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INTSORMIL

1997 Annual Report

Fighting Hunger with Research . A Team Effort

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

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Dr. Larry Butler

The 1997 INTSORMIL Annual Report
is dedicated to the memory of Dr Larry Butler
in remembrance of his contribution to INTSORMIL
and sorghum/millet research

Dr Larry Butler, an outstanding scientist and an active member of our INTSORMIL CRSP died unexpectedly before the end of the this report year The following is an itemized list of his contributions as an INTSORMIL Principal Investigator Because these contributions are significant and express the pride and satisfaction that Larry had working as an INTSORMIL PI, we print this list enumerated by Larry verbatim and unaltered

Research Contributions by PRF-204 and Collaborators

(Contributions to Striga research (with Dr Ejeta) are not listed here)

- Discovery of the previously unsuspected high specificity of protein binding by tannin
- Elucidation of the role of proline content and other features (size, looseness) of protein structure in binding by tannin
- Discovery of the defensive function (against dietary tannin) of herbivores' salivary proline-rich proteins
- Development of an effective method for detoxification of high tannin sorghums by treatment with dilute ammonia
- Discovery that they cyanogenic glucoside dhurrin occurs in the grain of some sorghums and contributes to bird resistance
- Rediscovery of flavan-4-ols in sorghum, and demonstration of their correlation with mold resistance in some sorghums
- Discovery of pro-3-deoxyanthocyanidins, a new type of tannin in sorghum
- Determination of the pigments responsible for characteristic plant color in sorghum
- Recognition of the unusual 3-deoxyanthocyanidins and their derivatives as the major pigments of sorghum grain
- Development of a battery of assays for various sorghum polyphenols, some widely used Prussian blue, protein-precipitable phenols, protein precipitation capacity, flavan-4-ols, apigenin tannin degree of polymerization (and several other assays were improved from their previous usage)
- Development of an *in vitro* culture and regeneration system for sorghum, used for the first successful sorghum transformation and for the most extensive study of somaclonal variation ever carried out on sorghