening assay is based on the principle that the major storage protein, α-kafirin, digests away very quickly in the highly digestible sorghum Following an hour digestion with the protease, pepsin, the undigested proteins were extracted, analyzed by electrophoresis (SDS-PAGE), and the amount of α-kafirin visualized was inversely correlated to digestibility This relatively simple approach has reduced the normal digestibility time down from 2 to 3 days for about 20 samples, to analysis of around 60 samples per day We are currently trying to improve this assay more by further simplifying the procedure and increasing the number of samples/day that can be analyzed

Work on sorghum and millet-based couscous continued both in Niger (see country report) and at Purdue A decortication experiment showed that a 20-30% decortication (dehulling) degree for sorghum grain gave highest yield of optimum sized couscous particles, as well as improved color (more lightness) Although different size particle fractions are used for different foods in Niger (and other parts of West Africa), the most popular size fraction is intermediate (1-2 mm diameter) Much progress has been made in optimizing processing conditions using the couscous unit installed at INRAN/Niger through this project

A study on sorghum porridge pasting properties showed that liberation of free fatty acids from triglycerides during whole grain flour storage has a large effect on warm paste viscosity (at around 50°C) A substantial increase in paste viscosity was noted at two months of storage under ambient conditions Sorghum flour produced free fatty acids during storage much earlier than maize flour Thus, this study showed that whole grain sorghum flour changes in quality rather abruptly during storage at one to two months

A fungal protease was identified in partially weathered sorghum grain that is highly active in protein extraction solvents, and, in some cases, breaks down proteins completely in as little as a two hour extraction This finding was important primarily for analytical work on sorghum proteins where breakdown changes results Proteolysis can be pre-

vented by either decorticating the grain by 20% or by adding a protease inhibitor Because the protease was present in significant levels even in grain that did not appear appreciably weathered, it could also have an effect on functional properties of sorghum flours used for food This aspect was not investigated

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 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 Couscous

Work has continued both at Purdue and INRAN, Niger to optimize couscous processing procedures to achieve a high quality commercializable sorghum or millet couscous for the urban West African marketplace At Purdue, Nigerien Adam Aboubacar completed his Ph D in December 1997, entitled "Physicochemical Properties of Flour and Fine Structure of Starch in Relation to Sorghum Couscous Quality " The main findings from his thesis were reported on in previous INTSORMIL annual reports ('95-97) Part of this study is reported below In Niger, A Aboubacar installed a entrepreneurial-scale couscous processing unit ('96 report) with the central mechanized agglomerator designed and fabricated at CIRAD, France by Jacques Faure The couscous unit and product produced were recently exhibited and demonstrated at a regional agricultural research exposition in Ouagadougou, Burkina Faso by M Oumarou and M Moussa of INRAN As flour quality is critical to obtaining high quality couscous, and many other processed cereal products, a decorticator and hammer mill are in the process of being purchased for INRAN/Niger and IAR/Ethiopia

Effect of Grain Decortication Rate on Sorghum Couscous Color and Yield

Following a sensory study conducted in Niger last year, we reported that consumers accepted a wide range of couscous color, though there was a clear preference for light-colored couscous We also noted and reported that the manner of couscous consumption was dependent upon granule size There are three different types of couscous granules consumed in Niger Couscous of fine granules also called 'dambu' is consumed with milk, vegetable, or sauce and couscous of intermediate granule known as 'burabusko' is eaten with sauce or milk A third type of couscous called 'degué' is mostly composed of large chunks of agglomerated, pregelatinized flour This type of couscous is often mixed with spices and consumed with milk Studies were undertaken to determine the effects of extent of kernel removal on couscous color and granule size distribution

Grain samples from seven sorghum cultivars were decorticated with a tangential abrasive dehulling device to remove 10, 20, 30 and 40% of the kernel, and ground into flour Flour ash and protein content decreased with increased percent kernel removal Also, an increase in flour lightness and a decrease in flour red color was observed as decortication rate increased Couscous was prepared from the flours using a laboratory procedure Processing flour into couscous decreased the lightness and increased red and yellow color in couscous at all decortication rates These changes in color became obvious upon water addition to flour and accentuated during steaming On the average, flour lightness values were 82 1, 85 1, 87 0, and 88 3 at 10, 20, 30, and 40% kernel removal, respectively After flour was processed into couscous, the average lightness values dropped to 51 7, 56 4, 57 9, and 60 6 for 10, 20, 30 and 40% kernel removal, respectively For all the cultivars, couscous lightness increased with increased decortication rate The best couscous in terms of lightness were obtained with IRAT-204, SEPON, NAD-1 and SC283-10, while the worst couscous were derived from Mota Maradi, P721N, and P721Q Couscous from IRAT-204 and SEPON were the best in yellow color and resembled the color of durum wheat couscous Red color in flour was found to be the most important parameter that influenced final couscous color This study also showed that, for some sorghum cultivars, substantial improvement in couscous color can be achieved through appropriate decortication

Dried couscous was sieved and separated into three granule sizes (< 1mm, 1-2 mm, and > 2 mm) Couscous granule size distribution was different among the sorghum cultivars at all decortication rates For all the cultivars, high proportion of fine (< 1mm) couscous granules was obtained at 10% kernel removal As percent kernel removed increased, the proportion of fine (< 1mm) granules decreased and that of intermediate (1-2 mm) and coarse (> 2mm) granules increased gradually (Figure 1) We observed that couscous granules prepared with flour from 10% decorticated grain tended to break easily when dried, whereas couscous from 40% decorticated grain gelatinized quickly during steaming and produced high proportion of large chunks of granules that were very hard after drying The best couscous granules were obtained when flours from 20 and 30% decortication rates were used Figure 1 shows that, as percent kernel removed increased, ash content in the flour decreased with concomitant decrease in fine (< 1 mm) and increase in coarse (> 2 mm) couscous granules

Sorghum with High Protein Digestibility

We previously reported ('94-97 INTSORMIL annual reports) on the identification of sorghum lines within J Axtell's high lysine population that have markedly higher uncooked and cooked protein digestibility levels compared to normal types Biochemical and microstructural studies in our laboratory showed that higher digestibility was due to altered morphology (folded structure) of the kafirin-containing protein bodies, resulting in a more rapid digestion of the main storage protein of sorghum, α-kafirin

Rapid Assay to Identify Highly Digestible Sorghum Cultivars

The discovery in our laboratory of highly digestible sorghum cultivars prompted the need for the development of a rapid assay to screen breeders' lines for protein digestibility This complementary work to INTSORMIL PRF-212 was funded by the Texas Grain Sorghum Board Protein digesti-

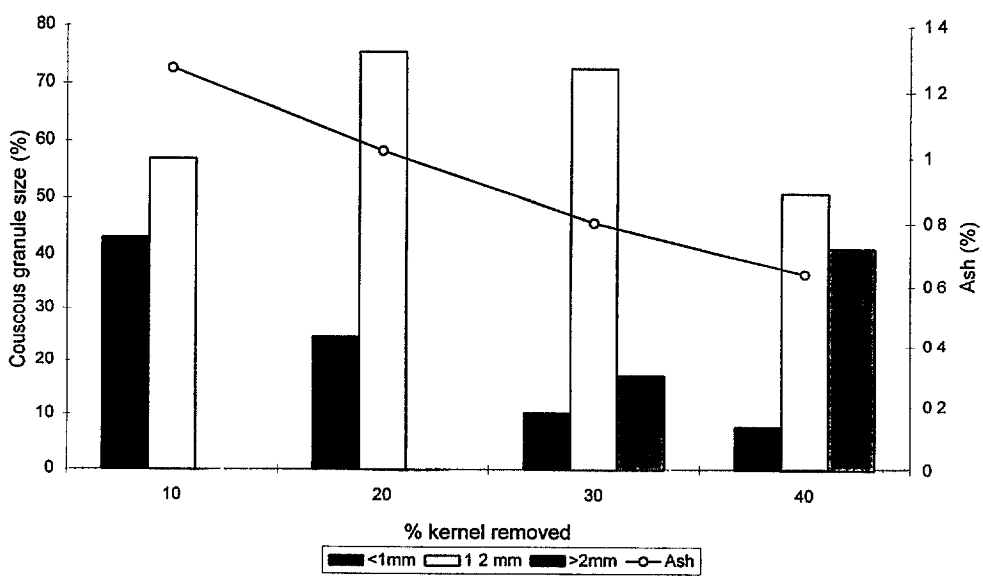

Figure 1 Effect of % kernel removed on flour ash content and couscous granule size distribution

bility of 16 sorghum cultivars was determined using standard procedures (pepsin digestibility and pH-stat) and compared to a newly developed rapid electrophoresis-based assay The new assay is based on the rate of α-kafirin disappearance after pepsin digestion α-Kafirins are the major storage protein and make up about 70% of the total protein in the sorghum grain In the new assay, samples are first digested with pepsin for one hour and undigested proteins are then analyzed by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) Figure 2 is a representative SDS-PAGE of normal (N) and highly digestible (H) sorghum cultivars The intensities of the undigested α-kafirin bands are then measured Higher band intensity indicates lower protein digestibility Highly significant correlation coefficients were obtained between values obtained by the new assay and the standard procedures (r=-0.96 and r=-0.85, with pepsin digestibility assay and with pH-stat procedure, respectively) This indicates that the new assay is comparable to the existing procedures and can be used for screening sorghum lines for protein digestibility

The new assay was further tested using a larger sorghum population Fifty sorghum cultivars were used The cultivars were derived from two populations of sorghum grown in Mexico during the 1996-97 crop season Two high lysine and highly digestible (P850115 and P851171) and two normal (MR732 and SRN39) sorghum cultivars were crossed to generate the two populations Both are of the F10 generation Figure 3 shows a regression line between protein digestibility of the 50 sorghum cultivars determined using the new assay and digestibility determined by the standard pepsin procedure Figure 3 represents results obtained when samples where compared on same flour basis A slightly higher correlation (r=-0.92) was obtained when compared on the same nitrogen (protein) basis The similarity between the two determinations is of significance since it

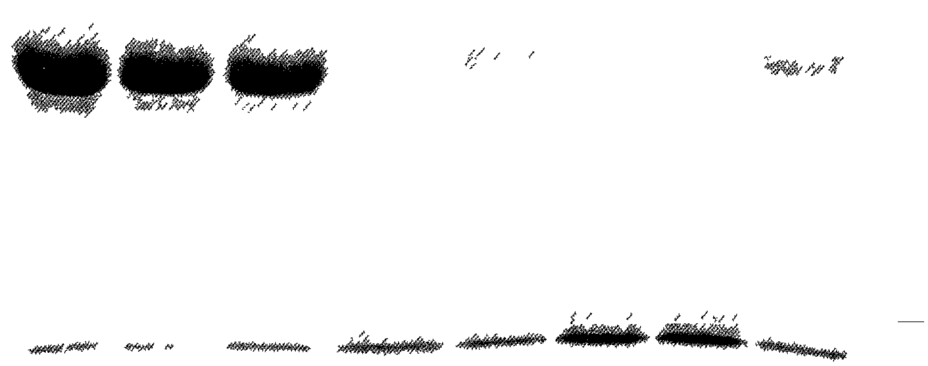

Figure 2 Electrophoresis gel (proteins separated by molecular mass) showing the basis of the protein digestibility screening assay for sorghum grain Lanes (from left to right) are 1) molecular weight standards, 2-4) normal cultivars, 5-9) highly digestible lines The large protein band is α-kafirin and its band intensity is inversely related to digestibility

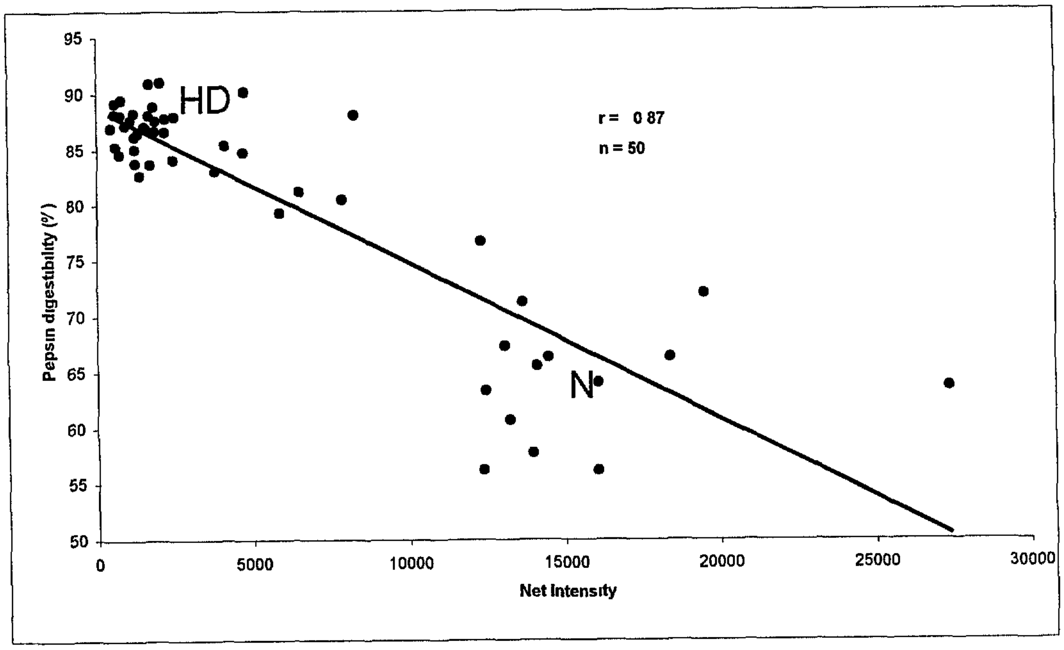

Figure 3 Regression line between standard pepsin digestibility assay and electrophoresis-based assay where net intensity is the α-kafirin band intensity after 1 hr digestion (HD=highly digestible, N=normal cultivar)

eliminates the extra step of nitrogen (protein) determination used in the two standard procedures More importantly, two distinct populations of highly digestible (H) and normal (N) sorghum types were obtained indicating that the new assay is highly efficient in differentiating the two populations Advantages of the new assay over the standard procedures include considerable reduction in analysis time and sample size required for the analysis For example, analysis time was reduced by about one quarter and sample size by one tenth when the new assay was used as compared to the pH-stat procedure We estimate that about 60 sorghum cultivars can be screened in a day by a single operator using the new assay For qualitative analysis to simply separate highly digestible from normal genotypes, the SDS-PAGE method can be used with visual scoring (+ or -)

Production of Free Fatty Acids in Stored Sorghum Flour and their Effect on Paste (Porridge) Properties

Sorghum porridge is a popular staple food in many regions of Africa, particularly West Africa Porridge texture is one of the most important sensory-related factors from which consumers base their judgements of quality and acceptability In this study whole grain sorghum was ground to flour and stored under ambient conditions to examine the effect of flour storage on pasting properties of porridges Paste viscosity profiles, as measured by a device called the Rapid ViscoAnalyzer, were measured, as well as production of free fatty acids caused by enzymatic breakdown of triglycerides (the native form in oil) Large increases in cooling paste viscosities (at about 50°C) were observed when free fatty acids were liberated from triglycerides at around month two of storage (Figure 4) Further study (not shown) indicates that the component interactions that produce this large change in viscosity, thereby affecting porridge texture, are based on a three-way interaction between fatty acids, starch, and probably protein Stored sorghum flour showed breakdown of triglycerides to free fatty acids at a much faster rate than comparable stored maize flour The reason for this difference is unclear

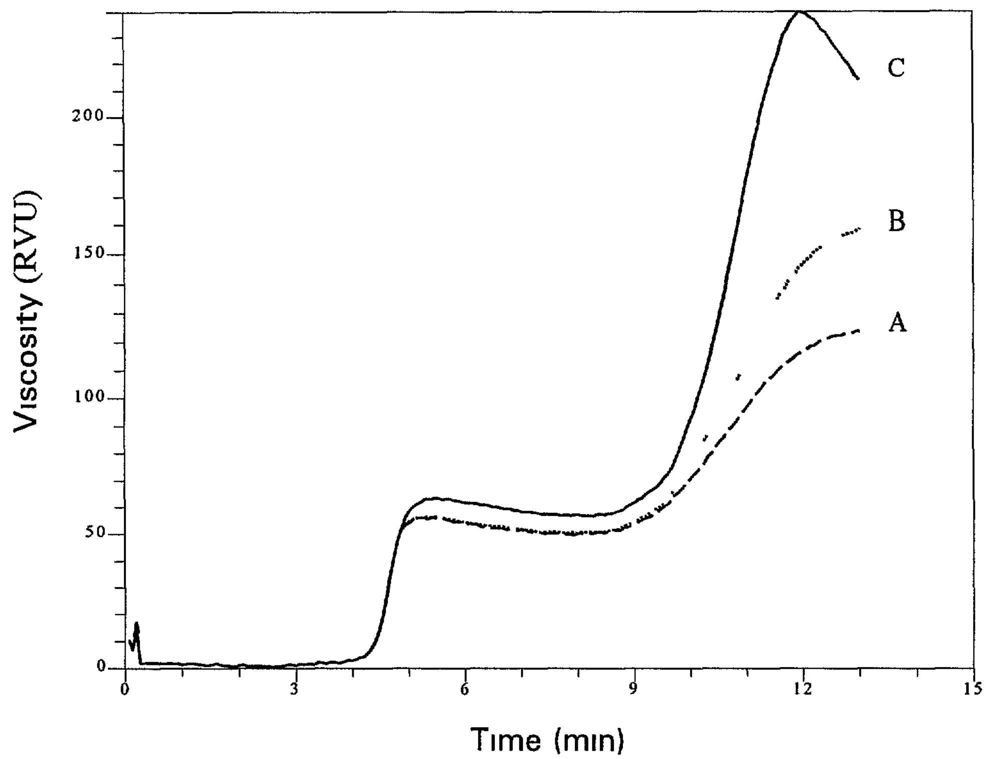

Figure 4 Rapid ViscoAnalyzer paste viscosity profiles of whole grain sorghum (P721N, '97) flours stored for 0, 1, and 2 months

Protein Digestibility of Normal Sorghum

Effect of Drydown on Protein Digestibility

Research in our laboratory has shown that sorghum protein digestibility decreases throughout development This decrease coincides with the formation of disulfide bonds in g-kafirin, a sorghum protein body protein, and possibly other related proteins Sorghum reaches physiological maturity at approximately 40 days after half bloom (DAHB), but is allowed to field dry until approximately 90 DAHB (moisture content to about 14%) The formation of disulfide bonds has been speculated to be due to oxidation during dry-down In this experiment, sorghum samples (45 DAHB, moisture content = 31%) were dried under varying environmental conditions Samples were freeze-dried immediately after harvest or allowed to air-dry at room temperature (18 days) Additionally, several samples were dried under artificial environments To investigate the effect of oxygen during drying, sorghum was dried at 0, 21 (ambient), and 42% oxygen, nitrogen made up the balance of the atmosphere The digestibilities of all samples dried at 45 DAHB under the various environments had higher digestibility (approximately 92%) than samples harvested at 90 DAHB following field drying (77%) These results indicate that dry-down alone is not the cause of disulfide bond formation during development Another factor, possibly an enzyme, may facilitate the formation of these bonds

Fungal Protease in Sorghum Grain

Sorghum grain, as well as millet, is subject to weathering prior to harvest due to seed exposure on the panicle In this study, a fungal protease present in even slightly weathered grain was shown to interfere with sorghum protein analysis by SDS-PAGE The protease was highly active in protein extraction solvent containing SDS and 2-mercaptoethanol at alkaline pH of 10, and was inhibited using 15 mM PMSF Thus, under the conditions of extraction, the foreign protease effectively hydrolyzed the sorghum protein and resulted in marked loss of protein bands on SDS-PAGE Moreover, the protease was active under electrophoresis conditions, as it created a clear zone on a casein-impregnated gel from migration at the top of the separating gel to its band formation at about 45 kDa The protease was found only in the bran portion of weathered-sorghum grain In those cultivars most highly affected (e g , SRN39), proteolysis during alkaline-detergent extraction for 1 hour removed over 80% of sorghum proteins normally seen in an SDS-PAGE banding pattern Grain of sorghum cultivar SRN39 that was separated visually for weathered (darkened to any extent) versus clean grain showed high and no proteolytic activity, respectively, following a two hour alkaline-detergent extraction These finding are significant due the interference that is caused by proteolysis in chemical studies on sorghum proteins Interference can be avoided by decorticating grain or by adding a protease inhibitor

Networking Activities

Workshops

B Hamaker participated in an East Africa regional workshop held in Nazret, Ethiopia in September 1997 Collaborative projects were planned with S Yetneberk of IAR, Ethiopia and plans were finalized for B Bugusu of KARI, Kenya to come to Purdue for her M S degree studies Ms Bugusu arrived in January 1998 to begin her program

B Hamaker also participated in a workshop for the new project entitled "Millet Promotion Through Improvement of Processing Technologies" of the West and Central Africa Pearl Millet Research Network (ROCAFREMI), March 1998 in Niamey, Niger The focus of the project is on processing of locally grown millet to products for sale to urban consumers

Research Investigator Exchange

A Aboubacar traveled to INRAN, Niamey, Niger in September-October 1997 to conduct sensory studies on sorghum couscous produced using the new couscous processing unit, and to meet with local entrepreneurs and an NGO active in processing of locally grown crops

B Hamaker traveled to India in September 1997 to initiate a project funded by the Mahyco Research Foundation (Mumbai) designed to study the potential of introducing the high protein digestibility sorghum identified through INTSORMIL PRF-212 into Indian germplasm He also visited B R Barwale, chairman of Mahyco Ltd and Drs Usha and Brent Zehr of same company, Dr Rana of the All India Sorghum Program, and A Chandrashekar (collaborator) of the Central Food Technology Research Institute, Mysore

B Hamaker traveled to CIMMYT, Mexico in April 1998 to explore further the possibility of setting up a nutritional impact study on Quality Protein Maize

An information pamphlet was designed and printed by A Aboubacar to promote couscous processing for commercial markets The pamphlet was carried to INRAN/Niger and was distributed within the Niamey area and at a regional exposition in Burkina Faso An entrepreneurial-scale decorticator and hammer mill are in the process of being purchased for the INRAN/Niger and IAR/Ethiopia laboratories

B Hamaker and students working on INTSORMIL-related projects (A Aboubacar, B Buckner, G Zhang) attended and presented research findings at the annual American Association of Cereal Chemists meeting in San Diego, California in October 1997

Publications and Presentations

Abstracts

Aboubacar A and B R Hamaker 1997 Variation in couscous properties among sorghum cultivars Cereal Foods World 42 623

Buckner R J and B R Hamaker 1997 Sorghum protein digestibility is not affected by artificial dry down Cereal Foods World 42 634

Zhang G and B R Hamaker 1997 The effect of protein on sorghum starch digestibility Cereal Foods World 42 646

Journal Articles

Weaver C A B R Hamaker and J D Axtell 1998 Discovery of grain sorghum germplasm with high uncooked and cooked in vitro protein digestibilities Cereal Chem in press

Oria, M P B R Hamaker and J D Axtell 1998 A highly digestible sorghum cultivar exhibits a unique folded structure of endosperm protein bodies Proc Natl Acad Sci USA, in press

Zhang G and B R Hamaker 1998 Low α amylase starch digestibility of cooked sorghum flours and the effect of protein Cereal Chem in press

Book Chapters

Hamaker B R M P Oria, C A Weaver and J D Axtell Improving sorghum nutritional quality 1997 In B A Larkins and E T Mertz (eds) Quality Protein Maiz 1964 1994 Purdue University West Lafayette IN

Hamaker B R and A Rahmanifar 1997 QPM and nutritional needs of children in poor communities In B A Larkins and E T Mertz (eds) Quality Protein Maize 1964 1994 Purdue University West Lafayette IN

Proceedings

Hamaker B R and J D Axtell Nutritional quality of sorghum and pearl millet In D Rosenow et al (eds) Proceedings of the International Genetic Conference on Sorghum and Millet September 23 27 1996 Lubbock Texas

Dissertations and Theses

Aboubacar A 1997 Physicochemical properties of flour and fine structure of starch in relation to sorghum couscous quality Ph D diss Purdue University West Lafayette IN

Zhang G 1997 Sorghum starch hydrolysis and digestibility M S thesis Purdue University West Lafayette IN

Food and Nutritional Quality of Sorghum and Millet

Project TAM-226
L W Rooney
Texas A&M University

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Dr Sergio Serna-Saldivar, Professor and Head, Food Science, Institute of Technology, Monterrey, Mexico

Ms Trust Beta, Lecturer, Department of Food Science, University of Zimbabwe, Harare, Zimbabwe

Professor John R N Taylor, Head, Food Technology Department University of Pretoria, Pretoria, South Africa

Summary

Jo-KRISP, Jowar Flour, pearled sorghum, several bakery mixes and other products based on identity-preserved white food-type sorghums are available from a Texas-based company Our research provided the basis for this commercial activity White sorghums can be substituted for wheat and maize in a wide variety of products

Flour from food sorghums can be used in Mexican-type cookies at levels up to 100% provided the flour is of high quality At 50% substitution of sorghum for wheat flour, differences are slight if any Milling properties of food-type sorghums were superior to others in several nurseries grown in Texas

Two methods to objectively evaluate texture of tortillas were devised, published and used to evaluate changes during storage Waxy sorghum (10 to 15%) improved the flexibility of stale sorghum and corn tortillas A commercial tortilleria plans to test the concept in corn tortillas using yellow waxy corn White waxy sorghum could be used to improve white corn tortillas since white waxy corn is unavailable

The Rapid Viscosity Analyzer (RVA) is useful in studying how to prevent staling of other baked products as well as tortillas We have initiated a strong collaborative relation with Mr Bueso at Escuela Agricola Panamericana (EAP) The EAP is expanding teaching and research activities in food science and technology His research and teaching program on sorghum and maize tortillas will transfer technology to the students from Central and South America

Variables affecting noodles from sorghum and use of malt to decrease the viscosity of weaning foods from cowpeas and millet were elucidated in a M S and Ph D thesis respectively

Grain mold resistance is critically important, but very difficult to select for in breeding programs Hence, a molecular linkage map for physical properties, kernel characteristics, milling quality, antifungal proteins (AFP), and other sorghum characteristics is nearing completion Some inoculated mold-resistant sorghums responded by producing higher levels of AFP while others did not Once we understand the role of AFP in molding, we may be able to improve mold resistance of sorghum cultivars more efficiently

The major constraint to utilization of sorghum and millet in the world is lack of a constant supply of good quality grain This concept was explained to anyone who would listen Attempts to demonstrate the value-added properties of

N'Tenimissa in Mali to processors have been partially successful These efforts continue

Profitable systems to produce value-added products from good quality grain are needed using existing or improved technologies

Two Ph D and two M S graduates joined the food industry and/or universities in the U S , Honduras and Colombia Short-term training programs were completed for personnel from Honduras and Nigeria

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 acceptability that can generate income for village entrepreneurs

The major constraint to development of profitable sorghum and millet foods is the lack of a consistent supply of good quality grain Until a source of identity-preserved, good quality grain can be produced, sorghum and millet products will continue to be inferior That is why it is imperative that the plant improvement programs develop cultivars with good quality for value- added processing at the local level In addition, we must promote a system of marketing identity-preserved grains as value-added products for urban consumers

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

Utilization of Sorghum in Noodles

Ms Kunetz completed her M S thesis on sorghum utilization in noodles We are following up on her activities by interacting with Dr Corke's laboratory at the University of Hong Kong where they have an extensive program on noodle quality We are sending our sorghum flour and isolated starches to them for processing into noodles to compare with our procedures An undergraduate food science honors scholar is using this as part of her research project

Ms Kunetz' method consists of cooking the sorghum flour and water by stirring the mixture over a hot plate followed by extruding the dough through a simple extruder and drying the noodles by exposure to air for 12 to 24 hours The noodles have lower quality using this method of production but they can be cooked into a product with acceptable texture and low dry-matter losses These techniques can be utilized in areas where sorghum and millet are produced to improve the products available to urban areas Modifications of the techniques would be required

Particle size, color, presence or absence of black specs and type of sorghum affected noodle properties significantly Whole grain flours did not produce acceptable noodles due to poor taste, dark color poor texture and high dry-matter losses during cooking

Effect of Waxy Sorghum on Tortilla Texture

We continue to evaluate sorghums for tortillas since they are used in Central America alone or mixed with maize Staling is a major problem for corn and sorghum tortillas We developed new methods of evaluating texture and staling to sorghum and corn tortillas

Sorghum tortillas were prepared using fresh masas containing different levels of amylopectin by substituting 0, 10, 15 and 20% of a white food-type non-waxy sorghum with waxy sorghum Tortillas were also prepared with 100% heterowaxy sorghum They were stored in polyethylene bags at 25° C for 2 and 72 hours Tortillas were evaluated using bending and extensibility tests with a texture analyzer They were tested cold, and after reheating in a microwave oven (30 sec)

Inclusion of waxy and heterowaxy sorghum increased tortilla softness at 2 and 72 hours of storage Less force was required to deform these tortillas (Figure 1) The addition of waxy sorghum successfully modified and improved the texture of the tortillas When warmed, tortillas with a higher amylopectin content were softer and more extensible than warmed control samples

We developed a method using the RVA to follow starch changes during staling (Figure 2) Samples that had reduced peak viscosity contained more strongly retrograded starch that was not easily redispersed by the RVA After 72 hours of storage, tortillas with an increased amylopectin levels (10, 15 and 20% waxy sorghum) had a significantly higher peak viscosity than waxy tortillas stored for only two hours This phenomenon appears to be caused by the retrogradation of amylopectin during storage that allowed more hydrogen bonding between amylopectin chains and thus increased the volume and viscosity

After 2 hours of storage some water-soluble amylose and dextrins were present in the control and waxy tortillas After 72 hours of storage only amylopectin was detected during the HPLC-SEC analysis of all the samples (waxy and non-waxy) indicating that this was the only water soluble carbohydrate (at 65°C) remaining in the staled tortillas

The use of waxy sorghum (up to 20%) can improve tortilla properties significantly Reheating dramatically improved tortilla texture This corresponded to the melting of retrograded amylopectin

The new RVA method of monitoring staling of tortillas appears to be sensitive enough for use with other baked products It is faster and significantly more convenient and practical to use in staling studies

We have found the subjective texture of waxy tortillas is significantly improved, they can be easily wrapped around food after warming and are significantly more flexible after storage These results were reported at a Tortilla Industry Technical Conference A tortillero is conducting a trial using yellow waxy corn substituted for normal corn Since there are few if any white waxy corn hybrids, waxy sorghum could be used to improve tortilla flexibility while maintaining a white color tortilla

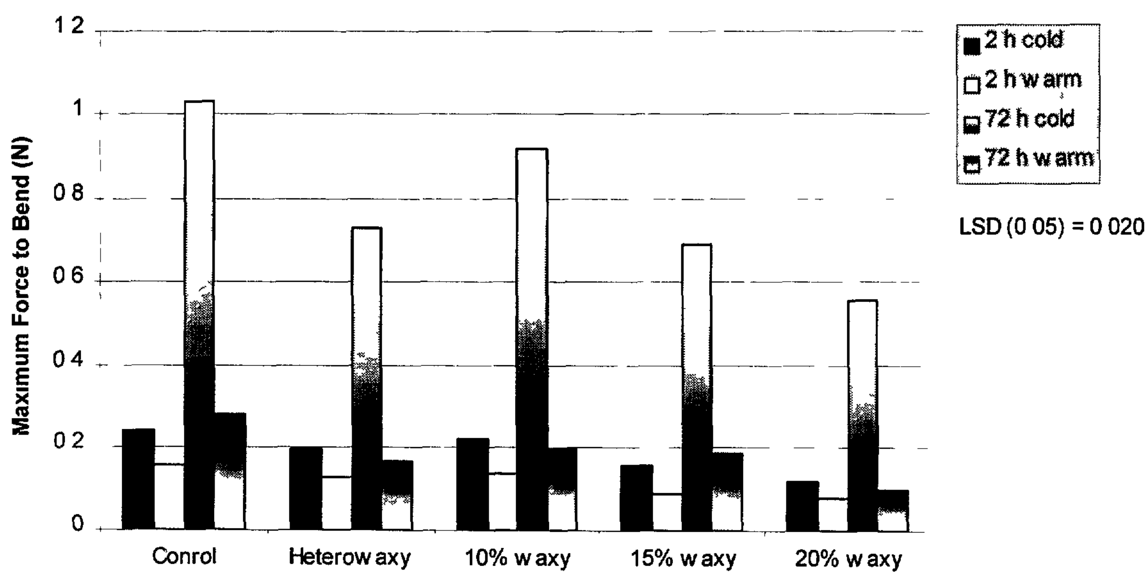

Figure 1 Texture analyzer bending test Effect of heterowaxy and waxy sorghum on sorghum tortilla texture The results are the means of two replicates and six tortillas within a replicate

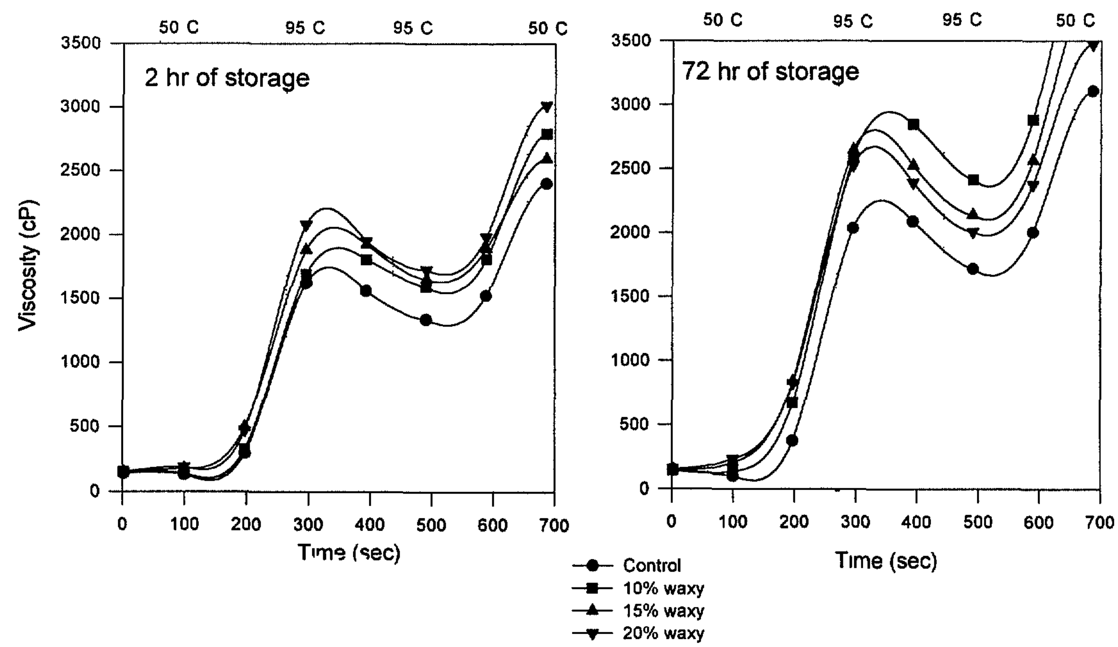

Figure 2 Pasting characteristics Sorghum tortillas 2 and 72 hours after baking and cooling control (ATx631 × RTx436), 10, 15 and 20% waxy (15% solids) Values are means of two observations (sample was a composite of four defatted, ground and dried tortillas)

The methods of objectively measuring tortilla texture were developed and are in press and have been reported to the tortilla industry Several companies are using these techniques

Specialty Tortilla Chips

A black sorghum grain cooked in alkali produced tortilla chips with a very intense, blue (black) color The grain has the highest level of polyphenols we have found in sorghums It could be used as a niche market for production of reduced cost high quality "blue tortilla chips and related products We are evaluating the effect of pH alkali level and other factors on color stability and intensity The black sorghum produces tortilla chips with more intense blue color than the best blue corn varieties available Several bright red sorghums are being evaluated for potential production of a bright red, natural tortilla chips

Weaning Food Systems

Dr Sam Asante from Ghana completed his Ph D on factors affecting weaning food caloric density The research on liquefication of weaning foods clearly indicated that sorghum or millet malt can be used to increase caloric density of cooked gruels Additional field studies are continuing in Mali to utilize these concepts to enhance weaning foods made from local blends of millet flour, cowpeas and malted sorghum or millet to enhance the nutritional density

Sorghum Flour in Baked Products

Numerous inquiries concerning use of sorghum flour in baking have been received from Mexican food processors Therefore we initiated research on production of cookies and related products from 100% sorghum flour and blends with wheat flour

Sorghum flour was prepared from a white food-type sorghum with tan plant color The grain was decorticated and ground using a Brabender Quadramat Junior Mill and sieved to obtain flour Cookies were prepared using a Mexican cookie formulation as well as the standard AACC sugar cookie testing procedure In the Mexican cookies, sorghum was substituted at 10, 25, 50, 75, and 100% levels, with a 100% wheat flour cookie as a control Sorghum flour was also toasted to see the effect on cookie texture In sugar cookies, both the white sorghum above and a red commercial sorghum sample (red, heteroyellow endosperm, Plainview, TX), were substituted at 10, 50, and 100% levels

As sorghum flour content increased in the Mexican cookie formulation, the spread factor (width/thickness) increased only slightly (Table 1) The color of the cookies became slightly darker and more yellow, but the differences were not significant The cookies became softer, and were more easily bent and broken, as the level of sorghum increased Cookies containing 50% or less of wheat flour were acceptable in flavor and texture Cookies prepared from 100% sorghum were palatable, but were crumbly, gritty, and easily broken

For sugar cookies, up to 50% sorghum flour could be used (Table 1) Above that level, the grittiness became no ticeable and the crumb was too dry As the level of sorghum increased, the spread factor increased, more so than in the Mexican style cookie Cookies prepared from 100% sorghum were slightly darker and more yellow than those from wheat flour Cookies prepared from commercial red sorghum flour were darker (browner) than those using the white food-type sorghum flour The AACC sugar cookie had high sugar water and sugar flour ratios, making it less suitable for the evaluation of the role of flour in the formulation

The addition of 5% pre-gelatinized corn starch to the formulation significantly improved the texture of the cookies We are now seeking ways to gelatinize part of the sorghum flour to improve the texture of 100% sorghum cookies Problems in the cookie formulations relate to the gritty, sandy texture of the sorghum flour, the presence of black specks in the flour, and the level of moisture in the baked cookies Work continues to improve the characteristics of the flour

Our research demonstrating the potential for utilization of improved quality sorghums in various food products has been the focal point for presentations in many areas of the world to illustrate its potential in sophisticated human foods ranging from snacks, ready-to-eat breakfast foods, composite flour baked products and tortillas The new information on sorghum flour use in Mexican type cookies addresses specific questions raised by Mexican millers and bakers who have expressed interest in sorghum flour for use in cookies and related products It has been used in market development activities sponsored by the Sorghum Producers Association and the U S Feed Grains Council in Mexico and other areas

Economics and availability of sorghum flour are critical factors limiting use of sorghum High prices for wheat stimulate interest which sometimes is short lived when wheat prices drop However, over the long term, sorghum of good quality will be used in composite flour products because it has a bland flavor which does not mask other flavors like the strong flavor of maize does

Sorghum Starch, Malting and Brewing Studies

Dr Serna-Saldivar, ITESM, Monterrey, Mexico, has completed a three-year research project on sorghum utilization funded by CONACYT Six students completed M S theses on sorghum, malting, brewing and starch isolation and conversion Food-type white, normal, waxy, and heterowaxy types were compared to commercial red sorghums

Malting Studies

Malted waxy, heterowaxy and nonwaxy sorghums lost from 4 9 to 8 4% dry matter during malting due to modifications of the protein matrix and starch granules Maximum diastatic activity was reached 4 5 days after steeping and

Table 1 White food sorghum flour substitution for wheat flour in a Mexican cookie formula

Treatment (%)		Spread	Color			Peak force (N)		
SF	WF	factor	L	a	b	Bending	Puncture	Comments[b]
0[a]	100	100 3	78 2	1 9	24 5	11 9	15 0	Firm crispy dry at first but then it moistens and holds together in the mouth Subjective hardness 5
10	90	91 1	77 4	2 4	26 4	11 5	12 8	Firm crispy very similar in texture to cookie with 100% wheat flour(control) Subjective Hardness 5
25	75	98 8	78 1	1 6	24 3	11 5	11 9	Firm crispy dry but it stills holds together in the mouth also similar to control Hardness 4
50	50	98 7	77 3	2 2	24 5	9 4	10 9	Firm crispy a little gritty but almost as good as control Hardness 4
75	25	95 8	78 1	1 5	25 1	6 1	7 7	Softer but still firm a little crispy gritty and dry It does not form a moist dough in the mouth Hardness 3
100	0	96 1	77 0	2 6	26 6	3 2	3 7	Soft still firm but less crispy than the rest of the cookies Very dry and gritty texture it does not moisten inside the mouth Hardness 2
100 (10% toasted)	0	107 7	76 5	2 4	26 5	3 8	7 5	Not as firm as control but more than the 100% SF cookie crispy dry and gritty It does not hold together in the mouth some nutty aftertaste

[a] SF = sorghum flour WF= wheat flour
[b] Subjective hardness according to force needed to break cookie between the index and thumb
5= Most resistant to crumble
4= Some resistance to crumble
3= Relatively easy to crumble
2= Easy to crumble
1= Very easy to crumble

germination Dorado had the highest diastatic activity and dry matter losses of the sorghums tested Dry matter losses were lowest in the waxy variety It is possible to replace part of the barley malt mixtures used in brewing with sorghum malt, and thereby reduce costs

In another study, weaning foods were prepared using quality protein maize, maize and pearl millet At low sorghum malt levels (1%), the viscosity of the 15% slurries of weaning foods decreased significantly The result was a high caloric density nourishing food suitable for use in weaning

Wet Milling

Two sorghums, a white waxy and a commercial red nonwaxy, were wet-milled to produce starch using sulfur dioxide and lactic acid The waxy cultivar produced starch yields comparable to corn A cellulase enzyme mixture added to the steep solution, improved the starch yield from the nonwaxy sorghum, corn and waxy sorghum starch yields remained unchanged In another experiment, white waxy, heterowaxy and nonwaxy sorghums, and commercial red sorghum starches were converted to glucose syrups using a continuous enzymatic hydrolysis system Corn starch was degraded faster and had higher conversion rates than the sorghum starches The waxy sorghum gave the most promising results in glucose production, but required increased enzyme concentration and/or processing time The tan plant white sorghums produced starch with the lightest color due to the lack of anthrocyanin pigments and the reduced yellow of the endosperm White sorghum can be used as an alternative raw material for starch production

Brewing

White waxy, heterowaxy and nonwaxy sorghums and a red nonwaxy sorghum were decorticated to produce brewer's grits Yields of the waxy and heterowaxy grits were highest and the control lowest The color of the grits from the white sorghums was significantly lighter During conversion, the waxy grits required less filtration time than the other varieties Under standard conditions, no significant differences were found in wort pH, color and viscosity The white sorghum with waxy endosperm had excellent properties as a brewers adjunct In all these experiments, the food-type sorghums performed better than or equal to the red sorghums The waxy and heterowaxy sorghums had an advantage for conversion during mashing over normal sorghum Hard waxy endosperm was deemed the best for production

In general, the research done in Mexico confirmed that sorghum can be utilized in starch and sweetener production and brewing effectively Sorghum is the second largest crop in Mexico after maize Economics will decide its use

Commercial Food Products Available in U S

Many commercial hybrid seed companies in the U S have expanded their efforts to produce white, tan plant, food-type hybrids We have reached the point where significant quantities of food-type sorghums are available Additional hybrids are needed to increase the availability of food sorghums Jowar Food, Inc continues to market sorghum food products for ethnic and dietary groups The food-type hybrids are given a small premium by some feedlots in West Texas

Dry Milling Properties of Sorghum

The milling properties of food-type sorghum hybrids grown under commercial production were compared with a standard red hybrid (Table 2) The white food grains had slightly higher test weight, true density, reduced floaters and slightly higher yields of decorticated grain than the red sorghum However, the major difference was in the color which was significantly lighter and brighter for the food-type sorghums The red pericarp contributes significant color to the flour which would have been worse if grain had been weathered slightly The heterowaxy hybrid produced grain with a smaller kernel and reduced test weight

Sorghum samples from several performance trials were analyzed and evaluated for milling characteristics The new food-type sorghums consistently had equal or improved grain and milling yields, and the color of the decorticated kernels was far superior to those of white sorghums with purple plant color Certain parents improve the milling properties of their hybrids significantly

We evaluated the International Food Sorghum Trials grown at Lubbock, Texas during 1994 to 1997 for endosperm color and for milling properties Sorghum progeny from a Sureño (white endosperm) × Tx430 (yellow endosperm) cross grown at College Station and Halfway were

Table 2 Physical and milling properties of food-type sorghums grown commercially in West Texas, 1997

Sample	Endosperm Type[a]	Endosperm Color[b]	Test Wt lb/bu	TKW g	Density g/cc	Floaters %	Yield of decorticated %	Color L	Color a	Color b
Jowar 1	N	2 0	61 5	26 5	1 375	32	83 0	67 8	1 07	22 5
NC+ Hybrid	HW	3 0	58 1	19 8	1 354	52	84 2	65 3	2 24	24 3
Warner 902 W	N	2 0	61 6	26 1	1 371	28	83 6	67 5	1 2	22 9
Normal Red	HY	4 0	60 0	28 0	1 343	50	82 5	62 8	3 82	24 4

[a] Endosperm Type HW = Heterowaxy N = Normal HY= Heteroyellow
[b] Endosperm Color 1 = White to 5 = Yellow

analyzed for physical and milling properties, molding and levels of AFP The information is being used to produce a linkage map of the chromosomes affecting quality and parameters affecting mold resistance of sorghum

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 bright red appearance of the grain and reduced color of milled products from the tan red sorghum hybrids make them extremely promising for areas that cannot grow white sorghums

Role of AFP in Minimizing Grain Molding of Sorghum

Grain molds and weathering greatly affect utilization quality of sorghum We are continuing to evaluate the role of AFP in mold resistance Mr J Bueso completed a M S thesis on AFP with Drs Waniska, W L Rooney and Mr Raul Rodriguez (Ph D Candidate, Sorghum Breeding)

Chitinase and sormatin are AFP found in developing sorghum caryopses We previously reported that AFP vary in concentration among cultivars, and were related to resistance to grain molding when measured in caryopses at physiological maturity We conducted additional experiments to determine changes in AFP when selected resistant and susceptible cultivars were inoculated with molds and subjected to malting

Sorghums were grown in the field, stressed with pathogenic fungi, caryopses were sampled during development, and chitinase and sormatin in the kernels were quantified Ten cultivars differing in mold resistance and accumulation of AFP were tested in a split plot design Panicles were inoculated at anthesis with a solution of F moniliforme and C lunata spores or with water Caryopses were collected 10, 17, 24, 30 and 50 day after anthesis (DAA) Chitinase and sormatin were extracted, separated by PAGE, transferred to a membrane, and quantified by polyclonal AFP antibodies using western blots

Sorghums exhibited different patterns of accumulation of AFP For these samples, chitinase and sormatin levels at physiological maturity were not correlated with grain mold resistance (Table 3) We expected they would not be correlated and designed the experiment to determine the changes that occur when they were exposed to different conditions

Wetting of panicles significantly reduced or did not change levels of AFP in most sorghums (Figure 3) Wetting caused levels of chitinase to increase in three sorghums SC719-11E, Malisor 84-7, and Hegari*Dobbs Sprinkling panicles with water every fifth day provided an environment favorable for fungal colonization and growth The increased fungal pressure and/or the "wet" environment caused levels of AFP to decrease

Inoculation with fungal spores at anthesis caused significant reductions or did not change AFP levels of most sorghums (Figure 3) Two of the three moderately resistant sorghums, however, responded with increased levels of AFP after inoculation Hence, two cultivars with grain mold resistance had high levels of AFP in dry (control) environments and levels of AFP increased after wetting and/or inoculation with grain molds

The combination of inoculation and wetting increased chitinase in only Malisor 84-7 Other cultivars had reduced or no change in levels of AFP with the combined stresses

Further reductions in AFP occurred post physiological maturity The exceptions were 1) wetting of R9025 caused increased levels of sormatin, 2) all stresses on SC719-11E caused increased levels of chitinase

Sorghums were classified into "responders" and "nonresponders" using this data The mold resistant variety, SC719-11E, containing a pigmented testa and tannins, is a "nonresponder" that has low levels of chitinase and sormatin The other "nonresponders", BTX638 and Hegari*Dobbs, were susceptible to grain molding Two positive "responders", Malisor 84-7 and R9025, were moderately resistant to grain molding Five negative "responders" included one moderately resistant, Sureño, and four

Table 3 Characterization of sorghums according to kernel traits and degree of mold resistance (1996-97 data)

Cultivar	Mold resist	Flower	Pericarp color	Testa	Spreader	Hardness	Sormatin (ug/kernel)	Chitinase (ug/kernel)
SC719 11E	High	Early	Red	Yes	Yes	Medium	3 (e)	97 (e)
Malisor 84 7	Mod	Medium	White	No	No	High	16 (de)	190 (de)
R9025	Mod	Medium	Red	No	No	Low	54 (ab)	650 (ab)
Sureño	Mod	Medium	White	No	No	High	36 (c)	484 (c)
E35 1	Low	Late	White	No	No	Medium	25 (d)	102 (e)
IS2319	Low	Late	White	Yes	No	Low	60 (ab)	587 (bc)
RTx2536	Low	Medium	White	No	No	Low	70 (a)	240 (d)
RTx430	Low	Medium	White	No	No	Low	44 (bc)	319 (d)
Btx 638	Low	Medium	Red	No	No	Medium	31 (cd)	506 (c)
Hegari*Dobbs	Low	Medium	White	Yes	Yes	Medium	46 (bc)	740 (a)

Note Early maturity = <60 days Medium = 61 80% Late = >81% When spreader (S) gene is dominant tannins accumulate in pericarp and testa Hard = <30% decortication Medium = 30 50% Soft = >51%

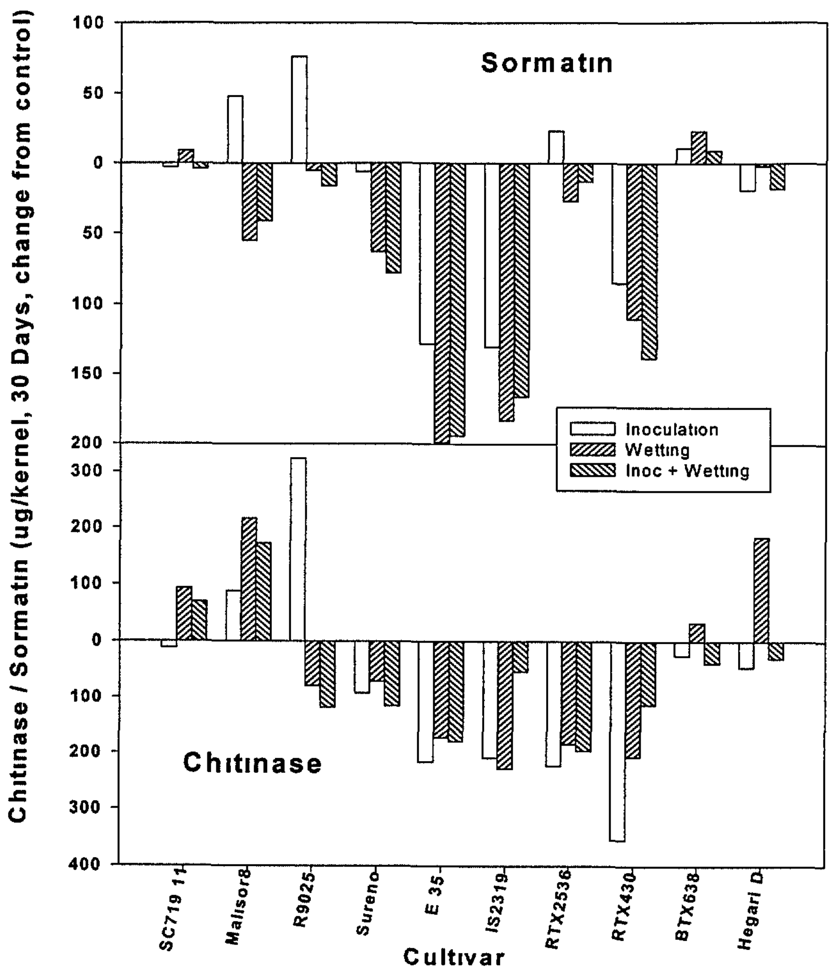

Figure 3 Changes in antifungal proteins in 10 kernels of 10 sorghum cultivars 30 days after anthesis All values are compared to the control The grain was grown at College Station, TX in 1996

susceptible sorghums The two moderately resistant "responders" had pericarp colors of red and white

The two moderately-resistant, white-pericarp sorghums, however, exhibited different responses to wetting and inoculation with fungal spores Optimistically this could indicate that two or more independent mechanisms relate to grain mold resistance The tannin containing sorghum SC719-11E probably has a different mechanism

Additional research on AFP will focus on comparing sorghums with resistance to mold that have white or red pericarp without a pigmented testa AFP may be important in preventing or reducing molding of some sorghums The grain must be inoculated and tested for AFP We know that kernel characteristics, plant architecture, glume type, endosperm hardness and wax covering of the pericarp affect molding and weathering

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 From this research, several inbreds that produce white, tan-plant sorghum hybrids with excellent food and feed processing quality have been released 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 Tamaulipas in Mexico The need to understand sorghum molding and weathering is critical

Networking Activities

Southern Africa

L W Rooney traveled to Botswana, Zimbabwe and South Africa to participate in the Southern African International Food Science and Technology Congress at Pretoria L W Rooney presented a paper on major constraints to utilization of sorghum and millet The conference was well attended by food scientists from Southern and Eastern Africa

L W Rooney presented a seminar to food science and technology students at the University of Pretoria and discussed the research projects of more than 10 students who are working on sorghum and millet post harvest projects Ms T Beta's research was reviewed along with a draft of a paper on Zimbabwean sorghum properties

A special discussion on sorghum quality improvement was conducted at the University of Pretoria by Professor J R N Taylor

Foods Botswana and other processors confirmed that major constraints to sorghum utilization is the lack of a consistent supply of good quality grain Foods Botswana has spent considerable time and money to acquire good quality sorghums with only limited success

A research project by Ms Trust Beta, Lecturer, University of Zimbabwe, was approved by INTSORMIL on sorghum and millet dry milling in Zimbabwe It is cooperative with SMIP and the Department of Research and Special Services (DRSS) in Zimbabwe Ms Beta has utilized the SMIP laboratory in Matopos A poster paper was presented at the 1997 SAAFoST Congress in Pretoria Ms Beta is conducting Ph D research at the University of Pretoria

Honduras, Mexico and South America

L W Rooney traveled to Honduras twice to assist Mr Javier Bueso initiate research and teaching activities at EAP Nixtamalization of sorghum from advanced breeding nurseries has begun Sorghum and maize tortillas processed in the tortilleria at EAP were liked by students

The EAP has restructured its curriculum and will emphasize food science and technology New courses and activities are being developed for the food science program This provides a unique opportunity to transfer our sorghum/maize technology into Central and South America For example, Mr Bueso has a 4th year student from Nicaragua conducting sorghum and maize tortilla quality research using the tortilleria in the food service center at EAP

A computer was provided to Mr Bueso along with small items of equipment and supplies to initiate the alkaline cooking trials of advanced sorghum lines in the improved Maicillo nurseries This work previously done here in the Cereal Quality lab will provide a way of transferring technologies into the region through the graduates of EAP Workshop(s) on grain quality are planned

L W Rooney presented a lecture at EAP on nixtamalization products from maize - recent developments in the U S More than 60 food science and related students participated

Mr Bueso may continue studies toward a Ph D in Food Science in 1999

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 We have provided samples of sorghum for planting and for analysis in addition to the use of our laboratory for analytical tests, i e, reducing sugars, rapid viscosity analyses, color, texture, etc

Mali

N'Tenimissa (one new white, tan plant, locally adapted photosensitive sorghum cultivar specifically designed for value-added processing in Mali) has some agronomic problems, but it is apparently liked by farmers for its tô quality Ms Berthe and others in the IER Food Technology laboratory have been testing N'Tenimissa in a wide variety of food products The real key is to produce large enough quantities of grain for value-added processing This year another large increase is planned to permit large scale testing of value-added products

N'Tenimissa has high yields with slightly softer grain than local cultivars so some adjustments in milling time are required It consistently has lighter color, provided it is not contaminated with off types Identity-preserved grain production is required

N'Tenimissa's panicle breaks off after grain fill and causes harvesting problems Sister selections and other advanced breeding materials will be evaluated for production The increased yield of grain may overcome the panicle breakage for the near term until an improved type is available

The laboratory in Mali provides information on milling and other quality attributes which can be used for selection

Dr A Toure, IER sorghum breeder, returned to Mali and will expedite the breeding and testing program

Global 2000, World Vision and other groups are collaborating in Mali to evaluate maize and sorghum production and utilization

Sorghum Market Development Activities

The Grain Sorghum Producers Association has market development activities to capitalize on the new food sorghums for use in value-added products in Mexico, Central and South America Our research activities on composite flours, tortillas, snacks and other food products from sorghum was presented at U S Feed Grain sponsored value-added market development workshops in Mexico and Guatemala The interest in sorghum flour use was stimulated by recent high prices in wheat flour Since wheat prices have decreased recently, short-term interest is less, but, there is a long-term interest in sorghum for human food since it is a major crop in Mexico

The concept of identity-preserved production and marketing of grains is expanding significantly in value-added corns such as high-oil corn hybrids The development of white food-type, waxy, heterowaxy and nonwaxy sorghums fits into these marketing schemes

L W Rooney presented information to Mexican flour millers, bakers and dry masa processors who visited Texas as guests of the Sorghum Producers Association

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in San Diego, CA L W Rooney presented sorghum quality/ utilization discussions to Texas Sorghum Producers Board Members, to sorghum production conferences in San Antonio and Edna, Texas, to U S Feed Grain Council market development teams and others, and to many visitors to our laboratory from Mexico, Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador, China and Japan Our laboratory conducted short courses on practical snack foods production and maize quality evaluation in which sorghum utilization quality was part of the program

Training, Education and Human Resource Development

Dr Omueti Obafemi Awolowo University, Institute of Agricultural Research and Training, Nigeria, spent six weeks in our laboratory to obtain information on practical snack food production from maize and sorghum She learned how to optimize the nixtamalization process to produce masa for use in a variety of potential foods She became familiar with the extrusion of cereals into a wide variety of snacks

Monterrey Institute of Technology our collaboration with Dr Serna-Saldivar, ITESM, Monterey, Mexico has lead to completion of six M S theses that deal with sorghum quality They are

> Kathya Liliana Allende Rangel 1995 Determination of the Optimum Conditions for Malting of Sorghum
>
> Maria Luisa Barragan Delgado 1996 Production of liquified weaning food made from different cereals and sorghum malt
>
> Angelica Villaseñor Medina 1997 Glucose syrups from sorghum starch using enzymatic conversion and membrane ultrafiltration
>
> Jorge Alberto Moheno-Perez 1994 White sorghums as raw materials for starch production
>
> Sara Gabriela Osorio Morales 1995 Production of brewers adjuncts and wort from waxy and normal sorghums
>
> Martha Mezo-Villanueva 1997 effect of protein and fiber degrading enzymes on steep time and starch yields during sorghum wet milling

These young scientists have joined the Mexican food industry Thus knowledge of sorghum utilization potential has been transferred into the Mexican food industry along with the generation of useful knowledge Dr Serna's research was funded by CONACYT in Mexico Our role has been to provide samples of grain, analytical methodology, access to laboratory facilities and some interaction For example, Dr Serna-Saldivar visited the CQL in 1997 and 1998 and L W Rooney conferred with ITESM program in 1998 and presented a paper, "Cereals for the 21st Century" at the Student Food Technology Symposium held at ITESM The students have usually spent time in the laboratory at College Station

Mr Javier Bueso, Honduran graduate student, completed his M S degree in food science and technology He was hired as an assistant professor, CITESGRAN, Escuela Agricola Panamericana, Tegucigalpa, Honduras where he has initiated sorghum/maize quality research and is teaching cereal quality/technology classes

Mr Rafael Mateo, Agronomist, EAP, Zamarano, Honduras, completed a two month INTSORMIL funded English language and practical hands-on experience in sorghum breeding and improvement programs at Texas A&M University He returned to EAP to conduct sorghum research

Three graduate students worked on INTSORMIL related research, with partial financial support

Two Ph D , two M S and two short term trainees completed their programs and returned to Honduras, Columbia, and Nigeria Two were employed in the U S food industry, the others in universities Projects included steam flaking, weaning foods, milling properties, snack foods, tortilla quality and baking properties of white sorghum flour

Publications and Presentations

Abstracts

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McDonough C M K Kunetz L W Rooney 1997 Structure and texture of sorghum noodles AACC 82nd Annual Meeting October 12 16 San Diego CA Cereal Foods World 42(8) 666

Kunetz C F H Almeida Dominguez C M McDonough R D Waniska, and L W Rooney 1997 Cooking characteristics and quality of noodles from food sorghum AACC 82nd Annual Meeting October 12 16 San Diego CA Cereal Foods World 42(8) 624

Quintero F X R D Waniska, and L W Rooney TIA 1998 Effect of amylopectin level on texture during aging of maize and sorghum tortillas 8th Annual TIA Technology Seminar May 10 14 Dallas TX

Suhendro E L H D Almeida Dominguez L W Rooney and R D Waniska 1998 An objective measurement of tortilla texture 8th Annual TIA Technology Seminar May 10 14 Dallas TX

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McDonough C B J Anderson and L W Rooney 1998 The effect of conditioning agents on the structure of tempered and steam flaked sorghum Cer Chem 75 (1) 58 63

Suhendro E L H Almeida Dominguez L W Rooney and R D Waniska 1998 Objective rollability method for corn tortilla texture measurement Cereal Chem 75(3) 320 324

Suhendro E L H D Almeida Dominguez L W Rooney R D Waniska and R G Moreira 1998 Tortilla bending technique an objective method for corn tortilla texture measurement Cereal Chem (In press)

Suhendro E S C M McDonough L W Rooney R D Waniska and S Yetneberk 1998 Effects of processing conditions and sorghum cultivar on alkaline processed snacks Cereal Chem 75(2) 187 193

Toure A K Traore A Bengaly J F Scheuring D T Rosenow and L W Rooney 1998 The potential of local cultivars in sorghum improvement in Mali African Crop Science Journal Vol 6(1) 1 7

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McDonough C B J Anderson and L W Rooney 1997 Structural characteristics of steam flaked sorghum Cereal Chem 74(5) 542 547

Moheno Perez J A H D Almeida Dominguez and S O Serna Saldivar 1997 Effect of fiber degrading enzymes on wet milling and starch properties of different types of sorghums and maize Starch 49(12) 480 484

Seetharaman K E Whitehead Nancy P Keller R D Waniska and L W Rooney 1997 *In vitro* activity of sorghum seed antifungal proteins against grain mold pathogens J of Ag and Food Chem 45 (9) 3666 3671

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Rooney Lloyd W 1998 Applications of sorghum for human consumption US Feed Grains Council Value Enhanced Grains Conference May 21 22 Guadalajara Jalisco Mexico

Rooney Lloyd W 1998 Applications of sorghum for industrial uses US Feed Grains Council Value Enhanced Grains Conference May 21 22 Guadalajara, Jalisco Mexico

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Asante Sam December 1997 Production of weaning foods from cereal cowpea composites using traditional African processes Ph D diss Texas A&M University College Station Texas 133 p

Bueso Javier December 1997 Assessment of the activity of antifungal proteins against grain mold in sorghum caryopses in the field M S thesis Texas A&M University College Station Texas 126 p

Kunetz Christine December 1997 Processing parameters affecting sorghum noodle qualities M S thesis Texas A&M University College Station Texas 100 p

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Strategic Marketing of Sorghum and Pearl Millet Products in West and Southern Africa

Project UIUC-205
Carl H Nelson
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This INTSORMIL project began in early May of 1998 The primary activities during the two months covered by this report were organizational activities necessary to initiate the research

One major organizational task involved negotiations with ICRISAT over the employment of a co-principal investigator Dr Jupiter Ndjeunga was employed by ICRISAT as a research fellow at the Sadore Sahelian Center outside of Niamey, Niger His fellowship was scheduled to expire at the end of June, 1998 I wanted to retain Dr Ndjeunga at Sadore for at least the first year of this project in order to get the project firmly established in West Africa Dr Ndjeunga's primary task during his two year fellowship involved studying the West African Seed Systems in order to better understand the failure to adopt varieties developed by ICRISAT

An external evaluation panel recommended that ICRISAT devote more sociological and economic research to processing and utilization of sorghum and millet Since they had no social scientists or economists working on these issues, ICRISAT decided that it was in their interest to employ Dr Ndjeunga

The negotiations resulted in an agreement to share the cost of Dr Ndjeunga's salary equally between INTSORMIL and ICRISAT during the coming year This INTSORMIL project will supply half of Dr Ndjeunga s salary ICRISAT will supply the other half, as well as research overhead expenses such as office space and vehicle use This means that the objectives of this project have been included in the ICRISAT research plan for the coming year Dr Ndjeunga's work on these objectives will be monitored by Dr David Rohrbach, as well as myself Dr Rohrbach will also serve as a collaborator on the Southern Africa portion of this research project

Research Objectives

- Identify and Analyze Constraints that Prevent Farmers from Adopting and Marketing Varieties Preferred by Food Processors
- Identify and analyze constraints that limit the application of cash inputs in the production of varieties preferred by food processors
- Identify and analyze the constraints that prevent processors from securing a regular and reliable supply of quality grain needed for processing
- Identify, analyze, and implement forms of marketing organization that could support sustained cooperation between farmers and processors

Host Country

Program Enhancement

Central America and Honduras

Gary C Peterson
Texas A&M University

Coordinators

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Ing Carlos Merlo, Agronomist, Cargill of Central America, Honduras
Ing M S Alejandro Palma, Breeder, DeKalb of Central America, Honduras
Ing Laureano Pineda, Agronomist, INTA, Nicaragua
Ing Oscar Martinez, Agronomist, ICTA, Guatemala
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Collaborative Program

Institutions

Panamerican Agricultural School (EAP)-Honduras
Direccion de Ciencia y Tecnologia Agricola (DICTA) - Honduras
Instituto Nicaragense de Technologia (INTA) - Nicaragua
Texas A&M University
Mississippi State University

Organization and Management

The INTSORMIL Central American Regional Program is based at the Panamerican Agricultural School (EAP), Zamorano, Honduras This central location provides the opportunity to conduct sorghum research in Honduras, through outreach and networking to evaluate new technologies throughout Central America, interact with private seed industry, and identify students from the EAP for advanced degree training The EAP regarded as the premier regional school, has excellent faculty and students, and provides an ideal location from which to conduct research and training The Direccion de Ciencia y Tecnologia Agricola (DICTA) provides Government of Honduras support and research locations (primarily the LaLujosa Experimental Station at Choluteca) All nurseries and trials are planted at Zamorano and Choluteca The program is managed by Hector Sierra and Rafael Mateo in collaboration with Dr Juan Carlos Rosas, EAP Agronomy Department Head The Honduras program has extensive ties with the private seed industry and developed the first multi-location sorghum performance test to provide unbiased data on hybrid performance in a range of environments Texas A&M University is developing collaboration with Christiani Burkard (Guatemala), the largest local seed company in Central America

Research is conducted in sorghum breeding, entomology, plant pathology and cereal quality Primary support for the breeding program is from Texas A&M University Entomology research is conducted by Mississippi State University and the Department of Plant Protection Previous research has dealt primarily with insect complexes in the maicillos Research to study sorghum midge (*Stenodiplosis sorghicola*) in Nicaragua has been initiated Pathology research has been conducted by Texas A&M University in collaboration with the Department of Plant Protection During 1997-98 research in cereal quality was initiated between Texas A&M University and the CITESGRAN program

Three types of grain sorghum are grown in Central America Maicillo criollos, an indigenous landrace unique to Central America, are grown on hillsides primarily by very small producers in an intercropping system with maize Primary growing region for the maicillos is the steep hillsides of the Pacific regions of Honduras, Nicaragua, Guatemala, and El Salvador Research on maicillos is conducted by the Honduras program Small to medium producers frequently grow varieties Many small producers in Nicaragua are interested in varieties The INTA sorghum program does research on improved varieties Larger producers throughout Central America grow hybrids that are produced by private industry

INTSORMIL, in collaboration with the CLAIS network, strengthens research among Central American countries This collaboration has several aspects - training, publication of research results, and germplasm exchange The Grain Sorghum Performance Trial publication offers to sorghum producers an evaluation of the cultivars available in Central America as well as their performance in multiple localities Private seed companies have used this trial to take advantage of the increasing demand for hybrids by providing better germplasm adapted to tropical conditions

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America regional budget For FY1997-98, the regional budget was $80 000 Funds in the amount in $47 000 were initially transferred to EAP for operation of the program The funds supported all phases of the research program including supplies general operations, and salary Two partial scholarships for fourth year EAP students were also funded The students conducted thesis research on sorghum production The remaining INTSORMIL funds remained at the Management Entity and were used for travel, supplies, equipment, repairs, and maintenance of the regional program INTSORMIL is collaborating with the Soil Management CRSP on research on the steeplands of southwestern Honduras, the primary maicillo criollo growing region The Soil Management CRSP transferred $10,000 to Honduras to support research activities Funds were also generated through operation of the PCCMCA sorghum performance trial This fee entry trial was initiated and organized by this program with 12 testing sites in 1997-98 EAP supports the research through facilities, land, financial management and general supervision of the program operations DICTA supports the research by providing land and facilities at the La Lujosa Experimental Station, Choluteca Although the sorghum program received a significant level of USAID support (PL 480) in previous years, reduction in funds available to the mission eliminated direct financial support of the sorghum program in 1995

Collaboration

The Honduras sorghum program has collaborated with many organizations and has served as a catalyst for sorghum research in Central America The program has been providing seed to the LUPE (Land Use Productivity Enhancement) project funded by USAID for several years Since its inception the program has collaborated with organizations including but not limited to Associates in Rural Development (ARD-USAID), Center for Agricultural Development (CEDA-Japan/GOH), Consolidated Agrarian Reform in the South (CORASUR- Belgium/GOH), Integrated Rural Development (DRI-Yoro-Swiss/GOH), Escuela Nacional de Agricultura (ENA-GOH), Friederich Ebert Foundation (F E Foundation W German Social Democrats), Luis Landa Ag School, Rural small business development program (PER-INFOP-Dutch), COSUDE Cooperacion Suiza al desarrollo (Swiss), Lempira Rural Development Project (FAO) Rural Development Program (GTZ), Evangelist Committee on National Emergency (CEDEN-PVO), Mennonite Social Action Commission (PVO), World Vision (PVO) Choluteca Support Project (PROAPACH-UN) San Jose Obrero (PVO) and World Neighbors (PVO) Seed of two varieties was distributed in 1998 Extensive collaboration with the ICRISAT Latin America Sorghum Improvement Program (LASIP) was achieved prior to the closing of that program

Consistent with increased regional activities an MOU with INTA, Nicaragua was signed in May, 1998 Initial research in Nicaragua will center on entomology and sorghum breeding Nicaragua grows approximately 46,000 ha of sorghum The INTA sorghum program emphasizes photoperiod insensitive germplasm Collaboration with INTA will broaden the impact of INTSORMIL activity in Central America by providing better access to the range of sorghum grown in the region

Production and Utilization Constraints and Research Findings

Introduction

Sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans The area devoted to sorghum in 1997 was 283,202 ha ^{1} with an average grain yield of 1 466 kg ha ^{1} (FAO, 1998) During the last decade sorghum grain yield in Central America increased due to improved technology available to producers The improved technology includes improved cultivars and hybrids, herbicides, insecticides, planting date, minimum tillage, seed treatments and fertilization

Small-scale farmers in Central America are burdened with problems of low productivity and limited land resources Intercropping provides these farmers with a means to increase total productivity per unit land area and reduce the risk of being dependent on a monocrop The dominant cropping system in the area is maize intercropped with landrace sorghums called maicillos criollos These tropical sorghums are three to four meters tall, drought tolerant, and sensitive to photoperiod Although maicillos have very low yield they are widely planted on 235,000 ha ^{1}, or 67%, of the sorghum hectarage in Central America Maicillos are cultivated along the Pacific side of the isthmus, from southeastern Guatemala through El Salvador and southern Honduras and south to Lake Nicaragua Maicillo is the last remnant of tall, photoperiod sensitive sorghums brought to the new world during the colonial period Although of African descent, maicillos possess 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 in Central America increases, maicillos are slowly being replaced by higher yielding but uniform cultivars

National sorghum yield in Honduras has increased substantially during the last several years but is still only about 1 1 MT per hectare This low yield is due to the environment in which sorghum is grown and the preponderant use of maicillos with low but stable yield The inability of maicillos to respond to management practices with increase grain yield is a primary constraint to increased production Before new technologies like soil and water conservation can improve soil fertility and become economically feasible, the genetic potential of cultivars to respond with increased grain production must be enhanced Increased sorghum yield and area is primarily due to the utilization of improved cultivars (hybrids and varieties), which are increasing Central American sorghum production The long-term maicillo improvement program is producing a significant amount of superior genetic combinations These novel genetic combinations are being introgressed into maicillo populations and superior lines with higher yield potential developed

Maicillo is an old world crop adapted to neotropical slash and burn agroecosystems More than 60 percent of the sorghum planted in Central America is maicillos intercropped with early maturing maize While maize is the preferred staple, it is often intercropped with sorghum by small 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 Maicillos have an acute sensitivity to photoperiod and day lengths of 12 hours or less are required for floral initiation In Central America, floral initiation occurs during the first fortnight of October regardless of planting date The photoperiod response prevents maicillos from spreading beyond their 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

The traditional farming system of clearing the forest, intense grazing during the dry season, and residue burning prior to planting have all contributed to severe erosion and runoff from the steeplands in southern Honduras This severe erosion reduces crop productivity by decreasing the amount of available nutrients necessary for plant growth It also increases the likelihood of crop failure due to drought by decreasing the amount of topsoil which reduces soil moisture storage In response to intensifying land use pressure on hillsides in southern Honduras, some farmers have adopted soil conservation techniques but the majority still practice traditional agriculture Previous research of planting enhanced maicillos on steepland areas with soil conservation techniques showed dramatic increases in sorghum yield

Sorghum is successfully replacing maize as an animal feed, releasing white maize for human consumption During the last 10 years the increase in sorghum consumption by agro-industry is estimated at 5732 MT per year This increase in sorghum consumption is estimated at 16 3 percent while maize increased at 7 2 percent Studies indicate that the Honduras poultry industry is the most important consumer of grain sorghum for meat and egg production Similar trends are becoming apparent in El Salvador and

Nicaragua During the 1988-94 period, poultry consumption in Honduras increased from 6 kg to 10 kg per person Estimated consumption for 1996 was 11 4 kg per person

New alternative uses of sorghum need to be developed to encourage sustainable growth including both improved maicillos and commercial hybrids White grain, tan plant color sorghums are well adapted to Central American food and feed systems Innovative processing systems to increase starch digestability and maximize net energy intake, like extrusion and flaking, need to be incorporated into the system to produce better and more efficient animal rations based on sorghum Human consumption needs to be promoted, especially in tortilla related products and extruded snacks There are sufficient superior grain quality sorghums to be used in human food systems and opportunities have to be identified and pursued

Plant Breeding Research

Hybrids

The sorghum program continued the commercial hybrid performance test for private seed companies This testing program provides an excellent source of information about the commercial hybrids available for Central American sorghum producers The performance test charges a fee for each hybrid entered in the test In 1997 the test was conducted at 10 locations in Central America and 2 in Mexico Choluteca, Comayagua, and Zamorano (Honduras), Managua (Nicaragua), Rio Hato and El Ejido (Panama), Tiquiste, Asuncion, and Chiquimulilla (Guatemala), and Tapachula and Puerto Vallarta (Mexico) Seven companies participated in the test Asgrow, Cargill, Cristiani Burkard, DeKalb, Pioneer, ICI, and Seminal Results are published annually in a bulletin and distributed to institutions and organizations involved in sorghum production Increased use of hybrid and improved cultivars would have a tremendous impact on Central American sorghum production

Hybrids tested in 1997 exhibited excellent grain yield potential averaging 7 t ha^{-1} (Table 1) Data was also analyzed using AGROBASE™ to determine statistical differences The hybrids CB-897-5, ICI 770, DK68, Pioneer 8346, MX 7124, AS 63155, Ambar, MX44977, and CB-897-1 had the highest and more stable grain yield across locations ICI 770 was the most stable hybrid with a yield of 6 1 t ha^{-1}

Collaboration has been developed with Cristiani Burkard, Guatemala, for germplasm evaluation This provides INTSORMIL sorghum breeding programs at Texas

Table 1 Average grain yield of 24 grain sorghum hybrids over 11 locations in Mesoamerica during 1997 (t ha^{-1})

Hybrid	Company	Average	Guatemala	El Salvador	Honduras	Nicaragua	Panama	Mexico
CB 2966	Cristiani	7 1	7 2	7 6	6 1	8 8	6 3	6 7
DK 72	DeKalb	7 0	6 7	6 1	5 8	10 6	6 8	5 8
82G55	Pioneer	6 9	7 8	5 5	4 4	11 6	6 6	5 7
DK 69	DeKalb	6 9	7 6	5 1	6 1	11 0	5 8	5 9
Ambar	Asgrow	6 9	6 8	6 7	5 6	9 4	6 3	6 5
DK 68	DeKalb	6 8	6 6	6 4	6 0	10 1	5 6	6 0
MX 7124	Asgrow	6 7	6 9	7 4	5 9	8 2	5 9	5 9
ICI 770	Seminal ICI	6 5	6 9	5 3	5 7	9 1	6 2	6 2
CB 897 1	Cristiani	6 5	6 7	6 1	5 7	8 8	5 8	6 1
CB 897 2	Cristiani	6 3	6 6	5 8	5 3	8 8	5 9	5 8
CB 897 5	Cristiani	6 3	6 9	5 9	5 9	8 8	5 9	4 2
CB 8966	Cristiani	6 2	6 7	5 3	5 4	8 3	5 9	5 8
DK 560	DeKalb	6 0	6 1	4 6	5 4	8 1	6 0	6 1
Mx 44977	Asgrow	6 0	6 3	5 0	4 8	9 2	5 0	5 8
8346	Pioneer	6 0	6 7	4 7	4 3	8 5	5 9	5 7
AS 63155	Asgrow	5 8	6 4	5 4	4 6	8 6	4 2	5 6
Tauro	Cargill	5 8	6 4	5 7	4 8	7 5	5 4	5 1
Mercurio	Cargill	5 8	6 1	4 9	5 0	8 9	4 9	4 9
ICI 737	Seminal ICI	5 6	6 2	4 6	5 5	7 1	4 8	5 2
SR 93	Seminal ICI	5 4	5 4	5 0	4 1	8 4	4 5	4 9
Orion	Cargill	5 3	6 0	3 4	5 3	7 3	5 2	4 7
5560	Cargill	5 3	6 1	2 8	4 6	8 0	5 3	5 1
DK 48A	DeKalb	5 1	5 5	3 9	5 4	6 3	4 2	5 4
ICI 730	Seminal ICI	5 0	6 3	3 6	4 5	6 8	3 8	5 1
$\bar{x}$		6 1	6 5	5 3	5 2	8 7	5 5	5 6

Locations Guatemala = 3 Honduras = 2 Nicaragua = 1 Panama = 2 Mexico = 2 EL Salvador = 1

A&M University the opportunity for additional evaluation of experimental germplasm and to obtain information on potential commercialization of U S developed germplasm in Central America In 1997, the All Disease and Insect Nursery (ADIN) was provided to Cristiani Burkard for evaluation Data was obtained on reaction to four diseases (rust, zonate, grey leaf spot and anthracnose), overall desirability, and grain yield Released lines identified with excellent potential use by the Central American hybrid seed industry include RTx430, TAM428, Tx7078, and BTxArg 1 Experimental lines with excellent potential use are 91B2978, B9411, 95BRON131, 96GCP OBS152, 95BRON151, and 96GCP OBS167 In June, 1998 the following tests were provided for evaluation ADIN, Grain Weathering Test (GWT), International Food Sorghum Adaptation Trial (IFSAT), Drought Hybrid Test (DHT), and Drought Line Test (DLT)

Enhanced Maicillos

Since 1981, the sorghum project has conducted research to improve maicillo cultivars Maicillos can not be replaced by photoperiod insensitive cultivars because cultivars are not adapted to the maize-sorghum intercropping system Selections of advanced generation improved maicillos are evaluated in the International Improved Maicillo Yield Trial (EIME) Superior materials from the EIME are then evaluated in on-farm demonstration plots Last year the EIME consisted of 21 entries and was planted in three locations in Honduras Zamorano, Choluteca, and Jutiapa (Table 2)

Five enhanced maicillos DMV-137, DMV-221, DMV-228, DMV-210, and DMV-219 averaged higher than 3 4 t ha^{1} These enhanced cultivars showed excellent grain yield potential and will be evaluated in on-farm demonstration plots Porvenir Mejorado (DMV-198) averaged 3 5 t ha^{1} and Gigante Mejorado (DMV-179) only yield 2 3 t ha^{1} Both cultivars have been evaluated on farm plots since 1991

Steepland Research

Honduras has seen increased demands for cropping and grazing land These factors threaten the sustainability of hillside farmers, particularly in southern Honduras Slash and burn agriculture is the most common practice used by steepland farmers The principal cropping pattern is landrace sorghum intercropped with early maturing maize varieties Traditionally a fallow period has been used to restore soil productivity, but fallow periods have been shortened due to increasing land use pressure associated with increased population Susceptibility of steeplands to erosion is attributed to a combination of factors including high rainfall erosivity, intense land use and absence of soil conservation practices

The Soil Management CRSP, in collaboration with INTSORMIL, is conducting research on the steeplands areas of southern Honduras to measure the impact of soil conservation techniques on sorghum production Evaluation of an improved maicillo (DMV-198) in six different locations in the Choluteca region showed that enhanced maicillos planted on terraced areas produce 50% more grain than landrace maicillos planted on unterraced areas (Table 3) Ac-

Table 2 Average grain yield of 21 maicillo cultivars in the EIME in three locations in Honduras, 1997

Maicillo	Zamorano	Choluteca	Jutiapa	Average
DMV 137	6044	4202	4066	4771
DMV 221	4749	2520	3886	3718
DMV 228	4168	3988	2280	3479
DMV 210	5887	2011	2913	3604
DMV 219	4000	3233	2935	3389
DMV 198	5537	2457	2668	3554
MC	4324	2597	1903	2941
MC	4319	2583	2978	3293
DMV 218	3321	3388	1988	2899
DMV 213	4371	2719	1968	3019
MC	4784	3109	1562	3152
DMV 224	2719	3535	1541	2598
DMV 222	2857	3616	1748	2740
DMV 223	3345	3258	1500	2701
MC	3493	1967	2629	2696
DMV 225	2047	3363	2222	2544
DMV 179	3262	1372	2217	2284
MC	3036	2508	1498	2347
DMV 226	2154	2716	1485	2118
DMV 239	1739	1596	2883	2073
DMV 238	1763	942	2156	1620
$\bar{x}$	3710	2747	2335	2931

cording to this data the farmer can double sorghum yield with use of an improved variety and soil conservation (MT) versus a local landrace variety and no soil conservation (UC) Although improved maicillos produce higher yield than landrace maicillos when both are planted on unterraced areas, it will be necessary to use soil conservation techniques to obtain excellent yields Effective soil and water conservation strategies should be implemented in conjunction with other technologies (improved maicillos, fertilizer, pesticide) because unchecked soil erosion and water loss undercut the potential benefits that could be achieved

Comparison of sorghum grain yield between locations along the transect in six different locations is shown in Table 4 There were significant differences in sorghum grain yield between locations within the transect Sorghum grain yield was always greatest at the downslope location of the terrace Greater availability of soil, water and nutrients associated with deeper soils on the lowest part of the terrace may provide enough additional resources to increase sorghum grain yield

The transect was divided into five sections of two square meters The upper section corresponds to T5 and is the place where more soil erosion occur The lowest section of the transect is T1 and is the place where the eroded soil tends to accumulate Again the trend is about the same, sorghum grain yield tends to be greater at the lowest part of the terraced field as compared with the upper part

Entomology Research

Insect damage is a serious constraint for sorghum and maize production A complex of lepidopterous defoliators including *Spodoptera frugiperda* (fall armyworm), *Spodoptera latifascia* (black armyworm) *Metaponpneumata roghenhoferi* and *Mocis latipes* (grass loper) may cause severe damage during the early growth stages This complex annually damages or destroys grain crops on subsistence farms, thus requiring costly replanting if resources are available Studies on aspects of the biology, ecology, behavior and population dynamics of the three armyworm species in this complex have identified the role of these insects in crop production systems in southern Honduras A system was developed for integrated management of this pest complex Recommended practices include two low cost but labor intensive cultural practices, planting date and weed management Delayed planting (8-12 days) and weed control 12-16 days after crop emergence results in less crop damage A single insecticide application may be required if a 40% infestation occurs Improved sorghum cultivars and early maturing maize are recommended to escape or tolerate insect damage Seed treatment with insecticide provides some seedling protection Natural enemy parasitization did not appear to influence crop damage by the defoliators and weed management practices did not influence parasitoid populations This information indicated the limited role that naturally occurring biological control agents might play in developing integrated insect pest management strategies for this lepidopterous caterpillar complex on sorghum and maize during the early crop growing season in this agricultural ecosystem and may possibly relate to other areas in Central America with similar insect pest constraints to production of these grain crops in similar agricultural environments Sorghum production using the pest management system developed was increased 20% and maize 35% at the farm level In years when grain yields and market prices are high, the recommended practices could return $2 9 million a year to the southern Honduras production area and possibly similar returns in other areas experiencing identical insect problems in Central America

Table 3 Multiple Range Test for sorghum grain yield (t ha $^{-1}$) in six different localities with four different technologies (p≤ 0 1)

	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6
MT	2 9 A	2 5 A	2 3 A	3 5 A	2 0 A	3 4 A
UM	2 1 B	2 3 B	1 9 B	2 4 B	1 6 B	2 0 B
CT	1 6 C	1 7 C	1 1 C	1 9 C	0 9 C	1 6 C
UC	1 3 D	1 4 D	1 0 C	1 5 D	0 9 C	1 0 D

MT= improved variety terraced field
UM= improved variety unterraced field
CT= criollo variety terraced field
UC= criollo variety unterraced field

Table 4 Sorghum grain yield of an improved variety (DMV-198) along a transect of a terraced field (t ha ^{1}) (p≤ 0 1)

	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6
T1	3 9 A	2 8 A	2 6 A	3 9 A	2 4 A	4 2 A
T2	3 2 B	2 4 AB	2 4 B	3 8 B	2 3 A	3 9 A
T3	2 6 C	2 8 A	2 3 C	3 7 A	1 9 B	3 1 B
T4	2 4 C	2 3 BC	2 0 D	3 4 A	1 8 B	2 8 B
T5	2 3 C	2 0 C	2 1 D	2 7 B	1 8 B	2 9 B

Plant Pathology Research

Several diseases can threaten sorghum production in Central America These diseases include sorghum downy mildew (*Peronosclerospora sorghi*), anthracnose (*Colletotricum graminicola*), leaf blight (*Helminthosporium turcicum*), and ergot (*Claviceps africana*) Ergot, a very aggressive disease with a capacity for rapid, wide spread dispersal, was initially reported at Zamorano in late 1996 In 1997, honeydew was observed in sorghum panicles of hybrids in the PCCMCA sorghum trials in Zamorano and Choluteca

Collaborative research to study the response of sorghum to ergot has been initiated between Texas A&M University, INTSORMIL and the Panamerican School of Agriculture (Zamorano) The study is the M S thesis research of Mr Jorge Moran The main objectives of the study are a) Determine if variation for response to ergot exists among and within sorghum A-lines, B-lines, R-lines and hybrids, b) Characterize elite R-lines and hybrids for pollen production and vigor and to determine if ergot incidence is correlated with either trait, c) Determine if the duration of stigma receptivity in elite A-lines is correlated with ergot incidence Three field experiments to determine ergot susceptibility were established at Zamorano, Honduras The first test included twelve A/B pairs of sorghum inbreds and was used to determine if differences in ergot susceptibility exist among different A/B pairs The second test included twelve R-lines and twelve hybrids produced using the R-lines as the male parent This test was used to determined if differences in ergot susceptibility exist among different R-lines and/or hybrids The third test was a four-parent complete diallel created to determine the inheritance of the duration of stigma receptivity This experiment was used to determine the relationship between the duration of stigma receptivity and ergot susceptibility Within each test pollen shed and anther exsertion were measured on fertile lines, and stigma exsertion was rated on male sterile lines The results obtained from this study will be compared with data collected from Puerto Vallarta, Mexico, and College Station and Lubbock, Texas

Grain Quality Research

Grain sorghum is used by farmers in the Pacific Coast of Central America as a crop insurance for maize to ensure grain production for tortillas and forage, especially when drought becomes severe Maicillos criollos have been improved by farmers over centuries by selection for grain quality traits related to their ability to produce good tortillas In the Honduras program, white sorghums with tan plant color have been released because they have excellent tortilla color (Sureño) Optimum quality sorghum for tortillas must have a white pericarp, tan glumes and tan plant color The kernel should also have a high density (>1 30 g/cm3) and a thousand kernel weight of at least 25 g The anthocyanin pigments of the purple maicillo criollos produce dark off color tortillas

Sixteen advanced lines of improved maicillos from the 1997 EIME are being tested for grain and tortilla quality compared to corn This research complements the agronomic evaluation of these materials performed by Rodolfo Pacheco in 1997 In addition, two white-tan commercial hybrids (DeKalb DK 72 and Asgrow MX7124) have been included in the study because of their kernel quality traits and yield potential Sureño was included because of its popularity among farmers for forage and tortillas

All 19 cultivars showed a density over 1 37 g/cm3 (1 38 g/cm3 in average) Kernel size was small (25 g in average) and endosperm hardness was appropriate (30% decortication and 53% of floaters) Protein, fat and crude fiber content of all cultivars ranged within normal values (9-11%, 3 5-4, and 2%) for grain sorghum Variations for all these traits were very low among all 19 cultivars Therefore, the 16 maicillos and the two commercial hybrids can be considered as good materials for food processing Jorge Medina Fonseca, a fourth year student from Nicaragua is testing seven of these cultivars (Table 5) for tortilla quality at a semi-commercial level, using the tortilleria located at Zamorano's cafeteria Two of the improved maicillos (DMV-179/Gigante Mejorado and DMV-198/Porvenir Mejorado) have been tested for tortilla quality at Texas A&M University

Table 5 Kernel quality traits of sorghum cultivars tested for tortilla quality

Cultivar	Plant color	Grain color	Glume color	Test weight	1000 Kernel weight	% Decortication	% Floaters	% Protein	% Fat
DMV 179	Tan	White	Tan	91 0	25 0	21 7	32	10 5	3 8
DMV 198	Purple	White	Purple	92 4	30 0	20 3	30	10 0	3 9
DMV 224	Tan	White	Tan	88 7	21 3	30 7	32	9 9	3 9
DMV 219	Tan	White	Tan	87 3	18 0	24 8	44	11 4	3 8
DMV 228	Tan	White	Tan	88 3	18 0	31 0	74	11 7	3 8
Sureño	Tan	White	Tan	91 1	27 0				
MX 7124	Tan	White	Tan	91 0	25 0	27 0	42	9 0	3 9

Every cultivar is also tested in comparison with corn (Hybrid H-29) for tortilla quality traits such as color, taste, texture, odor and rollability Also sorghum-maize masa combinations are tested at 4 levels 100-0, 75-25, 50-50 and 25-75, with 100% corn as the control Preliminary results show that tortillas made with 100% sorghum taste and have a rollability comparable to corn Tortilla color for tortillas made from DMV-198 were unacceptable because of purple pigmentation introduced by the glumes Tortillas made with a 50-50 combination of sorghum and corn could not be differentiated from 100% corn tortillas for all quality traits tested

A group of 54 Zamorano students were asked to rate tortillas made with 100% Sureño All quality traits were rated using a 1-3 scale (Table 6) The results indicate that when good quality sorghum is used for making tortillas the color is acceptable A new fourth year student will be recruited in January 1999 to finish testing the remaining 11 improved maicillos Further studies to be performed include staling tests comparing sorghum tortillas vs corn tortillas, continuing with acceptability tests using larger population samples, and development of a cooking procedure for commercial production of sorghum tortillas

Table 6 Quality traits of tortillas made with 100% Sureño

Quality Trait	Rating*
Taste	2 7
Color	2 2
Texture	2 4
Rollability	2 8

* 1 = bad 2 = acceptable and 3 = very good

Mutual Research Benefits

Many production constraints are similar between Central America and the United States These constraints include drought, several diseases, insects, and adaptation U S based scientists can provide germplasm that could alleviate, at least partially, the effect of some of these constraints The maicillo criollos are a unique type of sorghum Maicillos can potentially contribute useful food quality traits to U S germplasm Exchange of germplasm will contribute to development of novel genetic combinations with multiple stress resistance, wide adaptation, and improved food quality

Institution Building

Training and Education

In 1997, INTSORMIL awarded two Zamorano students a half tuition scholarship Rodolfo Pacheco, a Honduran student conducted research on the agronomic characterization of sixteen enhanced maicillos Augusto Teran, a Nicaraguan student, studied planting densities of sorghum hybrids Marfil and CBX896-10 Both students graduated on April 1998 In 1998 two new scholarships were awarded Jorge Medina, a Nicaraguan student is working on the evaluation of five enhanced maicillos for tortilla quality Mr Medina will be working under the supervision of Javier Bueso, a cereal quality scientist The second student will be conducting research on plant protection working with Dr Allan Hruska

Ing Rafael Mateo traveled to Texas A&M University from March to May, 1998 Ing Mateo attended English classes at the Texas A&M University English Language Institute (ELI) and participated in a training course on plant breeding and nursery management

Ing Jorge Moran is pursuing an M S degree at Texas A&M University Ing Moran is conducting research on host plant resistance to ergot

Roberto Cordero and Johnson Zeledon, both from Nicaragua are pursuing M S degrees in entomology at Mississippi State University Mr Cordero studied biological control strategies for *M rogenhoferi* in southern Honduras Mr Zeledon is studying the occurrence, host plant relationships and management of sorghum midge (*Stenodiplosis sorghicola*) on sorghum in Nicaragua

Travel and Networking

Hector Sierra and Jorge Moran traveled to Nicaragua in April to attend the PCCMCA meeting

Jorge Moran traveled to Puerto Vallarta, Mexico in May to conduct research on ergot

Hector Sierra and Rafael Mateo traveled to Nicaragua in May with John Yohe and Gary Peterson They participated in discussions to develop INTSORMIL collaboration with INTA

Rogelio Trabanino traveled to Corpus Christi, Texas in June to attend the U S Ergot Conference

Publications and Presentations

Bueso J 1997 Assessment of the activity of antifungal proteins against grain mold in sorghum caryopses in the field M S thesis Texas A&M University College Station Texas

Moran J 1996 Genotype * environment interaction in the 1996 PCCMCA sorghum commercial hybrids (In Spanish) In 1996 proc PCCMCA Panama Panama March 17 21 1997

Moran J and F Gomez 1997 Ergot in Central America. Sorghum meeting PCCMCA Panama Panama March 17 21 1997

Moran J and R Mateo 1998 1997 Grain sorghum performance test for the PCCMCA (In Spanish) Tech Rep No AG 9801 Escuela Agricola Panamericana El Zamorano Honduras

Noticias Official Newsletter of the Latin American Commission of Sorghum Researchers Gomez E Editor Zamorano 1997

Pacheco R Agronomic characterization of sixteen enhanced maicillos (In Spanish) Ingeniero Agronomo thesis Escuela Agricola Panamericana April 1998 Zamorano

Teran A C 1998 Evaluation of two planting densities on sorghum hybrids Marfil and CBX896 10 (In Spanish) Ingeniero Agronomo thesis Escuela Agricola Panamericana April 1998 Zamorano

Tonnes A T L Thurow and H E Sierra 1998 Sustainable management of tropical steeplands an assessment of terraces as a soil and water conservation technology USAID/Soil Management Project/Texas A&M University Technical Bulletin No 98 1

Networking

Strong collaboration has developed between the Honduras sorghum program, the Land Use Productivity Enhancement Project (LUPE), World Vision, and other organizations that implement programs to improve the sustainability of steepland agriculture production A partial list of collaborators was listed previously in this report This collaboration has been on-going for many years and has been critical to testing of new technologies in producers fields Many producers have adopted the new technologies after working with the technical outreach program The primary role of the Honduras sorghum program has been to provide seed of improved varieties for use in cropping systems research and demonstration (Table 7)

Table 7 Seed distributed during 1998

Institution	DMV 198 (Lb)	Sureño (Lb)
Lupe	300	300
World Vision	200	200
Municipality Yauyupe	200	200
Total	700	700

Summary of Research Accomplishments

INTSORMIL was instrumental in rejuvenating the Honduran National Sorghum Program by initiating collaborative activities in 1981 INTSORMIL renovated the La Lujosa Experiment Station near Choluteca

A landmark study was conducted on the sorghum-maize intercropping farming system, as well as nutritional studies, in the subsistence farm, hillside agricultural area of southern Honduras Sorghum was identified as an important risk aversion crop in the area because of its drought tolerance Sorghum serves as a multipurpose crop with the grain used to make tortillas for human consumption, especially when the corn crop is poor, and grain and stover being fed to livestock The major constraints to production and utilization were identified and are the basis for the direction of the INTSORMIL/SRN collaborative program

Extensive sociological and nutritional field research studies were conducted in southern Honduras where sorghum is a staple food Although a substantial amount of malnutrition exists (65 to 68% of children suffering some degree of malnutrition), it was determined that with the use of sorghum in the diet, it is possible to grow enough maize, sorghum, and beans to meet energy and protein requirements Diets were deficient in vitamin A, riboflavin, and ascorbic acid

Initial releases from the breeding program were the variety Tortillero (1982), the hybrid Catracho (1984), and the variety Sureño (1985) All are white seeded, food type sorghums that produce good quality tortillas Sureño is a dual purpose variety with good disease resistance, tan plant, and grain with resistance to the maize weevil, grain mold, and weathering

Extensive on-farm testing indicated that Sureño and Catracho produced higher grain yields that traditional maicillo criollo varieties The magnitude of their yield advantage increased considerably when seed was treated with a systemic insecticide (37% and 63% respectively) and when seed treatment was combined with 60kg/ha nitrogen (68% and 113% respectively)

Improved maicillo advanced breeding lines performed well in yield trials, including the EIME On-farm trials in 1989 indicated that the improved maicillo lines yielded slightly better that the traditional maicillo with traditional cultural practices, but had 30 to 50% higher yield when using an insecticide, seed treatment, and fertilizer Grain of the improved maicillos was supplied to the Texas A&M University Cereal Quality Laboratory, where extensive grain quality evaluations were performed A few of the improved maicillos had grain and tortilla quality equal or superior to the local cultivars

Hybrid maicillos showed a large yield advantage over local maicillo varieties

A sorghum-sudangrass F_1 hybrid (ATx623 × Tx2784) to be called Ganadero, for use as a forage for livestock was planned for release in 1993

Research on grain quality indicated that sorghum grain with certain traits can produce tortillas of comparable quality to those of maize Important traits were found to be white grain with an absence of pigment or staining, grain with little or no grain mold or weathering, grain with a thick pericarp to facilitate pericarp removal, and grain which retains a light color in the presence of alkali Tan plant color and tan or straw colored glumes are also desirable Quick quality tests and cooking trials have been developed to screen breeding material for these traits Development of high yielding, food type sorghums with these grain quality traits should have direct and significant application not only to Honduras but to surrounding countries such as El Salvador and Guatemala where sorghum is a traditional food, as well as to Mexico and other countries of Central and South America where sorghum can be used as a replacement or substitute for maize

Sureño and some of the improved maicillo lines produce tortillas superior in quality to the local landrace maicillo criollo cultivars, especially those with tan plant and glume color, and enhanced grain mold/weathering resistance

Diseases of sorghum in Honduras have been identified and their importance determined through incidence, severity, and loss assessment studies Diseases of major importance are downy mildew, MDM, grain mold, acremonium wilt, and foliar diseases such as gray leaf spot, rust, zonate ladder spot, and oval leaf spot Local and introduced germplasm has been screened for resistance, and resistance sources have been incorporated into the breeding program

Downy mildew was identified as a serious disease in several areas in Honduras A new, virulent pathotype (P5) was identified in 1986 at Comayagua which attacks most of the commonly used sources of resistance in the U S New sources of resistance have been identified

Studies on biological control of the fall armyworm and stem borers have been completed, and an exotic parasite effective in controlling stem borers was mass reared and released in Honduras and El Salvador and apparently has become established, at low number, in both countries Three effective native predators of fall armyworm were identified - fire ants, earwigs, and wasps

The complex of insect pests, especially seed and seedling pests, on intercropped sorghum and corn in southern Honduras has been identified, studied, and control strategies developed Important seed and seedling pests include several soil inhabiting arthropods white grubs, wireworms, rootworms, ants, and millipedes The Langosta, a lepidopterous larval pest complex which ravages young sorghum and maize plants in southern Honduras in May and June, was identified to include southern armyworm, fall armyworm, and two grass loopers A study of the ecology and population dynamics of these pests indicated that the presence of noncrop vegetation is important in the buildup of insect infestations prior to feeding on the crops A grass weed was observed to be a good ovipositional host plant Several native maicillos criollos, AF28, and TAM428 were identified as possessing a good level of resistance (antibiosis) to the fall armyworm Midge resistant sorghums from the U S also show good resistance in Honduras

Conservation of genetic diversity in-situ is a major thrust, and is being accomplished by the extensive use maicillos in breeding lines, and through the extensive use of on-farm trials where improved maicillo are evaluated and then saved and used by farmers along with the landrace cultivars

Over 200 native maicillos have been collected Over 75 have been introduced into the U S and 44 have been entered into the Sorghum Conversion Program They should be very useful in broadening the sorghum germplasm base available in the U S and as sources of desirable grain quality and disease and insect resistance

Numerous U S derived sorghum germplasm lines have been evaluated in Honduras and provide the primary sources of disease resistance, high yield resistance, insect resistance, and weathering resistance used in the Honduran sorghum improvement program

A network of sorghum researchers was developed This was accomplished through five Latin American workshops (one each on pathology, quality, breeding, farming systems, and seed production) with ICRISAT/LASIP held at CIMMYT, participating in and presenting research results at the annual CLAIS and PCCMCA meetings, participating in regional CLAIS sorghum trials and nurseries, through germplasm exchange

A major regional workshop emphasizing research on the maicillos criollos was held in Honduras in Dec 1987, co-sponsored by INTSORMIL, SRN, and ICRISAT/CLAIS

A growth analysis of a native maicillo and improved maicillo in pure stand and in association with maize indicated that the late maturing native maicillo has tremendous potential to produce biomass in the tropics

Shade tolerance has been identified in several maicillos and improved maicillos This trait could be very useful, not only in Honduras, but in other countries

Seven Hondurans, plus two other Central American students, have been trained with most conducting their research in Honduras Several Central American researchers have been involved in short term training missions to the U S

An extensive farm-level analysis conducted in southern Honduras was used to estimate the effects of adoption, income impact, and constraints to new technology introduction On the hillsides, once soil conservation practices (rock terraces) were in place, farmers were interested in other new technologies The combined use of terraces and new cultivars (Sureño and Catracho) increased expected income by 15% If price collapse in good rainfall years is avoided, the income increase would be 58% Estimates of the adoption of the new cultivars (primarily Sureño) by hillside farmers of southern Honduras range from 5 % to 13% of the sorghum area

Sureño has found widespread acceptance throughout the sorghum growing regions in Honduras A study was conducted of farmers who tried Sureño in 1988, and results showed that Sureño had substituted for 28% of the maicillo area Much of its success is due to its improved grain and cereal quality (tan plant and glume color and grain traits), yield potential, and dual purpose for use as both a forage and grain

Male-sterile pearl millet lines were provided to support tropical pasture and forage research in the EAP Animal Science department The lines were used to develop an interspecific forage hybrid with elephant grass (*P purpureum*)

Two broomcorn varieties, IS11 and Acme, showed outstanding fiber yield and quality in on-farm trial A sustained quality fiber supply, in conjunction with economic information, seed availability and technical support, with directly impact the national economies of Honduras and Nicaragua through an increase in broom manufacturing, job creation (especially for women), and export earnings Both varieties have excellent resistance to pathotype 5 of *Peronsclerospora sorghi* (Weston and Uppal)

Final field evaluation of the hybrid ATx626 × R8502 (named Zam-Rojo) was completed and the hybrid is ready for release An EAP student completed his thesis on ANicking of ATx626 and R8503, and ATx623 and Tx2784", a thesis problem oriented to foster seed production over a range of different environments and management conditions

Worked with the NGO, "Poligono Industrial Copaneco" funded by the Belgium an Canadian governments, to provide technical advice and seed for on-farm demonstrations on broomcorn production

In 1992, two improved maicillos have completed on-farm tests and were ready for release The cultivars Porvenir Mejorado (DMV-197) and Gigante Mejorado (DMV-179) has withstood farmers, housewives and extension personnel criticisms, as well as environmental conditions during the course of evaluations

A commercial performance test for hybrids was developed The test was started at four locations in Honduras The tests gave farmers access to better sorghum hybrids and helped companies to up-grade hybrids available for Honduras

CITESGRAN (International Seed and Grain Technology Center) received support from INTSORMIL in developing its research capability

In May, 1995, CITESGRAN/Zamorano held the "Grain Standard for Central America Workshop" The workshop was cosponsored by INTSORMIL, FAO, Swiss Corporation for Development, Collaborative Agribusiness Support Project Canadian Grain Commission Federal Grain Inspection System of USDA and others Participants worked on developing the grain standards that will regulate the grain trade among Central American countries

Results obtained in 95 on-farm demonstration plots during 1992 through 1995 indicated 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 replacing the maicillo cultivar with an enhanced maicillo Increased 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 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 show a height reduction of 0 5m with respect to maicillo criollos Forage quality is substantially increased by 3-4^{o} Brix, which turns the stover more nutritious and palatable to cattle Maturity has been kept one week earlier than maicillos criollos This earliness is adequate for escaping late dry periods and minimizing grain molds

Maicillo sorghums were evaluated for their reaction to *Colletotricum graminicola*, the pathogen causing anthracnose Pathotypes attacking maicillos genetically resemble those attacking johnson grass (*Sorghum halepense*) in the United States Anthracnose caused by *Colletotrichum graminicola* was studied in private lines, improved maicillos, and entries in the International Sorghum Anthracnose Virulence Nursery (ISAVN) TAM428 was identified as containing excellent resistance to anthracnose Most improved maicillos were resistant to anthracnose

INTSORMIL participated in the design, construction and equipment purchase for the seed plant at Zamorano

In 1996, INTSORMIL and the Soil Management CRSP initiated joint research to promote new sorghum technologies and soil conservation practices The premise for this effort is that in order to upgrade grain and forage yield in the maicillo area, both technologies should be deployed concurrently To exploit the yield potential bred into the new enhanced maicillos enhanced soil conservation practices are key to sustainable yield The collaborative effort interacts with LUPE and NGOs Ing Hector Sierra obtained an M S degree at Texas A&M University working with Dr Tom Thurow (Soil Management) and was located in Choluteca to direct the project

Four troublesome weed to sorghum production (*Cyperus rotundus*, *Melapodium divaricatum*, *Portulaca oleracea* and *Thitonia tubaeformis*) were used to evaluate the effectiveness of some old and new herbicides in sorghum Mr Juan Carlos Hidalgo conducted thesis research on the degree of control and phytotoxicity of these herbicides A new herbicide Permit' (halosulfuron) was identified as an alternative in early postemergence Halosulfuron can provide a broader spectrum of control with the least toxicity to sorghum when applied with the traditional atrazine at preemergence

Malı

D T Rosenow
Texas A&M Unıversıty

Coordınators

Dr D T Rosenow, Sorghum Breeder, U S Country Coordınator, Texas A&M Unıversıty, Texas Agrıcultural Experıment Statıon, Route 3, Box 219, Lubbock, TX

Mr Sıdı Bekaye Coulıbaly, Agronomy/Physıology, Malı Host Country Coordınator, IER, B P 438, Sotuba, Bamako, Malı

Collaboratıve Program

Program Structure

The program ın Malı ıs a coordınated effort between INTSORMIL and IER It ıs multı-dıscıplınary and multıınstıtutıonal ın scope and ıncludes all aspects of sorghum and mıllet ımprovement, productıon, and utılızatıon Each Malıan scıentıst develops research plans cooperatıvely wıth an INTSORMIL counterpart and ın concert wıth and as a part of the overall IER Malı research plan Major INTSORMIL collaborators travel to Malı annually durıng the crıtıcal perıod of the crop year to consult, revıew progress, and plan future collaboratıve actıvıtıes wıth theır Malıan counterparts Occasıonally, IER scıentısts travel to the U S for research revıew and plannıng These plans are revıewed by the country coordınators, consolıdated, and coordınated wıth IER research project plans for approval or modıficatıon Thıs ınsures that the research fits ınto the annual overall IER strategıc plan The plans then become part of the annual Amendment to the MOA The USAID sponsored bılateral IER/Texas A&M Unıversıty SPARC project has assısted IER ın research project development, executıon, and research financıal management for the entıre IER program ıncludıng other donor fundıng and agencıes

Memorandum of Agreement

The orıgınal Memorandum of Agreement formally establıshıng INTSORMIL collaboratıon wıth IER and allow transfer of funds was sıgned ın Malı on October 10, 1984 A revısed MOA was sıgned ın 1996 at the begınnıng of the current INTSORMIL five-year Project The annual Amendment to the MOA, whıch consısts of the 1997-98 work plan and budget (Amendment #14), was developed jointly by the country coordınators ın Aprıl-June, 1997, and approved by IER and INTSORMIL ın July, 1997

Fınancıal Input

The USAID Mıssıon has provıded sıgnıficant financıal support to the total IER research program, of whıch sorghum and mıllet are a part, through the SPARC Project whıch ended ın June,1997 IER makes decısıons on whıch specıfic project or locatıons are funded by SPARC, Cıba-Geıgy, and World Bank dependıng on needs, and where INTSORMIL country funds are allocated Approxımately 50% of the yearly Malı Country Budget ıs transferred dırectly to Malı from the INTSORMIL Management Entıty The remaınder ıs retaıned at Nebraska and used for major equıpment purchases, supplıes, IER scıentıst travel, IER scıentıst short term traınıng, or specıal needs as they arıse Also, some ındıvıdual U S INTSORMIL ınvestıgators transfer pass-through funds to Malıan counterparts or purchase equıpment or supplıes for Malı dırectly from theır project funds

Collaboratıng Instıtutıons

Instıtute of Rural Economy (IER), Bamako, Malı
Texas A&M Unıversıty
Unıversıty of Nebraska
Purdue Unıversıty
Kansas State Unıversıty
USAID/Bamako
ICRISAT/WASIP/Malı
WCASRN (Regıonal Sorghum Network) (ROCARS)
Soıl Management CRSP (formerly TropSoıls)

Research Dıscıplınes and Collaborators

Germplasm Enhancement - Sorghum - Aboubacar Toure, S B Coulıbaly, Abdoulaye G Dıallo, Mody Dıagouraga (mıllet), Kerıba Coulıbaly (Sıkasso), IER, D T Rosenow, G C Peterson, G Ejeta, D J Andrews, INTSORMIL A Toure was on a Rockefeller Foundatın sorghum bıotech Post Doc wıth Texas A&M Unıversıty/Texas Tech Unıversıty, thru June, 1998

Crop Protectıon Systems - Entomology - Yacouba Doumbıa, Mde Dıarısso Nıamaye Yaro, IER, G L Teetes, INTSORMIL

Crop Protectıon Systems - Pathology - Mamourou Dıourte, Mde Dıakıte Marıam Dıarra, Ousmane Cısse, IER, R A Frederıksen, INTSORMIL

Crop Protectıon Systems - *Strıga*/Weed Scıence - Bourema Dembele, Cheıckna Dıarrra, IER, G Ejeta, INTSORMIL

Crop Production Systems - Agronomy/Physiology/Soils - Adama Coulibaly, Sidi Bekaye Coulibaly, Abdoul Wahab Toure, Mamadou Doumbia (Soil Lab) IER, S C Mason, J W Maranville, INTSORMIL, Abdoulaye Traore, University of Nebraska student, (IER)(Agronomy), Samba Traore, University of Nebraska student, (IER)(Weed Science/Agronomy)

Utilization and Quality - Mde Aissata Bengaly Berthe, Mde Coulibaly Salimata Sidibe IER, L W Rooney, INTSORMIL

Economics - Bakary S Coulibaly, IER (Purdue student) J H. Sanders, INTSORMIL

On-Farm Trials and InterCRSP - S B Coulibaly, Oumar Coulibaly, IER, Philippe Dembele, World Vision, D T Rosenow, J W Maranville, 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 needed to encourage local production of grains and to enhance agribusiness activities of food processing, marketing, and poultry feeding that 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, marketing, and technology transfer 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, especially N'tenimissa, 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 Extensive on-farm trials of new cultivars has been initiated with World Vision and with the InterCRSP Technology Transfer Project An MOU between INTSORMIL and WCASRN (regional sorghum network) presents opportunities for technology transfer in sorghum across West Africa A similar MOU with ROCAFREMI (millet regional network) offers similar opportunities in pearl millet

Research Progress

Details of much of the research related to Mali are presented in individual PI project reports in this publication This Mali Country Annual Report will emphasize research done by the IER in Mali

Sorghum Breeding

The sorghum breeding program in IER is a large and diverse program With the departure of Dr Aboubacar Toure in January, 1996, for a two-year Rockefeller Foundation Post Doc Fellowship on sorghum biotechnology at Texas A&M University, the only persons in Mali with sorghum breeding experience were A Diallo (B S) and some technicians Sidi Bekaye Coulibaly (Agronomy/Physiology) was named to head the IER sorghum breeding program, as well as the INTSORMIL Host Country Coordinator and the head of the national IER sorghum program To provide assistance to the breeding program, Dr Toure traveled to Mali for one week in May, 1997 (along with Dr Rosenow) to assist in planning the 1997 sorghum breeding activities, locations, test entries and locations, breeding progeny locations, lines for crossing, as well as on-farm trials and the increase of grain of N tenimissa In November Dr Toure again traveled to Mali for four weeks and Drs Darrell Rosenow and Gary Peterson for three weeks, where they worked with the Mali Sorghum Collection characterization and harvest and assisted in making selections in breeding progenies planted at Samanko and Cinzana, evaluated yield trails, and on-farm trials and N'tenimissa increases Mr Charles Woodfin and Jerry Jones, Research Associates from Texas also traveled to Mali in November to coordinate the harvesting, threshing and packaging of the Collection Sidi Bekaye Coulibaly very capably coordinated the overall breeding program, with very little slowing of breeding progress

The IER sorghum breeding program does extensive crossing and intercrossing among elite introductions, improved non-guinea and guinea derived breeding lines, and elite local cultivars It utilizes genetically diverse germplasm from around the world resulting in much genetic diversity in the breeding program Extensive use is made of ICRISAT developed lines and elite lines from the U S Emphasis in the program centers on improving the head bug/grain mold resistance of high yielding tan-plant non-guinea breeding lines, guinea by non-guinea intergrades, and on developing tan-plant true guinea cultivars Breeding for the dry northern areas also involves some crosses with local Durras from the area and early Caudatum derivatives from Senegal

A standard system of moving progenies along at the different locations is in place and understood by the technicians After the F_2 progenies are separated into early, medium, and late maturing groups and then selected and advanced at appropriate sites Early materials are selected at the lower rainfall, more northern sites of Berma and Cinzana, while medium maturity materials are grown at Sotuba, Sougoula and sometimes Cinzana Late maturing progenies are evaluated mainly in the southern, high rainfall sites of Farako (Sikasso) and Kita Yield trials of advanced breeding lines also are divided into these three general maturity groups and corresponding sites Yield tests typically involve Preliminary and Advanced Trials

New breeding crosses are made annually, sometimes in the winter off-season In 1997 F progenies F_1 evaluated at Sotuba, 55 were selected At Cinzana, 52 F_1s, were evaluated and 36 selected New crosses were performed at Sotuba and Cinzana during 1998 off-season The F_1s will be planted in the 1998 rainy season at Cinzana and Sotuba The F_2s were evaluated at two locations (Cinzana and Sotuba) In this multilocation evaluation, 173 entries were grown in the 1997 rainy season There were 1021 panicles harvested at Sotuba within 173 families, along with 910 panicles in 173 families at Cinzana In 1997, 1231 F_3 families were evaluated at three locations Within 105 families in each location, 137 heads were harvested at Sotuba, 35 panicles at Cinzana, and 105 heads at Bema The F_4 generations were evaluated according to maturity group The early F_4 progenies were evaluated at Bema and Cinzana At Bema, 30 panicles were selected among 102 entries, and 57 panicles in 27 families at Cinzana For the medium cycles 167 F_4 progenies were evaluated in 1997 Eight families were selected with 60 panicles at Sotuba The late F_4s were evaluated at Kita and Farako with only 13 panicles selected The evaluation of the F_5 was also performed according to the maturity group In the early F_5s, there were 65 entries evaluated at both locations (Cinzana and Bema) with four families saved Among the 169 medium maturity F_5s, selected were 11 families at Sotuba, and 4 at Sougoula In the 76 late maturity F_5s, five and three families were selected respectively, at Kita and Farako

Of special interest are the breeding progenies to develop white-seeded, tan-plant true guinea cultivars The tan-plant breeding cultivar named N'tenimissa (Bimbiri Soumale × 87CZ-Zerazera) has been crossed extensively with local gruineas as well as with high yielding, non-guinea breeding lines which lack the necessary head bug tolerance Two F_4 progeny rows at Cinzana of the cross [N'tenimissa * Tiemarfing (local guinea)] identified in 1996 were advanced immediately and designated 96CZ-F4P-98 and 96CZF4-99 in yield trials in 1997 where their performance was good They are tan-plant with true guinea grain, panicle, and plant characteristics, and appear to possess a high level of head bug resistance They may prove to be superior to N'tenimissa A large number of other tan-plant guinea selections were made in the F_2s, F_3s, and F_4s

At Cinzana, the mean yield of the Early Trial was 2 07 t ha ^{1}, while at Bema it was low (0 93t ha ^{1}), mainly due to postflowering drought The Medium Maturity Trials were evaluated at Cinzana, Sougoula, Kolombada, and Sotuba At Sotuba the mean yield was 2 77 t ha ^{1} with the highest yield obtained with 96-SB-CS-F6-14 (4 13 t ha ^{1}) The highest yielding entry at Cinzana was 94-EPRS-GII-1069 (3 86 t ha ^{1}) Results from Kolombada showed that yields varied between 1 78 t ha ^{1} for CEM-325/11-5-1 and 0 60 t ha ^{1} for 95-EPRS-GII-1001 Highest yield was obtained at Sougoula with 95-EPRS-GII-1088 (3 00 t ha ^{1}) and 94-EPRS-GII-1136 had the lowest (0 90 t ha ^{1}) In the late Maturing Trial at Farako, 96-SB-CS-F6T-6 had the highest yield (2 00 t ha ^{1}) compared to the local Bimbiri Soumale which had 0 73 t ha ^{1} Yields were low at Kita because of late weeding with a mean yield of only 0 79 t ha ^{1}

Millet Breeding

Mody Diagouraga, technician/breeder at Cinzana, continued the pearl millet breeding effort with some assistance from Dr Oumar Niangado, IER Director General, and D J Andrews A pilot hybrid seed production block was planted in 1997 with very encouraging results

Entomology

Studies were conducted on varietal resistance (preliminary and advanced trials) to head bugs and on the behavior of improved varieties in on-farm tests In the preliminary trials, 93-EP-F6-GII-5 and 94-EPRS-GII-1077 had the same score as Malisor 84-7 (visual score=2) A local cultivar (Diebana) was also found resistant to head bugs Results obtained in advanced trials showed resistance to head bugs of 90-CZ-CS-TX-2, 90-CZ-CS-TX-12, and PR 2562 comparable to the local, CSM388 In the on-farm tests, N'tenimisa, N'Darila, and Dusu Suma were compared to Malisor 84-7 in five villages (Ouendja, Sikouna, Seribougou, Segue, and Sangoue) In three villages (Sikouna, Segue, and Sangoue), N'tenimisa had the lowest (best)visual score (2 8) But, in Seribougou, all the improved varieties had a high head bug score above 5

Observations of head bug damage in on-farm trials again indicated much less head bug damage than on Research Stations N'tenimissa showed very little damage to only mild damage on-farm, while it was extensively damaged on the ICRISAT Station Sorghums, however, with high susceptibility to head bugs showed extensive damage on-farm even in the presence of apparently relatively low infestations More research on the head bug ecology and damage in farmers' fields is needed

F_3 head bug evaluation trials from the cross (Malisor 84-7-head bug resistant * S-34-susceptible) were planted at Sotuba, Cinzana, and at the ICRISAT Center The 118 progenies were used by Dr Aboubacar Toure in his Post Doctrate research to identify molecular markers for head bug resistance Excellent segregation for resistance was present in the cross A 1 to 9 visual rating scale developed by George Teetes, in cooperation with Alain Ratnadass, was used in the visual scoring and worked well Threshing out some grain by rubbing panicles greatly enhanced the ease scoring Scores in 1997 again were consistent among different persons, across replications, and across locations In 1997 additional F_3 progenies from CIRAD/ICRISAT were also evaluated at ICRISAT and Cinzana in a cooperative effort among IER, INTSORMIL, and CIRAD

Pathology

Studies were conducted on foliar diseases Anthracnose (*Colletotricum graminicola*) and Sooty stripe (*Ramulispora sorghi*) Twenty seven breeding lines were used in these studies All of them showed some resistance with a severity score lower than 3 Studies were also conducted on covered kernel smut (*Sphacelotheca sorghi*) by using traditional fungicides It was found that the "Gon" (*Canavalia ensiloformis*) used in seed treatment had the same effects as Apron® Plus 50DS and Oftanol In terms of dose, there was an equivalence of 2, 5, 10, 15, and 20 g of "Gon" powder for 1 kg of sorghum seeds in reducing the effects of cover smut For long smut, some different inoculation techniques were used It was found that plots innoculated artificially had higher infestation than those treated with distilled water The variety SAR-10 had less infestation than the other varieties

Agronomy/Physiology

Studies were conducted on sorghum based cropping systems and legume crops plus the evaluation of new sorghum varieties In the first study, a rotation study involving sorghum-corn-cowpea-dolichos-peanut was performed Results showed that sorghum after corn had a 71% yield increase under no fertilization conditions compared to sorghum after sorghum The benefit of those crops on sorghum depends on their growth duration which may also influence the nutrients available for the following crop In the second study, the mutation derived breeding cultivars were compared to their origin (CSM 388) Some evidence of the superiority of the mutants compared to CSM 388 was found Results were the same with N'tenimisa and CSM 388 The screening for drought and high temperature resistance at the seedling stage usually carried out at Cinzana Station was not successful because of a one day rain of 110 mm

Rotation of pearl millet with cowpea in Mali again increased grain and stover yield of pearl millet as reported in previous years Seven-year averages show that crop residue incorporation slightly increased pearl millet grain and stover yields, while crop residue removal adversely effected cowpea yields The increases in crop and stover yield over time, and the better maintenance of soil nutrient levels as reported previously, suggest that leaving crop residues in the field and using crop rotation increases sustainability and productivity of pearl millet cropping systems

Weed Science/Striga

In a screening study of sorghum breeding lines the lowest number of *Striga* was found with the resistant check SRN 39 The breeding lines 94-EPRS-GII-1123 and 94-EPRS-GII-1054 also showed good resistance with (5 to 15 *Striga* plants/m^2 and 7 to 18 *Striga* plants/m^2, respectively) CSM 388 was the most susceptible to *Striga* (52 to 85 *Striga* plants/ m^2) In on-farm trials involving Malisor 84-1, Malisor 92-1, and Seguetana and the local, Seguetana showed the lowest infestation and had the highest yield (2 26 t ha^{-1}), therefore it was the most appreciated by farmers

Pearl millet cultivars from the CMDT millet collection were evaluated for *Striga* resistance, but infestation was low with no significant differences among varieties Yield varied between 2 38 t ha^{-1} for CMM-CMDT 39 and 0 71 t ha^{-1} for CMM-CMDT 61

Visual observation of some of *Striga* resistant lines from INTSORMIL/Purdue indicated excellent *Striga* resistance at Cinzana, but the cultivars had some grain quality problems

Grain Quality/Utilization

INTSORMIL programs in the Food Laboratory consisted of characterization of grain samples from research stations and sub-stations, sorghum diversification, and utilization The food laboratory obtained about five tons of N'tenimisa grain from a farmers association at Madina (Bougouni) Sorghum commercialization trials with food industries (GAM) and small entreprenors (UCODAL and ULTRA) were implemented The promotion and marketing of sorghum was funded by USAID Work was also done with bakers to make bread and confectioneries

Samples from advanced yield trials from Sotuba, Cinzana, Bema, Ouelessebougou, and Mara were characterized by analyzing them for tô consistency, color, vitreousness, thousand kernel weight, density, and ash In general, parameters affecting grain quality were good but the decortication yield varied greatly between 85% and 14%. Guinea cultivars and derivatives gave the highest decortication yield. Tô consistency and color were also good for the majority of the samples.

Regarding the test with bakers in pastry preparation, the quality of the cake was not affected with the substitution of 30% sorghum flour. With 50% substitution, the flavor and texture were good, but there was a problem with shelf life.

In a study of sorghum crunch, it was found that crunch produced for a 200g sample of sorghum grain has a net benefit of 150 FCFA. Many women associations are producing this snack and sell it in the supermarkets and in the open markets. It was found that larger size sorghum grain and semi-vitreous endosperm gave a good yield of crunch.

Preliminary tests on the use of composite flour with GAM (Sorghum flour from N'tenimisa and Wheat flour) showed that up to 30% of flour from this sorghum variety can be added to wheat flour (70%) for biscuit processing. Industrial production is proceeding and data will be available soon.

The major constraint to increased utilization of the flour from white, tan-plant sorghums in various products is a consistent supply of good quality grain. This will require some consistent sizeable production and a system to preserve the identity of that grain in marketing and processing.

On-Farm Trials

Three early/maturing improved varieties (89-CZ-F4-21AF, 89-CZ-F4-137AF, and 93-EARSP-29) were compared to farmers variety at Cinzana and Bema. The mean yield was 0.87 t ha^{-1}. Although it has long cycle, 93-EARSP-29 was appreciated by women because of the high percent at dehulling. The men's choice was 89-CZ-F4-21AF (bigger seed size and higher yield).

Three medium-maturing improved cultivars (Dusu Suma, N'Darila, and 93-EPRS-GII-11) were compared to the farmers variety at Koulikoro and Baguineda. Even though it matured later than the others, 93-EPRS-GII-11 was appreciated by farmers because of higher grain yield, its resistance to lodging, and the stay green characteristics.

In the late-maturity on-farm tests, three improved cultivars (Foulatieba, Sariaso 1, and 93-EPRS-GII-1027) were compared to the farmers variety at Kita and Sikasso. In the first location, Foulatieba and the local check had the highest grain yield (2.33 t ha^{-1} and 2.25 t ha^{-1} respectively,). In Sikasso, Foulatieba (1.17 t ha^{-1}) and Sariaso 1 (1.10 t ha^{-1}) yielded more than 93-EPRS-GII-1027 and the local check. Foulatieba was appreciated by farmers because of higher grain yield while for Sariaso 1 it was because of the good taste in making local meal.

Verbal communication with farmers in the World Vision InterCRSP on-farm trials near Bla indicated that farmers liked N'tenimissa grain quality and it yielded well but had some concerns over it's lodging. The head bug resistance of N'tenimissa looked good. In other trials, non-photosensitive sorghum with compact panicles had severe damage by panicle fading bugs.

Technology Transfer

Two surveys in the Segou region showed that the technology adopted to the greatest extent was use of the seed treatment Apron® Plus on pearl millet which improves stand establishment and reduces downy mildew problems. In one of the surveys the communities were using improved techniques to produce and collect quality animal manure for application to fields. In both surveys, only 16-17% of the farmers indicated use of improved pearl millet cultivars. It was concluded that greater future success in technology adoption would be promoted by proposing a technology package that includes improved cultivars, appropriate management practices, and use of organic and/inorganic fertilizers.

Mutual Benefits

All research results reported should benefit Mali, and surrounding countries of West Africa where similar production constraints occur. The use of the tan plant N'tenimissa should have benefit in the Guinea growing areas of West Africa. 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, pollinating bags, and breeding supplies to the IER collaborate program. Training in computer use was provided by G.C. Peterson.

Several Malian students at INTSORMIL institutions should make important contributions upon their return to Mali. Dr. M. Diourte in pathology at Kansas State University and Dr. N. Diarisso in entomology at Texas A&M University returned to Mali in 1997, and Dr. A. Traore in agronomy at the University of Nebraska returned in the summer of 1998 to strengthen the IER research program. Mde Salimata Sidibe Coulibaly returned with an M.S. in food technology from North Carolina A&T University and is now working in the cereal technology lab. The soil research component in IER has been strengthened with the return of Dr. M. Doumbia (M.S. and Ph.D. - Texas A&M University, Soil Management CRSP), who is now Director of the IER Soil Laboratory.

New students in training include Mamadou N'Diaye at Ohio State University in pathology and Niabe Teme, who completed his B Sc and is currently an M S student at Texas Tech University Dr A Toure has just completed a two year Post Doc Fellowship in sorghum biotechnology at Texas A&M University Adama Coulibaly (M S at Kansas State University) assumed the responsibility of Minamba Bagayoko in millet agronomy, and is the National Coordinator in Mali for pearl millet

The contribution of INTSORMIL trained Dr Moussa Traore (Ph D at the University of Nebraska) former physiologist and Mali Country Coordinator, and former Permanent Secretary to Minister of Agriculture, was huge in the reorganization and current operation of IER The contribution of Dr Oumar Niangado, Director General of IER, has also been significant He is a former INTSORMIL collaborator and millet breeder, and was instrumental from the beginning in INTSORMIL working in Mali Dr Aboubacar Toure, Ph D from Texas A&M University in breeding (currently on a sorghum biotech Post Doc at Texas A&M University and Texas Tech University) is a sorghum breeder with IER, and has served as INTSORMIL Country Coordinator, a member of the INTSORMIL Technical Committee, and has served as Head of the Mali national sorghum program Mr Sidi Bekaye Coulibaly (M S - University of Nebraska) is currently serving as the INTSORMIL Host Country Coordinator, is the head of the Mali national sorghum program, and is also serving as the head of sorghum breeding in IER in the absence of Aboubacar Toure

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, all from Texas A&M University, Drs J D Maranville and S C Mason, agronomists and Prof D J Andrews from Nebraska, Dr J H Sanders, economist, from Purdue Dr Tom Crawford, INTSORMIL Associate Director, and Dr Jeff Dahlberg, Sorghum Curator, USDA-ARS, Puerto Rico also traveled to Mali

Mr Sidi Bekaye Coulibaly traveled to the U S for an INTSORMIL Technical Committee meeting and to attend the INTSORMIL PI Conference and Impact Assessment Workshop in June, 1998 Dr Aboubacar Toure participated in one INTSORMIL Technical Committee Meeting and traveled twice to Mali to assist in planning harvesting and selecting in the IER sorghum breeding program

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 has participated in the ROCAFREMI (pearl millet network) meetings to develop collaborative activities with the millet network Jerry Maranville has represented INTSORMIL at the WCASRN (sorghum network) General Assembly meetings, and Darrell Rosenow has visited with the Steering Committee and Coordinator These contacts resulted in a MOU between INTSORMIL and WCASRN being signed in mid 1997 establishing guidelines on collaboration The new tan plant Guinea cultivar developed in Mali was entered in the WCASRN trial over West Africa in 1996 and 1997 The Steering Committee Chair, Dr Yagoua N Djool from Chad, attended the Genetic Improvement Conference in Lubbock

There has been a long history of collaboration with ICRISAT in Mali, and collaboration has been excellent with Drs H F W Rattunde, J C Chantereau, and A Ratnadass Arrangements were worked out to procure seed for the planting, seed increase, and characterization of the Mali Indigenous Sorghum Collection in Mali in 1997, in a collaborative effort among INTSORMIL, IER, ICRISAT, ORSTOM (France), CIRAD (France) and USDA-ARS Seed was obtained from ICRISAT (India), ORSTOM (France), U S , CIRAD, and Mali programs (IER and ICRISAT), arranged, and packaged and planted at both the Cinzana Station and Samanko (ICRISAT Center) in 1997 The Collection was characterized, and selfed seed harvested, and seed carried to the U S for introduction and quarantine growout

A Workshop on Sorghum Germplasm and Characterization was held November 10-12, 1997 at the Cinzana Station, Cinzana, Mali The Workshop was held in cooperation with the working, harvest, etc of the Mali Sorghum Collection grown at Cinzana The Workshop was co-sponsored by INTSORMIL, IER, ICRISAT, USDA-ARS, WCASRN, (ROCARS), ORSTOM, and CIRAD It was attended by over 40 sorghum scientists, mostly from West Africa Dr Jeff Dahlberg, USDA-ARS Sorghum Curator, was a major contributor to the Workshop and provided training on classification and description

The identification of molecular markers for head bug resistance is another collaborative activity involving the Rockefeller Foundation (which is funding Dr Aboubacar Toure as a Post Doc with Texas A&M University, but working in a biotech lab at Texas Tech), INTSORMIL, CIRAD, and ICRISAT (A Ratnadass) The CIRAD component in France utilizes a biotech lab in France The populations are screened for head bug resistance at Cinzana, Sotuba, and Samanko, and jointly evaluated by IER, INTSORMIL, and ICRISAT/CIRAD scientists The identification of useful markers should have a major impact across West Africa where head bugs are a serious problem

World Vision conducted a large number of on-farm trials in 1996 using N'tenimissa as well as some *Striga* resistant lines from Purdue Collaboration with World Vision increased in 1997 with the implementation of the new InterCRSP (INTSORMIL, Bean-Cowpea) West African Project on Technology Transfer Newly developed cultivars will be broadly distributed and evaluated in on-farm trials World Neighbors is cooperating with IER scientists and extension agents in 20+ communities in the Segou region involving seed distribution of both millet and sorghum and various crop production practices including rotation, intercropping, fallow systems, cover crops, and manure management

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, TROPSOILS, IER, Ciba-Geigy, and CIRAD USAID/Mali has supported the program with moral and financial support A significant accomplishment has been a major improvement in the capability of IER to conduct sorghum/millet research in Mali IER is recognized as having one of the best overall sorghum/millet research programs in Sub-Saharan Africa Accomplishments for the entire life of the project have been detailed in previous annual reports with some key items highlighted here along with new results

The Mali Sorghum Collection (2,543 plots) of indigenous cultivars from Mali was successfully grown in 1997, was characterized and seed increased and packaged for distribution A smaller tentative Working Collection was identified There was greater diversity in the collection than anticipated

The new white-seeded, tan-plant Guinea type breeding cultivar, N'tenimissa, performed well in on-farm trials It's yield is equal to or slightly superior to the local checks It had good farmer acceptance regarding yield and food use, even though it does show some peduncle breakage It is not quite as good as local cultivars in head bug resistance, but based on observation in on-farm trials it appears to be good enough at the on-farm level

Grain quality analysis of N'tenimissa shows it to be intermediate in decortication yield and hardness between local cultivars and non-guinea breeding lines Tô color and consistency were equal to that of locals

Two new white, tan, true Guinea breeding lines were identified, 96CZ-F4-98 and 96CZ-F4-99, from the cross (N'tenimissa * Tiemarfing), and seed increased for on-farm evaluation in 1998 These appear equal to locals in grain traits, but with tan plant color

Several mutant-derived Guinea type, breeding lines developed by the Dr Alhoussemi Bretoudeau, a geneticist at the Agriculture School at Katiabougou, showed promise for nitrogen-use-efficiency and grain yield

Rotation of pearl millet with cowpea again increased grain and stover yield as reported in previous years Crop rotation combined with low amounts of nitrogen fertilization results in the most efficient use of fertilizer nitrogen

Seven-year averages show that crop residue incorporation slightly increased pearl millet grain and stover yields, while crop residue removal adversely affected cowpea yields

Crop rotation with cowpea and leaving crop residues in the field (either incorporated or on the surface) increases the sustainability and productivity of pearl millet cropping systems

World Neighbors employees indicate widespread adoption of an early season improved (mass selected) sorghum (CSM219) and three improved pearl millet cultivars (IBV8001, Composite Souna Sagnon, and Benkadinyo) in the Segou area They also reported farmer use of improved manure management and improved intercropping systems

Bread made with 5-10% N'tenimissa sorghum flour was preferred over wheat/corn flour Cookies made with 5% and 10% N'tenimissa flour by GAM were good quality regarding taste, but the manager had some concern over black specs in the product, apparently due to some mixture with grain from non-tan plants Some women associations and small entrepreneurs are processing sorghum crunch for selling

Several *Striga* resistant lines from Purdue evaluated in Mali showed good *Striga* resistance, but had inferior grain quality compared to local cultivars

F_3 progeny of the cross (Malisor 84-7 * S-34) for molecular marker analysis of head bug resistance showed excellent differentiation for head bug damage

Nine new sorghum breeding progeny showed head bug resistance equal to that of Malisor 84-7

Observations indicate that head bug infestations in on-farm trials is much lower than in Station Nurseries This means that sorghum with somewhat lower levels of head bug resistance may well work at the farm level, even though they may show significant damage under certain Station infestations

INTSORMIL trainees are now in key administrative 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, developed in the IER/ICRISAT, USAID sponsored bilateral program in Mali, 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 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^{-1} N increased pearl millet grain yield at Cinzana by 17% (6 to 35% range)]

Nitrogen use efficiency (NUE) of improved sorghum cultivars has 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 Axtell and Issoufou Kapran
Purdue University and INRAN/Niger

Coordinators

Dr Samba Ly, Scientific Director and INRAN/INTSORMIL Coordinator B P 429, Niamey, Niger
Dr Issoufou Kapran, INRAN/INTSORMIL Coordinator, B P 429, Niamey, Niger
Dr John Axtell, Professor & Niger Country Coordinator, Agronomy Department, Lilly Hall, Purdue University, W Lafayette, IN 47906

Description of Collaborative Program

This program continues to be an interdisciplinary and multi-institutional program involving INRAN, ICRISAT and U S /INTSORMIL institutions (University of Nebraska, Texas A&M University, and Purdue University) Activities include development of the new sorghum hybrid, NAD-1, *Striga* research using INTSORMIL/INRAN tested *Striga* resistant varieties, millet breeding and production, farm level studies on the effect of tied-ridging and fertilization, pearl millet/cowpea cropping systems, production of sorghum and millet couscous and analyzing changes in relative prices of millet and sorghum to determine their effect on diffusion of new technologies

Partial support for Dr Lee House, INTSORMIL consultant, was provided by World Bank/Niamey, to assist INRAN in developing a seed multiplication unit

ICRISAT is an active collaborator on the seed production of a new INRAN sorghum hybrid designated NAD-1 Participants include Drs Anand Kumar, S C Gupta, and D S Murty In addition, Dr Ousmane Youm is supervising an INRAN graduate student in conducting field biology and laboratory studies on millet head miner

A Regional Hybrid Seed Workshop is scheduled for Fall 1998 in Niger, which is also being supported by the McKnight and Rockefeller Foundations as well as Winrock International, the W African Regional Sorghum (ROCARS) and Millet (ROCAFREMI) Networks This workshop 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 and their INRAN collaborators develop research plans on an annual basis The host country collaborators submit a budget which is then incorporated within the total country program

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 couscous and tuwo preparation

Research Methods

The collaborative research program in Niger includes the following sorghum and millet breeding, entomology, agronomy, pathology, physiology, food quality, and economics Research methods appropriate for each of these disciplines are used for this research program

Examples of Research Progress

Cereals Quality and Processing - M Oumarou, M Maiga, A Aboubacar, and B Hamaker

The couscous processing unit fabricated at CIRAD, France, is installed in the Cereal Quality Laboratory (LQC) at INRAN The unit consists of a flour agglomerator (rouleur), a solar dryer, a couscous steamer, and a plastic sealer for packaging The unit is being used to improve processing techniques to produce good quality couscous from millet and sorghum and mixture with peanut and other legumes The unit has also been used as a demonstration and testing tool to local entrepreneurs who are interested in commercial production of couscous

Studies on sorghum and millet couscous using the couscous processing unit continued this year Two studies were conducted the first, on the influence of flour-to-water ratio on couscous granule size distribution, and the second on improvement of flour and couscous color through fermentation Flours from two sorghum cultivars (NAD-2 and Sepon-82) and two millet cultivars (Souna III and HKP) were used Flours were produced manually using a mortar and pestle - decortication and milling at commercial mills were avoided because of the difficulty in obtaining pure flour due to contamination by flours from other sources

Results of the first study indicate that the proportion of couscous of a particular granule size that can be obtained with the rouleur (flour agglomerator) is strongly influenced by the amount of water used for agglomeration and by cultivar type It was previously reported (1997 report) that the manner of couscous consumption used in Niger varies according to granule size The findings of this study suggest that by controlling the amount of water for flour agglomeration, couscous of desired granule size can be produced and marketed separately

In the second study, fermentation was found to considerably improve the color of couscous from the millet cultivars and Sepon-82, whereas it had little effect on the color of NAD-1 couscous

With funding from INTSORMIL, a grain decorticator and flour mill fabricated at URPATA (Senegal) are in the process of being purchased and hopefully will soon be installed at the INRAN Cereals Laboratory

Mutuality of Research Benefits

Use of drought tolerant materials from Sahelian countries, including Niger, have been used extensively by the private and public sectors in the U S The principal benefit to Niger will be an efficient and productive research program at INRAN through training and collaborative research activities of INRAN staff

Institution Building

Research Supplies and Support

The Niger program did not purchase any major equipment this fiscal year, minor equipment (screens for the seed cleaner) were purchased and shipped to Niger The Cereals Laboratory at INRAN is in need of a flour mill and grain decorticator Equipment authorization and Request to Purchase is still pending since these have to be custom ordered in W Africa

Training of Host Country Researchers

When INTSORMIL first began collaborative research relationships with INRAN there were relatively few highly trained Ph D level scientist in their organization Over the past 16 years this situation has changed dramatically within INRAN 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 U S INRAN now has excellent leadership, excellent scientific direction and excellent scientists, either fully trained or in the final stages of their M S or 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

Issoufou Kapran, Rockefeller Fellow, completed his Ph D at Purdue University and returned to INRAN as a sorghum breeder He has been nominated as INRAN/INTSORMIL coordinator

Mamane Nouri completed his M S degree at the University of Nebraska He is now assigned to the Kollo Research Station

Host Country and U S Scientists Visits

Several U S PIs and INRAN trainees traveled to Niger

September 22-October 2, 1997, Issoufou Kollo
September 22-October 2, 1997, Heriberto Torres
September 27-October 18, 1997, Adam Aboubacar
October 23 November 22, 1997, Lee House
November 19-21, 1997, Thomas Crawford
November 19-21, 1997, Jerry Maranville
March 12-21, 1998, Bruce Hamaker
March 12-21, 1998, Steve Mason

Human Resource Development Strategy

Currently, there are four Nigerien students being trained in U S institutions These include

Adam Aboubacar, Post-doctorate food sciences, with B Hamaker at Purdue

Kadi Kadi, M S entomology, with F Gilstrap and George Teetes at TAMU

Kollo, Ph D pathology, with R Frederiksen at TAMU

Abdoulaye Tahirou, Ph D agricultural economics with J Sanders at Purdue University

Networking

The major constraint for adoption of new technologies in W Africa is the lack of a viable seed industry to deliver elite genetic materials to the farmers in a timely fashion and at a reasonable cost A major contribution of INTSORMIL will be a Regional Hybrid Seed Workshop to be held in Niamey, September 28 to October 2, 1998 This will highlight the important contribution that can be made by a seed industry and will offer opportunities for W African countries to share experiences One of the major foci of the meeting will be hybrid seed production for sorghum and millet as well as other crops

Research Accomplishments

Agronomy – M Nouri and S Mason

A two-year experiment to determine the dry matter accumulation and nutrient uptake of pearl millet cultivars Heini Kirei (local), Zatib (improved tall) and 3/4HK (Heini Kirei-improved short) grown under *Low Management* with no fertilizer application and plant population of 10,000 hills/ha, and *High Management* of 5 Mg ha ^{1} manure, 23 kg ha ^{1} nitrogen, 18 kg ha ^{1} phosphorous, and plant population of 20,000 hills per ha was completed, and was part of M Nouri's M S thesis Plots were sampled bi-weekly, plant parts separated, dried and weighed, and nutrient levels determined Data were analyzed to determine differences in grain yield, nutrient concentration, dry matter and nutrient uptake and particioning, and crop growth and nutrient uptake rates

Grain yield was 0 4 to 0 8 Mg ha ^{1} greater and dry matter production was 0 02 to 0 13 kgm^{2} greater in 1995 than in 1996 largely due to rainfall differences (Table 1) The pearly millet cultivar 3/4HK produced less dry matter than the other cultivars, and Heini Kirei produced the greater grain yield than other cultivars in 1995 Management level had a large impact on dry matter production in both years with high management increasing dry matter production 0 33 km/m^{2} in 1996, and increased grain yield 0 4 to 0 5 Mg ha ^{1} both years Nitrogen uptake and NUE was similar for varieties, except Heini Kirei took up less N and had lower NUE than other varieties in 1996 Management level had no effect on NUE in 1995, but in 1996 high management increased NUE Pearl millet cultivar differences, in spite of large differences in genetic background, had much smaller impacts on grain yield, dry matter N uptake and NUE than did the year (environment), and management level effects

Agronomy – Seyni Sirifi and Jerry Maranville

The main objectives were (1) on-farm testing on the effect of tied-ridging and fertilization on sorghum growth and productivity in comparison with the traditional cultural practices, (2) determining the effect of ridging in combination with organic and chemical fertilizer on soil structure and texture, and (3) water and nutrients use efficiency of sorghum under these cropping conditions

Due to the nature of the 1997-1998 cropping season (short in some zone and long but droughty in others), it may not be accurate to make any conclusion from this year's study Nevertheless, tied ridging and fertilization has shown interesting results on germination, stands, growth and production of sorghum in the three research regions (Thylacine, Konni and Bengbu) The results also tend to indicate a good performance of the hybrid NAD-1 in biomass and grain yield compared to the two other sorghum varieties used in the study (90SN7 and local variety)

Sorghum Breeding Program

The sorghum breeding program is being continued by INRAN technical staff while Kapran is completing his Ph D studies A major effort during the past year has been to demonstrate the producability of the sorghum hybrid NAD-1 in Niger INTSORMIL and World Bank have collaborated to provide Dr Lee House as a consultant to accomplish this objective Significant progress was made in the off-season and a strong record of seed production during the 1997 crop season appears to be on track This will provide a strong basis and example for participants in the Seed Workshop scheduled in the Fall of '98

Table 1 Grain yield, dry matter production, nitrogen uptake and use efficiency (NUE) of pearl millet varieties with high and low management at Kollo, Niger in 1995 and 1996

Treatments	Grain yield (Mg ha ^{1})		Dry matter (kg/m)		Nitrogen uptake (mg/m)		Biomass NUE (g DM/g N)		Grain NUE (g rain/g N	
	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Variety (V) Heini Kirei (V1	1 4	0 6	0 33	0 22	3 0	1 2	114	125	34	34
Zatib (V2)	1 1	0 6	0 35	0 22	3 2	1 7	110	93	34	29
3/4 HK	0 9	0 5	0 23	0 21	2 8	1 8	84	74	29	21
Management Level										
Low	0 9	0 3	0 14	0 09	1 4	0 1	96	105	24	33
High	1 4	0 8	0 47	0 34	4 6	2 5	109	90	41	22
F test and contrast probabilites					P>F					
Variety (V	**	NS	**	NS	NS	*	NS	**	NS	*
V1 vs V2 + V3	**	NS	NS	NS	NS	**	NS	**	NS	*
V2 vs V3	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Management Level (ML)	**	8**	**	**	**	**	NS	NS	*	**
V x ML	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
C V (%)	20	17	18	20	35	20	25	19	34	24

Southern Africa Region (Botswana, Namibia, Zambia, Zimbabwe)

David J Andrews
University of Nebraska

Coordinators

Mr Medson Chisi, Member, SADC Research Steering Committee and Sorghum Breeder, Golden Valley Research Station, Fringila, Zambia

D J Andrews, INTSORMIL Coordinator for SADC Region and Pearl Millet and Sorghum Breeder, University of Nebraska, Lincoln, Nebraska

Collaborators

Dr Gary Odvody, Plant Pathologist, Texas A&M University, Corpus Christi, TX

Dr Lloyd Rooney, Cereal Quality Scientist, Texas A&M University, 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, Pearl Millet Breeder, Ministry of Agriculture, Water and Rural Development, Tsumeb, Namibia

Dr A J Taylor, Department of Food Science, University of Pretoria, South Africa

Dr Janice Dewars, Research Scientist, CSIR, Pretoria, South Africa

Ms Trust Beta, Food Utilization Lecturer, University of Zimbabwe, Mt Pleasant, Harare

Dr Tunde Obilana, Sorghum Breeder, SADC/ICRISAT/SMIP, Bulawayo, Zimbabwe

Dr Emmanuel Monyo, SADC/ICRISAT/SMIP, Pearl Millet Breeder, Bulawayo, Zimbabwe

Collaborative Program

Organization

Each sub-project (breeding, pathology and food quality) is planned in conjunction with NARS collaborators Where SADC/ICRISAT/SMIP (called SMIP hereafter) has scientists in the research discipline, these are also involved

Financial Inputs

The MOU with SMIP has been finalized and will be signed in August 1998 To date therefore, regional funds have been used to obtain and send appropriate equipment, supplies, and for travel and conference attendance

Collaboration with Other Organizations

Research on pearl millet and sorghum breeding is organized with NARS in collaboration with the SMIP center at Matopos, Zimbabwe, which ensures complementarity to existing SMIP and NARS programs

Grain quality research is collaborative with the University of Zimbabwe, University of Pretoria, CSIR (South Africa), Agriculture Research Corporation, South Africa, and SMIP The CSIR has strong interactions with the private sectors in the region which will assist in transfer of information to help private entrepreneurs

The Planning Process

Research projects in breeding, pathology and food quality were based on ongoing linkages The future program will be shaped by priorities decided by SADC/NARS (SADC = Southern Africa Development Community), and the availability of matching INTSORMIL resource persons and funds In future INTSORMIL collaborative research in SADC will be developed as part of the SMIP Research and Technology Transfer program to ensure full integration with other sorghum and pearl millet research in the region

Sorghum and Pearl Millet Constraints Researched

Production and Utilization Constraints

Sorghum and pearl millet are major food crops in the SADC region Sorghum is also used to make opaque beer Sorghum is the major cereal in Botswana and parts of Zambia, Mozambique, Malawi and Tanzania, and pearl millet is the major cereal in Namibia and parts of Tanzania, Mozambique, Zambia and Zimbabwe 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 Genetic improvement can, to some extent and very economically, address some of these constraints through increasing yield levels and matching grain qualities to meet end-use requirements However, market channels still need development, since there are sorghum varieties with the required quality to meet commercial consumer re quirements, but production has been inconsistent The availability of a consistent supply of improved quality sorghum and millet for processing into value added urban products is a major problem limiting utilization Foods Botswana and other companies cannot acquire sufficient quantities of high quality sorghums for processing A strong need exists for developing a system of identity preserved production, marketing and processing Drought stress and charcoal rot are major constraints to sorghum production in Botswana, together with sugar cane aphid damage In Zambia, leaf pathogens (leaf blight, anthracnose and sooty stripe) are severe

Research Methods

Breeding

Lines selected from segregating germplasm supplied from UNL were selected over several years in Botswana conditions, principally for drought stress resistance, correct maturity and grain appearance Through collaboration with Dr Tunde Obilana in the SMIP program, the best of these lines (36) were converted into seed parents, whose combining ability worth was determined, and evaluated for other characteristics desirable in seed parents Drought tolerant food quality seed parents developed in this way are potentially useful in other SADC countries with similar agroecological sorghum production environments Pearl millet breeding continued with three-way research collaboration between Namibia, SMIP and INTSORMIL aimed at producing adapted A_4 tropical hybrids from local varieties in Namibia, with probable spill-over effects in other SADC millet producing countries

Plant Pathology

Sorghum disease nurseries and other sorghum nurseries, selected sorghum lines and advanced generation breeding germplasm are evaluated at two sites in Botswana (Sebele and Mpandamatenga) to identify sorghums with improved drought tolerance, and resistance to sugarcane aphids and disease Previous selections were re-evaluated again in 1997-98 at Sebele Sorghum disease nurseries primarily of lines and advanced generation germplasm are being 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

Breeding

The Botswana sorghum breeder, Peter Setimela, commenced a Ph D at the University of Nebraska During his absence, breeding was in abeyance, as no other scientist was available to do sorghum breeding However, the seed parents produced earlier were increased and evaluated in several tests in preparation for release by Dr Tunde Obilana of the SMIP program at Matopos, Zimbabwe Two 1997-98 trials were conducted to determine the inbred line levels of the seed parents (a measure of seed yields in hybrid seed production) Individual line yields ranged from 3 47 to 6 04 t ha^{1} These lines were also found to have good milling yields, up to 84 2% - a trait very desirable in resulting hybrids Individual hybrids made these seed parents using six testers gave yields between 4 56 and 10 0 t ha^{1}

The work on developing pearl millet hybrids for Namibia continued at SMIP Matopos by Emmanuel Monyo, and at UNL Nebraska by David Andrews Extreme drought, and lack of irrigation facilities at Okashana Research Station in Namibia prevented any crossing work there At Matopos, Emmanuel Monyo expanded the A_4 work considerably Two further backcrosses were made in developing the A_4 version of seed parent ICMB88006, and testcross hybrids were made Eighteen lines with complete restoration of male fertility from various SADC germplasms were identified Six of these came from crosses with R_4 sources from UNL-218 These are being made into a random mating population and hybrids have been made by crossing all the lines onto female 88006A_4 A search among the SADC germplasm collection identified a further 136 lines carrying R_4 genes These have the potential to produce further male parents This work will increase the diversity for the production of future hybrids based on the A_4 CMS system in the SADC region At UNL R_4 versions of Okashana derived lines in A_4 cytoplasm were developed by continued back crossing Fertility levels varied between backcross progeny, but importantly one line showed 100% male fertility, and hybrids made with 86006A_4 were 100% male fertile, indicating the R_4 transfer method is feasible

In 1997-98, four sorghum disease nurseries (provided by TAM-222 and B Rooney, TAES) were planted at Golden

Valley and Mansa, Zambia to evaluate response to anthrac nose, leaf blight, and sooty stripe At both locations leaf blight occurred at minimal levels and sooty stripe incidence and severity were moderate Anthracnose was generally low at Golden Valley but both foliar and seed anthracnose were moderate at Mansa Sooty stripe has become an increasingly prevalent disease at the Mansa location where anthracnose normally predominates Several sorghums in these nurseries continued to show good adaptation to the region and good overall resistance to the major foliar pathogens including leaf blight (at a Zimbabwe location) The importance of general leaf disease resistance in many areas of Zambia (and Zimbabwe) was demonstrated by the divergent response of some cultivars to the foliar pathogen(s) prevalent at each location Some cultivars had minimal damage by any foliar pathogen at one location due to low disease pressure but had a high incidence and severity caused by one or more pathogens at other locations Suscep tibility to minor pathogens was apparent in a few cultivars, especially at Mansa where a few had moderate severities of zonate leaf spot (*Gloeocercospora sorghi*) or ladder spot (*Cercospora fusimaculans*) SC146 appeared particularly vulnerable to ladder spot However, cultivar vulnerability to minor foliar pathogens goes unnoticed at these sites unless they have resistance to one or more of the major foliar pathogens The variable disease pressures and environments across sites in the same year and at the same site in different years demonstrates the value of strategic, multilocational testing of cultivars for more than one season

Several sorghum disease nurseries, other nurseries, selected sorghums, and advanced generation breeding germplasm developed or introduced in conjunction with TAM-222 and TAM-223 were evaluated at Sebele, Botswana The objectives were to identify those with improved drought tolerance and resistance to sugarcane aphids and disease Several materials from the Drought Line Test again showed good response to the drought but only a few had corresponding agronomic desirability Advanced generation materials generated primarily by TAM-222 included cultivars previously demonstrating good adaptation to Botswana plus a large number of new entries selected for evaluation based on drought response and agronomic characteristics at Corpus Christi in 1997 This nursery of 171 cultivars experienced severe but variable drought stress at the Sebele station Macia derivatives were predominantly the best throughout the test but of individual crosses the most consistently outstanding cultivars were those from Macia*Dorado and 87EO366*WSV387 (Kuyuma)

Food Quality

Food Quality and Utilization Research, by Ms T Beta, on characterization of Zimbabwean sorghums continued at the University of Pretoria, University of Zimbabwe and SMIP She presented a poster on Phenolic Compounds and Kernel Characteristics of Zimbabwean Sorghums at the Fourteenth SAAFoST and ICC Congress held in Pretoria South Africa In addition, Ms Beta has made excellent progress in evaluating the milling, malting and general processing properties of selected Zimbabwean sorghums Changes that occur in phenolic compounds when the grain is treated with various agents and processes have been characterized This is part of her Ph D dissertation at the University of Pretoria, which is continuing

Ms T Beta spent a short term research assignment at the University of Hong Kong in Dr H Corke's lab where she characterized the starch properties of a large number of sorghum lines from Southern Africa This study, although funded from University of Hong Kong sources, provides additional information on the properties of sorghum In addition, while she was there she learned how to produce noodles from starch based ingredients

A manuscript from Ms T Beta's work on the phenolic compounds of sorghum has been submitted to Journal of Science Food and Agriculture

Ms Leda Hugo, Ph D graduate student, University of Pretoria, summarized some of her work on composite sorghum-cassava breads at the Congress in Pretoria Her work showed that a combination of cassava and sorghum flours could be made into a bread like product that had better texture and flavor than expected A portion of this work had been done as part of her M S thesis in Food Science at Texas A&M University earlier

There is a significant amount of utilization research on sorghum and millet underway at the Department of Food Science, University of Pretoria, by Professor John Taylor's group He has students from all over the SADC region who are actively working on post harvest utilization projects This affords a unique opportunity to transfer information and technologies directly to students who will become leaders in the area of post harvest technology in the Southern Africa region

The major problems limiting sorghum utilization relate to the lack of consistent supplies of acceptable quality grain for processing There is a clear need to develop systems in which the improved quality cultivars can be delivered to processors or stimulate producers to implement processing of their sorghum production into value added products

Mutuality of Benefits

The productivity and utilization of both sorghum and pearl millet will ultimately be improved both in SADC countries and the U S through joint research Germplasm flow is useful in both directions Basic research from the U S 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 U S , or find new resistance to existing pests Sorghum ergot disease, which recently entered the U S from South America, is a case in point Prior research in South Africa on sources of resistance and environmental conditions conducive to disease spread and methods of research are now of vital interest to U S scientists Nutritional components of food quality researched in collaborative projects are often syn onymous with aspects of livestock feed values

Institution Building

Funding Support

Progress was made in developing an MOU directly with the SMIP program but it could not be completed during the report year This is needed to allow INTSORMIL funds to be expended in the SADC region for budgeted costs However funds were used to purchase equipment and supplies and for travel and subsistence costs to enable SADC/NARS representatives to participate in scientific meetings

Four computers and two printers are each being purchased for collaborators in Zambia and Botswana

Training of Host Country Researchers

Ms Trust Beta, Zimbabwe, continued a Ph D program in food quality research in the University of Pretoria, Harare, Zimbabwe under Dr Taylor, co-advised by Dr Lloyd Rooney Research equipment and part subsistence costs were provided by INTSORMIL

Mr Peter Setimela, sorghum breeder, Department of Agricultural Research, Sebele Research Station, Botswana, continued his Ph D program on the genetics of seedling heat tolerance in sorghum at the University of Nebraska with David Andrews under project UNL-218

Mr S A Ipinge, pearl millet breeder in Northern Namibia, commenced a six month visiting research program with David Andrews at the University of Nebraska in May, 1998 working on selection methods and breeding techniques

Host Country and U S Scientist Visits

Lloyd Rooney traveled to Zimbabwe, Botswana and South Africa He presented a paper on Constraints to Utilization of Sorghum and Millet for Food as part of the 14th SAAFoST Congress with the ICC and ECSAFoST held in Pretoria, South Africa The 550 participants included food scientists and post harvest technology personnel from Southern and Eastern Africa, plus many food science students from South Africa A large number of students participated by giving posters The theme was "Harnessing Food Science and Technology for Sustainable Development", which was discussed from numerous viewpoints

Ms Trust Beta, Professor John Taylor and I co-authored a poster entitled ' Properties of Zimbabwean Sorghums Ms Leda Hugo presented a paper on Production of Sorghum Cassava Bread which was from her M S thesis here at Texas A&M University She is currently working on a Ph D program at the University of Pretoria

L Rooney presented a seminar to 25-30 students from the University of Pretoria, Department of Food Science They were from all parts of the SADC region and beyond Individual conferences to review research of graduate students working on sorghum and millet projects were completed

Gary Odvody hosted Medson Chisi, sorghum breeder from Zambia, at Corpus Christi June 27-July 5, 1998, for interaction with other sorghum scientists in South Texas sorghum nurseries following INTSORMIL and Ergot conferences and to collaboratively evaluate sorghum cultivars in South Texas nurseries for future testing in Zambia

Gary Odvody traveled to Southern Africa April 1-24, 1998 to evaluate nurseries and determine future collaborative research activities in the region Locations visited include SMIP scientists and Zimbabwe national sorghum breeder in Bulawayo (Matopos), Zimbabwe, PPRI/RSS in Harare, Zimbabwe, sorghum program scientists in Mt Makulu, Golden Valley, Mansa, Zambia, and DAR in Sebele and Pandamatenga, Botswana

David Andrews attended the SMIP Regional Technology Transfer Steering Committee meeting in October, 1997, and discussed INTSORMIL's involvement through an MOU directly with the SMIP program with the next phase of funding for sorghum and pearl millet in the SADC region The Technology Transfer program will effectively become the SADC Regional Sorghum and Pearl Millet Research network

In March, 1998, David Andrews attended the Seed Production workshop in Namibia, visited Drs Obilana and Monyo at SMIP program, Matopos in connection with collaborative research and further developed the MOU with SMIP In Botswana David Andrews visited with Chris Manthe, Head of Cereals Research, DAR, Dr Ndunguru at SACCAR, and Mr Albert Merkel, Agricultural Development Officer at USAID's Center for Southern Africa

The travel costs and expenses were provided for Dr Medson Chisi from Zambia and Dr Neal McLaren from South Africa to attend the INTSORMIL PI and Ergot Conference 22-26 June, 1998 at Corpus Christi, Texas

Human Resource Strategy

In the past, through a regional USAID program, INTSORMIL has trained a large number of sorghum and millet scientists from the SADC region Human resource development continued with support for Ms Trust Beta's Ph D program in sorghum grain quality research at the University of Pretoria and Mr Peter Setimela's Ph D program in plant breeding at the University of Nebraska Mr S A Ipinge commenced a six month visiting researcher program with the pearl millet breeding program at the University of Nebraska This program was timed to fit between the field research seasons in Namibia

Networking

An efficient sorghum and millet research and technology transfer network exists in the SADC region conducted by the SMIP program The Memorandum of Understanding will allow INTSORMIL to be a component of the SADC sorghum and pearl millet research and technology transfer network, so that INTSORMIL's SADC collaborative research program is completely integrated on a regional basis The emerging interaction of the University of Zimbabwe, University of Pretoria, Council for Science and Industrial Research, South Africa and SMIP in conducting sorghum and millet utilization research is a positive one that efficiently utilizes scarce resources and personnel A workshop on Sorghum Food Quality is being jointly planned for 1998 at the University of Pretoria and CSIR in South Africa

Research Accomplishments

The variation in physical, chemical and processing properties of major Zimbabwean sorghums varied from soft and floury to hard kernels with various levels of tannins and phenols Kernels with pigmented testa had the highest levels of tannins and phenolic compounds

Milling properties varied significantly Abrasive decortication gave the highest yield of acceptable light colored milled products from the harder white kernels of sorghum

The emergence of strong research programs involving students from SADC and other areas in Africa at the University of Pretoria and collaboratively with CSIR is an outstanding development This provides strong collaborators for our INTSORMIL interactions

Sorghum hybrid tests, with seed parents developed at SMIP Matopos from Botswana/UNL germplasm, have identified seed parents and hybrids for wide testing in the SADC region In pearl millet three-way collaboration between Namibia, SMIP and INTSORMIL advanced the development of parents for A_4 hybrids in Namibia

Further information on sorghum disease patterns and severity in Zambia was obtained Drought testing in Botswana identified a number of tolerant lines from TAM-222, particularly those from Macia × Dorado and 87E036C × WSV 387 (Kuyuma) crosses

Publications

Hugo L F R D Waniska, and L W Rooney 1997 Production of bread from composite flours Proceedings Harnessing Cereal Science and Technology for Sustainable Development CSIR ICC SA Symposium September 1 4 1997 Pretoria, South Africa, p 100 114

Rooney Lloyd W 1997 Constraints to utilization of sorghum and millet Proceedings Harnessing Cereal Science and Technology for Sustainable Development CSIR ICC SA Symposium September 1 4 1997 Pretoria, South Africa p 19 33

Setimela, P C S Manthe L Mazhani and A B Obilana 1997 Release of three sorghum pure line varieties in Botswana S Afr J Plant Soil 14 137 38

Horn of Africa

Gebisa Ejeta
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Program Coordinators

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C K Kamau, Kenya Country Coordinator, Katumani National Dryland Farming Research Center, P O Box 340, Machakos, Kenya
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Peter Esele, Uganda Country Coordinator, Serere Agricultural and Animal Production Research Institute, Serere, P O , Soroti, Uganda

Collaborative Program

INTSORMIL/Horn of Africa is a new initiative proposed to regionalize our collaborative research efforts in Eastern Africa Before the start of the current regional effort, INTSORMIL had had a productive collaborative program with the Agricultural Research Corporation (ARC) in Sudan This 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 have been published and distributed widely Extensive raw and improved germplasm have been identified, assembled, and catalogued for the benefit of U S and Sudanese agriculture

Under the Horn of Africa initiative, new memoranda of agreements have been signed with NARS in Ethiopia, Eritrea, Kenya, and Uganda to go with the existing relationship with the Agricultural Research Corporation of Sudan With these MOA, INTSORMIL now has collaborative relationships with five countries in the Horn of Africa region A two-tier program has been under development in the Horn of Africa With each national program, we have initiated a traditional collaborative program between a NARS scientist and a U S principal investigator(s) on a topic of common concern and interest with at least one disciplinary project identified in each country A scope of work is jointly developed and submitted for review and approval by the NARS country coordinator, NARS research director and the Horn of Africa program coordinator before becoming the INTSORMIL/Host Country workplan 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-country to each collaborating scientist to carry out the research project With limited funds available to the INTSORMIL/Horn of Africa, it has not been possible to initiate a full range of collaborative projects with each of the NARS in the region Instead the intent has been to establish a full complement of collaborative partnerships with the Institute of Agricultural Research in Ethiopia and to use this program as a hub from which to network with the other member countries of the Horn A line item for networking has been built into the budget of the INTSORMIL/Horn of Africa program to catalyze exchange of information and ideas among member NARS and INTSORMIL scientists A major initiative that has been under consideration is the identification of major regional constraints upon which considerable research may have been undertaken by one or more of the NARS in the region There has been great interest among scientists in the region to identify such research projects and undertake regional evaluation and verification with the hope of generating technologies that could have regional application We continue to have dialogue on the feasibility of implementing such a regional initiative Once agreed upon, collaborative research projects among NARS in the region will be developed, in consultance with appropriate INTSORMIL scientists, on a priority research agenda of regional importance Inputs from concerned scientists in the region will be solicited in developing the research agenda as well as in refining the research protocol on a timely basis Collaborative scientists will be encouraged to meet regularly (preferably once a year) to exchange ideas and to sharpen the focus of the regional research agenda

Annual field/laboratory touring workshops will be organized alternately at a site in one of the host countries in the region Participation in the tour will be based on interest and the topic of the workshop for that year These tours will provide INTSORMIL PIs opportunities for interaction with very many scientists in the region Scientists from the region will also have opportunity to pick up useful germplasm, research techniques, or potentially transferable technologies that they may come across during these tours

Opportunities for collaboration with other organizations such as ASARECA, ICRISAT/East Africa, World Vision International, Sasakawa Global 2000, and the IPM CRSP have been good and there are initiatives under development with each of these organizations Discussions have also been underway to determine possibilities of buy-ins from USAID Missions in the various countries in the Horn of Africa Contacts have also been made with the new USAID initiative, the Greater Horn of Africa program as well as REDSO/East to check for possible financial assistance to INTSORMIL/Horn of Africa program

Research Disciplines and Collaborators

Sudan

Cooperative Sorghum Breeding and Genetic Evaluation - Osman I Ibrahim, ARC, Gebisa Ejeta, Darrell Rosenow, INTSORMIL

Cooperative Millet Breeding - El Haj Abu El Gasim, ARC, David Andrews, INTSORMIL

Plant Pathology Program - El Hilu Omer, ARC, Richard Frederiksen, INTSORMIL

Entomology Program - N Sharaf Eldin, ARC, Henry Pitre, INTSORMIL

Food Quality Program - Paul Bureng, ARC, Bruce Hamaker, INTSORMIL

Economics Program - Hamid Faki, Abdel Moneim Taha, ARC, John Sanders, INTSORMIL

Striga Research – A G T Babiker, ARC, Gebisa Ejeta, INTSORMIL

Ethiopia

Agronomy – Abuhay Takele, IAR, Jerry Maranville, INTSORMIL

Striga Management – Gebremedhin Woldewahid, IAR, Wondemu Bayu, MOA, Gebisa Ejeta INTSORMIL

Entomology – Tsedeke Abate, IAR, Henry Pitre, INTSORMIL

Agricultural Economics – Yeshi Chiche, IAR, John Sanders, INTSORMIL

Sorghum Utilization – Senait Yetneberk, Aberra Debelo, IAR, Lloyd Rooney, Bruce Hamaker and Gebisa Ejeta, INTSORMIL

Research Extension – Beyene Seboka, Aberra Deressa, IAR, Gebisa Ejeta, INTSORMIL

Pathology – Girma Tegegne, IAR, Larry Claflin, INTSORMIL

Kenya

Sorghum Breeding – C K Kamau, KARI, Gebisa Ejeta, INTSORMIL

Food Quality – Betty Bugusu, KARI, Bruce Hamaker and John Axtell, INTSORMIL

Uganda

Sorghum and Millet Pathology – Peter Esele, NARO, Richard Frederiksen, INTSORMIL

Striga Management – Peter Esele, NARO, Gebisa Ejeta, INTSORMIL

Eritrea

Sorghum Breeding – Tesfamichael Abraha, DARE, Gebisa Ejeta, INTSORMIL

Entomology – Asmelash Woldai, DARE, Henry Pitre, INTSORMIL

Striga Management – Asmelash Woldai, DARE, Gebisa Ejeta, INTSORMIL

Sorghum/Millet Constraints Researched

Sorghum and millet are important crops in all of the countries in the Horn of Africa (Table 1) ranking first or second in cultivated area among the major cereal crops of the region Sudan and Ethiopia are the indisputable centers of origin for sorghum and are major centers of genetic diversity for both crops In addition, a wealth of improved sorghum and millet germplasm has been made available in both of these countries as a result of association with INTSORMIL and ICRISAT Collaborative research between Sudan and INTSORMIL has also resulted in research and production technologies that can be shared by other members of the Horn of Africa

According to the sorghum and millet scientists in the Horn of Africa region, "the major sorghum and millet production and utilization constraints are generally common to all countries" (Table 2)

Table 1 Sorghum and millet production

	Sorghum			Millet		
Countries	Area 1000 ha	Yield kg ha[-1]	Production 1000 mts	Area 1000 ha	Yield kg ha[-1]	Production 1000 mts
Eritrea	60	842	51	15	546	8
Ethiopia	89	1236	100	280	1000	280
Kenya	120	745	90	85	682	58
Sudan	4684	785	2386	1150	192	221
Uganda	255	1498	382	407	1602	652

Table 2 Production constraints of sorghum and millet across eastern Africa countries

	Eritrea	Ethiopia	Kenya	Sudan	Uganda
Varietal development	x	x		x	x
Striga	x	x	x	x	x
Crop Protection					
Pest	x	x	x	x	x
Diseases	x	x	x	x	x
Drought	x	x	x	x	x
Production	x	x	x	x	x
Technology Transfer	x	x	x	x	x
Training Long term	x	x	x		x
Short term	x	x	x	x	x
Socioeconomics				x	
Utilization	x	x	x		x
Information exchange					x
Germplasm introduction	x	x	x	x	x
Soil/Water Conservation	x		x		
Seed production and marketing	x	x	x	x	x

These constraints include lack of improved germplasm, drought, *Striga*, insects and diseases (anthracnose, leaf blight, grain molds, smuts, ergot in sorghum, blast, downy mildew, and ergot in pearl millet) Other problems in the region include lack of adoption of new production and utilization technologies by farmers, soil/water management techniques, as well as the infrastructure and technology for production and marketing of seeds and other essential inputs

Agronomic research on soil and water conservation techniques have not been extensively evaluated in any of the countries in the region Lack of moisture and soil nutrients and poor husbandry are primary constraints of sorghum and millet production Breeding efforts currently in use to incorporate drought tolerance traits to genotypes with high yield potential are limited by lack of a field screening procedure and lack of knowledge of sources of appropriate germplasm with useful traits The lack of absolute definition of good food quality parameters and good screening methods for food quality to some extent also limit the utilization of high yielding sorghum and millet varieties Very little research has also gone in developing germplasm with resistance to the major insect pests and diseases *Striga*, a major parasitic weed of sorghum and millet, constitutes a major constraint to the production of these crops There is very little sorghum and millet germplasm with resistance to *Striga* and the mechanisms that render resistance to *Striga* are not well understood Knowledge about inheritance of many of these traits is also lacking In many of these areas, 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 to 10 years fallow/2 to 4 years cropping) In some areas, other crops are often grown in an intercropping system with millet and sorghum to maximize production Over the last two to three decades, rainfall in the Horn of Africa region 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, resulting in further reduction of sorghum and millet yields in the region Research on all of these aspects is needed to improve sorghum and millet production and utilization in the Horn of Africa

Research Methods

Research conducted by participating scientists of NARS in the Horn of Africa is primarily applied research In each of the NARS, research scientists appear to be closely in tune with crop production, protection, and utilization constraints encountered by farmers and farm communities in the sorghum and millet growing areas There are established protocols for assessing and prioritizing research constraints on a regular basis often annually in conjunction with a national research and/or extension conference organized to take stock of emerging technologies and to publicize developments in research Such fora have also been used to exchange ideas and concerns across disciplinary lines, and tend to lead to development of interdisciplinary initiatives Collaborative projects that have been agreed upon by participating NARS and INTSORMIL scientists would be presented to a national committee that would evaluate the merit and relevance of the research before formal approval and local research support is granted Field research facilities at most of the NARS are excellent Machinery and equipment have not been always adequate or appropriate Technical support and capabilities vary from country to country ARC, Sudan and IAR, Ethiopia have been the strongest sorghum and millet research programs in the area with a full complement of technical assistance particularly in field research As a newly independent nation, the Eritrean national program needs further strengthening in human capital at all levels Wet-lab facilities are very modest in all NARS of the region, with technical expertise most limiting In general, sufficient effort is committed to summarizing research results for subsequent sharing of information with production agencies and extension services

Research Progress

Beginning with the 1997 crop season, a full range of collaborative research projects has been initiated in Ethiopia between INTSORMIL and Ethiopian Scientists The following is a summary of the progress report of each of these disciplinary research projects from experiments undertaken in 1997

Sorghum Breeding - Aberra Debello, Zenbaba Gutema, and Geremew Gebeyehu

Striga Resistance

Striga infestation continues to be a significant production problem in many of the major sorghum growing environments of Ethiopia The northern lowlands have become particularly endemic and appear to need immediate intervention An integrated *Striga* control package, with host-plant resistance as a primary component, has been contemplated With availability from INTSORMIL of high yielding drought tolerant *Striga* resistant sorghum cultivars, initial effort has focused on adaptive testing of these varieties in major sorghum growing environments of the country Seven *Striga* resistant varieties with one local check were tested in *Striga* prone areas of the lowlands of Tigray and Gojam Most of the varieties performed well in these areas Yield data was not yet compiled by the time of this particular report In addition about 25 lines were tested at Sheraro in Tigray Clear difference in terms of *Striga* resistance was observed among these varieties The objective of these trials was to evaluate the adaptation and performance of *Striga* resistant sorghum varieties developed by Purdue University and to recommend an integrated *Striga* control package for on-farm demonstration and distribution From these trials, three of the most promising varieties were advanced for seed multiplication and on-farm demonstration during the 1998 crop season Seed multiplication of three *Striga* resistant varieties developed by Purdue University (P9401, P9403, and P9404) were undertaken during the off-season at Melkawerer, Meklassa and Meki using irrigation facilities A total of 15 Quintals of seed were produced for distribution to farmers by SG2000/Ethiopia in Tigray, Amhara and Oromia Regions Enough seed was generated for seed distribution and on-farm testing in over 300 farms

Evaluation of Introduced Germplasm from INTSORMIL

Several A and B lines and pollinators with different agronomic and genetic merits were introduced and evaluated at Melkassa Research Center Seed for these lines arrived late in the season and planted past the recommended sowing date for Nazret Hence, they may not have been properly evaluated for adaptation Nevertheless, eleven A and B lines were selected for crossing program at Melkawerer off-season Forty two lines were also selected for further testing and are in the intercropping program

Development of Long Cycle Sorghum Varieties for Moisture Stress Lowland Areas of Ethiopia

The objective of this particular program was to develop long maturing sorghum varieties, which when planted in April, resist the dry spell in May and resume growth in the main rainy season to complete their cycle in October or November Our entire sorghum working collection of entries with long maturity period was planted the previous year and about 27 selections were advanced for further observation across our lowland testing sites of Melkassa, Miesso and Kobo The trial at Kobo was exposed to severe drought which resulted in complete crop failure in the region About 20 entries were selected at Melkassa and Miesso for preliminary variety trial In addition, 48 landraces that we recently collected from various regions in the country were planted for preliminary observation Thirty entries were selected for further study We also received 200 landraces from the Biodiversity Institute of Ethiopia for screening varieties that resist early drought About 41 entries were selected for further evaluation and study

Sorghum Agronomy - Abuhay Takele

Seedling Establishment and Growth of Sorghum Varieties under Variable Soil Moisture Deficit

A pot experiment was conducted under glass house condition using sandy loam soils to study the germination and seedling growth of sorghum varieties under variable soil moisture deficits (20-30%, 40-50%, 60-70% and 80-90% field capacity) The varieties tested included M-36121, (148 × E-35-1)-1-4-1 × CS 3541 derive-5-3-2, 12 × 34/F_4/3/E/1, IS 2284 and 76 T_1 #23 Percent germination, seedling shoot and root length (cm/plant) were measured Germination percentage was not significantly affected by the moisture deficit levels while germination of sorghum seeds was significantly affected by varietal differences Data on seedling shoot and root length (cm/plant) as well as shoot and root dry weight (gm/plant) showed that the effect of moisture deficit levels was highly significant The highest value for measured variables were recorded at 80-90% moisture level whereas the lowest value was recorded at 20-30% field capacity moisture deficit levels In general, varieties 76 T_1 #23 and (148 × E-35-1)-1-4-1 × CS 3541 derive-5-3-2 had the lowest overall seedling shoot and root dry weight (gm/plant) while the other three had comparable high values

Nitrogen Use Efficiency Dry Matter Accumulation and Partitioning by Sorghum Under Rainfed Conditions

This field experiment evaluated the N use efficiency (NUE) of five sorghum varieties grown at five levels of N (0 23, 46, 69 and 92 kg ha ^{1}N) Sorghum varieties were grown during the wet season (June to November, 1997) Plant and soil samples are being analyzed for N uptake, and NUE for these varieties will be computed and results will be included in the 1998 report

Sorghum Pathology - Girma Tegegne

Management Study on Sorghum Covered Kernel

Traditional management practice for the control of sorghum covered smuts routinely employed by subsistence farmers in Ethiopia were evaluated for their efficacy, both on station and on farm, and compared with commercial seed treatment chemicals (Thiram and Apron® plus) These treatments employ the use of a preparation from a local plant and livestock urine Application of a powder form of the plant preparation as seed treatment at the rate of 33g/kg and socking sorghum seeds for 20 minutes in livestock urine diluted with water (1 1 V/V) effectively controlled covered smut incidence The efficacy of the traditional treatment was as good as commercial seed treatment chemicals It was also found that the treatments had no adverse effect on seed germination and emergence both in green house and field growing conditions Different rates, on a volume basis, were evaluated and no significant difference was observed, suggesting that rate determination may require knowledge of active compounds involved in the control of smuts in these preparations Hence further research is needed to investigate the possible chemical ingredients responsible for covered smut control both in our plant preparation as well as in the treatments

Sorghum Entomology - Tsedeke Abate and Selome Tibebu

The main emphasis of entomological research on cereals (sorghum and maize) is on developing an integrated pest management (IPM) against stalk borers, the spotted stalk borer *Chilo partellus*, in particular Our strategies for stalk borer IPM focus on the following areas 1) Integration of sowing date and pesticidal control measures, 2) Establishing baseline information 3) Identifying areas of emphasis (strategies) to develop and implement IPM, and the eventual implementation of IPM under farmers' conditions

Integrating Sowing Date and Insecticidal Control

An experiment consisting of four sowing dates and three insecticide treatments (application in the whorls of cypermethrin granules at four and six weeks after seedling emergence, and an untreated check) were conducted at Melkassa, Ziway, Arsi-Negele, and Mieso during the 1997 crop season The extended drought did not allow sorghum to grow over the intended times of planting at Ziway and Mieso and therefore no useful data were obtained at these two locations At Melkassa, sowing date had significant effects on the number of stalk borers per plant ($P<0 01$), percent chaffy head ($P<0 01$), percent peduncle damage ($P<0 01$) and seed yield ($P<0 01$) In general, number of borers per plant, percent chaffy heads and peduncle damage were highest and seed yields were lowest in the last sown plots On the other hand, differences among insecticide treatments were significant for borers per plant ($P<0 05$), percent chaffy head ($P<0 05$), and percent peduncle damage ($P<0 05$) but nonsignificant for grain yield Two applications showed consistently superior control to the check and one application At Arsi-Negele, only the sowing date showed a significant effect ($P<0 05$) for seed yield The lowest yield was obtained from plots sown last but it did not appear that the low yield was due to stalk borer damage as the insect counts and infestation levels were very low

Establishing Baseline Information

Work along this line concentrated on elucidating the significance of stalk borers and their natural enemies in major sorghum growing areas of the country Thus intensive surveys were conducted between 1996 and 1997 in many parts of the country and useful information has been obtained Borer density and species composition of the three stalk borers at various altitudes were determined We found out that Mieso and Asebot in Western Harage, Kobo, Genbober, and Tis-Abalima in Wello, and Welenchiti in Eastern Shewa are the hot spot areas for stalk borers on sorghum *Chilo partellus* was found to be the dominant species in all of these areas A good number of natural enemies (parasitoids and predators) have also been collected and sent abroad for expert identification The braconid wasp *Cotesia sesamiae* was the major larval parasitoid Earwigs (perhaps more than one species) were the major predators We also tried to see the reaction of selected genotypes to stalk borer damage at various locations It appeared that several factors, including location, crop genotype, and cultural practices play important roles in the economic importance of stalk borers on sorghum Percent infestation per se did not seem to be an important factor

Population Dynamics of Stalk Borers

A study on the population dynamics of stalk borers and their natural enemies has been conducted at Melkassa beginning in January 1997 Seeds of the short duration varieties 76 T1 #23' (sorghum) and ACV-3' (maize) were sown at monthly intervals in five rows of four meters long The experiment was laid out in an RCBD in split plots, crops (sorghum and maize) as main plots and control treatments (untreated check, neem seed powder applied in whorls at 4 and 4+6 wae) as subplots, in two replications Significant differences were observed among planting time, crop, and neem treatments in terms of stalk borer numbers per plant recorded at various growth stages of the crops The influence of these factors on percent pupation was dependent on the crop and the growth stage of the crop Pupation on maize was significantly greater than on sorghum Larval and pupal parasitism were also studied, a large number of parasitoids and predators have been collected and sent for identification

Identifying Areas of Emphasis and IPM Implementation

Results obtained so far indicate that, although a good number of parasitoids and predators attack stalk borers under natural conditions, their incidence is lower than expected and they do not seem to keep pest numbers below economic levels However, this was site specific - i e , pest numbers and the accompanying damage levels were very high in a few areas whereas the pest did not seem to be the limiting factor for crop production in the majority of areas surveyed Varietal effects and cultural practices also showed differences Thus, in the immediate future, stalk borer IPM should attempt to integrate cultural practices Biological control with introduced natural enemies can be tested in limited areas in the intermediate term and the use of host plant resistance can be entertained as a long term strategy

Based on studies carried out so far the following general conclusions can be made Stalk borers are widely distributed in sorghum growing areas of Ethiopia that have been surveyed so far Several factors (altitude, crop variety, and cultural practices) appear to influence stalk borer incidence and abundance *Chilo partellus* is the most important pest of sorghum (especially below 1800 m) *Busseola fusca* commonly occurs at altitudes above 1700 m, but does not appear to be of economic importance on sorghum A good number of natural enemies attack stalk borers in Ethiopia The braconid *Cotesia sesamiae* is the most important larval parasitoid, others include the pupal parasitoids *Pediobus fervus* (Eulophidae) and *Euvipio rufa* (Braconidae) Parasitism levels are usually low (introduction and release of effective parasitoids may be considered once the survey is completed) Several species of earwigs, spiders, and ants are important predators

Food Science - Senayit Yetneberk

Evaluation of Sorghum Varieties for Malting Quality

Our major activities during the 1996-97 season included some efforts to identify sorghum varieties with good malting quality and to assure the potential for using sorghum and malt as a substitute for imported barley-malt A significant amount of time was spent in putting in place the necessary logistics for the initiative Arrangements were made with Assela Malt Industry soliciting their collaboration and assistance with malting of sorghum Due to unexpected rain during harvest the samples received were molded and appropriate experiments were not initiated

Variability Among Sorghum Varieties in Injera Keeping Quality

Our objectives were to establish sorghum varietal differences in injera keeping quality and to identify sorghum lines that are superior in injera keeping quality in cooperation with scientists in the sorghum breeding program Though materials required for injera storage were purchased and the experiments could have been underway, the work has not yet started because of badly molded grain samples following the heavy rains received towards the end of the crop season in 1997

Research Extension - Aberra Deressa and Beyene Seboka

Community-based Secondary Sorghum Seed Multiplication and Diffusion Network

Our objectives were to train farmers interested in improved sorghum seed production techniques and enable them to become secondary source of improved seeds It was also our goal to alleviate shortage of improved sorghum seeds by establishing a seed diffusion network in the farming communities through formation of farmers' peer group as well as social and/or family-ties One early and one medium maturing sorghum varieties were selected for use in the program in Western Haraghe and North-east Shoa zones From farmers involved in the program, yields obtained by 88 sample farmers were recorded These farmers were able to harvest 138 22 qt of seeds The mean productivity level, however, did not exceed 9 qt/ha mainly due to low rainfall in the main season followed by bird damage of the crop prior to harvest

Agricultural Economics - Yeshi Chiche

Factors Affecting Adoption of Improved Sorghum Technologies in Major Sorghum Growing Areas of Ethiopia

Once a package of technologies is put together and recommended to farm communities, an assessment of the potential economics benefit of these recommendations is essential Recent collaborative effort with INTSORMIL has resulted in an on-farm testing of an integrated *Striga* control package including the use of host-plant resistant, nitrogen fertilizer, and tied ridges Our Economics Unit is interested to evaluate the potential economic benefits of these technologies individually and in combination Plans have been underway to initiate this project in 1998 This project will be undertaken as a joint effort with INTSORMIL Our collaborator from Purdue University, Professor John Sanders, spent four and half days earlier in the year and held discussions on how to implement this new initiative During his stay different input supply and distributing agencies were visited We also visited the extension office of Oromia as well as the Global 2000 and USAID offices to obtain information on current status of input (fertilizer and seed) distribution patterns We made plans to collect further information on sorghum prices and adoption patterns of farmers A checklist was prepared for discussion with farmers Price data obtained from the Ethiopian Grain Marketing Board is currently being analyzed in preparation for the planned field work in the crop season of 1998 INTSORMIL collaborators, Drs John Sanders and Gebisa Ejeta plan to visit farmer fields where these tests will be conducted in September 1998 We hope to gather sufficient data and observe regional differences during the visit

Institution Building

Research Equipment

No major research supply or equipment was purchased in 1997 in support of INTSORMIL/Horn of Africa program A request by Dr Tsedeke Abate, Ethiopian entomologist, for payment to get insect predator and parasites (collected as part of an integrated stalk borer control project) identified by a laboratory in England was approved

Host Country Scientists who visited the U S

INTSORMIL scientists, Drs G Ejeta, B Hamaker, J Lesley, H Pitre and T Crawford attended and participated in the first Traveling Workshop held in Ethiopia and Eritrea Dr John Sanders visited Ethiopia in early 1998 to establish a collaborative impact assessment of an integrated *Striga* control project to be implemented beginning with the 1997 crop season

Networking

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 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

INTSORMIL and ICRISAT jointly supported and organize a regional workshop in Kampala Uganda in November 1995 to discuss the need for a regionalized sorghum and millet forum in the region 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

In 1996 we signed MOUs with Ethiopia, Kenya, and Eritrea following discussions initiated during the workshop in November This gave 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 1995 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, have been published 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 However, with or without additional funding, 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

In September 1997, a successful Traveling Workshop involving sorghum and millet scientists from INTSORMIL and the Horn of Africa countries was held in Ethiopia. The week-long workshop was attended by three scientists from Kenya, two from Eritrea, one from Uganda, several scientists from the Ethiopian national program, and four INTSORMIL principal investigators Workshop activities included round-table discussion, visit to experiment stations, tour of farm communities, as well as visits to sorghum and millet milling and baking factories The workshop was useful in enhancing a better understanding of sorghum and millet research as well as the production and utilization environments in Ethiopia It also provided a forum for exchange of ideas and information among collaborating scientists During the Traveling Workshop, joint workplans were developed identifying specific research projects in each of the participating NARS with at least one disciplinary project already identified in each country Furthermore, one of the purposes of the workshop was to develop specific regional research projects to be undertaken jointly by NARS scientists on the region and their INTSORMIL collaborators in common areas of great importance After lengthy discussion, workshop participants identified five such projects These regional research projects are expected to be undertaken in addition to the individual bilateral projects already in place Implementation of these regional projects, however, was tabled until additional funds are made available to the INTSORMIL - Horn of Africa program

Research Accomplishments

Although the Horn of Africa regional project is a new initiative, INTSORMIL has had a strong collaborative program in the region with Sudan as a prime site Much of the collaborative effort has been in working with the Agricultural Research Corporation (ARC) of the Sudan The collaborative research relationship between the Agricultural Research Corporation (ARC), Sudan and INTSORMIL that started in 1980 was developed into a strong, mutually beneficial partnership that produced several excellent results Tangible results ranging from training to development of useful technologies and elite germplasm have been generated

Even before the advent of INTSORMIL, ARC/Sudan had a "critical mass" of well-trained manpower in place Sudan is unique in Africa in this regards Over decades it had invested its own scant resources into developing a sufficient cadre of agricultural manpower However INTSORMIL has also trained several Sudanese scientists who have returned and filled in key positions particularly in sorghum/millet research related areas Sudanese graduates of INTSORMIL institutions currently provide service in sorghum breeding (2), plant pathology (1), entomology (1), agronomy (1), food science (1), and agricultural economics (1) A few Sudanese trained and sponsored by INTSORMIL currently also serve IARCs and national programs elsewhere Of significance has been the contribution made by INTSORMIL in mentoring of young graduates as they returned to ARC Furthermore, several ARC scientists have spent valuable time in the laboratories of their counterparts in the U S Some have done this more than once In some of these cases, significant research findings have come out of these experiences and the results have been published as joint contributions of ARC and INTSORMIL

On numerous occasions, and at times on a regular basis annually, INTSORMIL and ARC scientists have held round table discussions on assessing and reevaluating production and utilization constraints in sorghum and millets in Sudan, assessing of research findings and utility technologies jointly developed, and more significantly in setting priorities The ARC has used these deliberations to assess priorities and progress and to sharpen the focus in the sorghum/millet research in Sudan ARC has often involved INTSORMIL PIs in setting the national agenda around sorghum/millet research as well as in finding better ways of extending technologies derived from research

Tangible technologies that resulted from ARC/INTSORMIL partnership include

Development, release, and distribution of Hageen Dura-1, as the first commercial sorghum hybrid

Identification, wide-testing and release of SRN39 and IS-9830 as the first *Striga* resistant sorghum releases

The development of an infant seed industry that began with the pilot project around HD-1 seed production Today some 500,000 acres of sorghum fields are targeted for HD-1 production

The testing and recommendation of use of composite-flour for bread making and the better quality mix obtained with use of HD-1 grain

The economic evaluation on the impact of HD-1 (the social returns to research investments)

The development of a technology to produce "instant nasha" as a weaning food Establishing fermentation (a traditional process as an effective method to alleviate problems of protein digestibility associated with sorghum grain)

Benefits accrued to INTSORMIL scientists and U S agriculture from ARC/INTSORMIL collaboration include the following

Contribution of germplasm tested in Sudan in enhancing drought tolerance of material developed for the U S seed industry Recently 10 drought tolerant lines were derived from crosses between U S and Sudan sections were released to the seed industry in the U S

Raw germplasm from Sudan for potential use in the U S Recently over 3000 Sudanese land races were contributed by ARC to the USDA

The development and refinement of new technologies with potential use in the U S For instance Long Smut is not a disease of economic importance in the U S However, should it become one, screening technology INTSORMIL scientists helped develop in Sudan, will come in handy

The finding that traditional process of fermentation as a means to alleviate the protein digestibility problem in sorghum laid the foundation for the scientific understanding of factors that influence protein digestibility in grain sorghum

The excellent field demonstration program by Global 2000 and the persistent efforts of ARC/INTSORMIL in assisting the seed production programs have established Hageen Dura-1 as an ARC generated technology with significant impact to sorghum agriculture in Sudan Added to other research technologies which have been generated by ARC, including those listed above, ARC has been recognized by the GOS and other agencies operating in Sudan For instance, the USAID mission with prodding from INTSORMIL PIs, granted a substantial amount of PL-480 funds to ARC in support of sorghum/millet research In return, that encouraged the Ministry of Planning to continue to provided unprecedented level of support specifically for sorghum/millet research in Sudan Individually, particularly ARC scientists in the area of *Striga*, pathology, and cereal quality, have produced significant results that have given them due recognition in the sorghum/millet research community The collaborative partnership between INTSORMIL and ARC has clearly demonstrated that sustained support and focused research efforts would produce tangible and useful results It also showed that an effective utilization of research generated technologies would in return eventually bring due recognition to scientists and research programs, and generated increased and sustained support for agricultural research, even in a national program of a developing country with numerous, seemingly insurmountable problems

Promising results have emerged from the new collaborative research projects between INTSORMIL and the Institute of Agricultural Research in Ethiopia

New *Striga* resistant sorghum cultivars introduced from Purdue/INTSORMIL and tested in *Striga* endemic areas with excellent results These outstanding lines (P9401, P9403, and P9404) were selected Seed of these varieties was multiplied during the off-season in a joint effort with

Global 2000 About 1 ½ ton of seed was produced to be distributed to about 200 farmers

An integrated *Striga* control study including the three *Striga* resistant selections, nitrogen fertilization, and tied-ridges was planned for implementation starting with the 1998 crop season

Formulation of a local plant product and an animal by-product traditionally used by Ethiopian sorghum farmers for the control of covered smut was tested and confirmed

A comprehensive integrated pest management study for control of stalk borers was initiated and the necessary base-line data generated

We also held a Traveling Workshop in Ethiopia and Eritrea for our regional collaborators The workshop allowed for exchange of ideas and establish understanding for undertaking regional sorghum and millet research collaboratively

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, 55 students from 23 different countries were enrolled in an INTSORMIL advanced degree program Approximately 78% of these students come from countries other than the U S which shows the emphasis placed on host country institutional development (Figure 1)

INTSORMIL also places a high priority on training women which is reflected in Figure 2 In 1998, 16% of all INTSORMIL graduate participants were female Twenty-three of the total 55 students received full INTSORMIL scholarships An additional 15 students received partial INTSORMIL funding and the remaining 17 students were funded from other sources as shown in Figure 3

All 55 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

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 1997-1998 this has decreased to seventeen

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 Five post doctoral scientists and seven visiting host country scientist were provided the opportunity to upgrade their skills in this fashion during 1997-1998

The following table is a compilation of all INTSORMIL training activities for the period July 1, 1997 through June 30, 1998

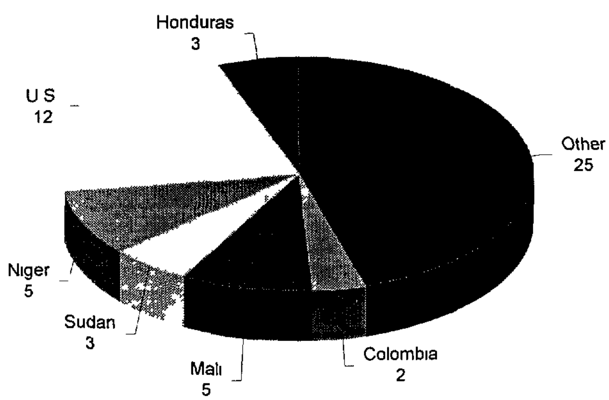

Figure 1 Participants by Country

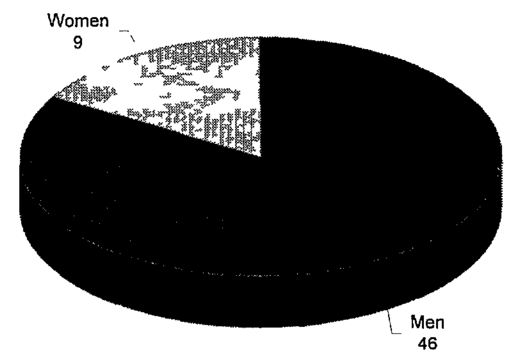

Figure 2 Participants by gender

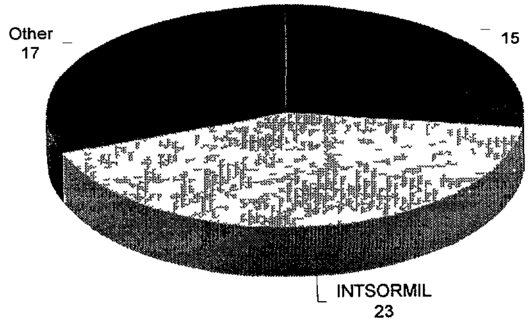

Figure 3 Source of Funding

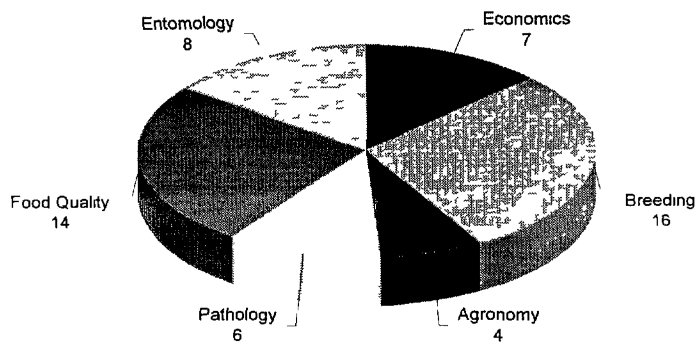

Figure 4 Discipline Breakdown

Year 19 INTSORMIL Training Participants

Name	Country	Univ	Discipline	Advisor	Degree	Gender	Funding*
Traore Abdoulaye	Mali	UNL	Agronomy	Maranville	PHD	M	I
Kim S Young	Korea	UNL	Agron/Physiol	Maranville	MSC	M	O
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
Melakebrhan Admasu	Ethiopia	PRF	Breeding	Ejeta	PD[2]	M	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	P
Mulatu Tadesse	Ethiopia	PRF	Breeding	Ejeta	MSC	M	P
Rich Patrick	U S	PRF	Breeding	Ejeta	PD[2]	M	I
Tuinstra Mitchell	U S	PRF	Breeding	Ejeta	PD[2]	M	O
Katsar Catherine Susan	U S	TAM	Breeding	Peterson/Teetes	PHD	F	P
Rodriguez Hererra, Raul	Mexico	TAM	Breeding	Rosenow/Rooney	PHD	M	P
Teme Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Ipinge S A	Namibia	UNL	Breeding	Andrews	VS[1]	M	I
Rai K N	India	UNL	Breeding	Andrews	VS[1]	M	O
Setimela, Peter	Botswana	UNL	Breeding	Andrews	PHD	M	P
Tiryaki Iskender	Turkey	UNL	Breeding	Andrews	MSC	M	P
Ahmed Mohamed M	Sudan	PRF	Economics	Sanders	PD[2]	M	I
Coulibaly Bakary	Mali	PRF	Economics	Sanders	MSC	M	O
Kazianga Harounan	Burkina Faso	PRF	Economics	Sanders	PHD	M	O
Kebbeh Mohamed M	Gambia	PRF	Economics	Sanders	VS[1]	M	O
Sidibe Mamadou	Senegal	PRF	Economics	Sanders	PHD	M	O
Tahirou Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	I
Vitale Jeff	U S	PRF	Economics	Sanders	PHD	M	I
Boire Soualika	Mali	TAM	Entomology	Gilstrap/Teetes	PHD	M	I
Kadi Kadi Hame	Niger	TAM	Entomology	Gilstrap/Teetes	MSC	M	I
Calderon Pedro	Honduras	MSU	Entomology	Pitre	MSC	M	O
Cordero Roberto	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Johnson Zeledon	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Vergara, Oscar	Ecuador	MSU	Entomology	Pitre	MSC	M	O
Jensen Andrea	U S	TAM	Entomology	Teetes	PHD	F	I
Lingren Scott	U S	TAM	Entomology	Teetes	PHD	M	O
Aboubacar Adam	Niger	PRF	Food Quality/Util	Hamaker/Axtell	PHD	M	I
Bugusu Betty	Kenya	PRF	Food Quality/Util	Hamaker	MSC	F	I
Zhang Genyi	China	PRF	Food Quality/Util	Hamaker	MSC	M	I
Acosta, Harold	Colombia	TAM	Food Quality/Util	Rooney	PHD	M	P
Asante Sam	Ghana	TAM	Food Quality/Util	Rooney	PHD	M	P
Barron Marc	U S	TAM	Food Quality/Util	Rooney	BSC	M	P
Bueso Francisco Javier	Honduras	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	I
Kunetz Christine	U S	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Lee Jae K	Korea	TAM	Food Quality/Util	Rooney/Waniska	VS[1]	M	O
Leon Chapa, Martha	Mexico	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	I
Mateo Rafael	Honduras	TAM	Food Qualtiy/Util	Rooney/Waniska	VS[1]	M	I
Miranda Lopez Rita	Mexico	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Omueti Olusola	Nigeria	TAM	Food Quality/Util	Rooney/Waniska	VS[1]	F	O
Quintero Fuentes Ximena	Mexico	TAM	Food Quality/Util	Rooney	PHD	F	P
Narvaez Dario	Colombia	KSU	Pathology	Claflin	MSC	M	P
Jurgenson Jim	U S	KSU	Pathol/Genetics	Leslie	VS[1]	M	O
Hanson Amy	U S	KSU	Pathol/Genetics	Leslie	MSC	F	O
Zeller Kurt P	U S	KSU	Pathology	Leslie	PD[2]	M	O
Kollo Issoufou	Niger	TAM	Pathology	Frederiksen	PHD	M	I
Torres Montalvo Jose H	Mexico	TAM	Pathology	Frederiksen	PHD	M	O

* 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 Sponsored and Co-Sponsored Workshops 1979 - 1998

	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
47	INTSORMIL PI Conference	Lubbock Texas	9/96
48	International Conference on Genetic Improvement of Sorghum and Pearl Millet	Lubbock Texas	9/96
49	Conference on the Status of Sorghum Ergot in North America	Corpus Christi Texas	6/98
50	Principal Investigators Meeting and Impact Assessment Workshop	Corpus Christi Texas	6/98

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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
CICP	Consortium for International Crop Protection
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 Developpement
CLAIS	Consejo Latin Americana de Investigadores en Sorgho
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research Senegal

CORASUR	Consolidated Agrarian Reform in the South - Belgium
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
DICTA	Direccion de Ciencia y Tecnologia Agricola Mexico
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
IAR	Institute of Agricultural Research - Ethiopia
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 Cooperacion para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agriculture
ILCA	Instituto Interamericano de Cooperacion 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
INTA	Instituto Nicaraguense de Technologia Agropecuaria
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
NARO	National Agriculturall Research Organization Uganda
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
PNVA	Malien Agricultural Extension Service

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 AfricanMedical 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	Reseau 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
SARI	Savannah Agricultural Research Institute Ghana
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
UPANIC	Union of Agricultural Producers of Nicaragua
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
WVI	World Vision International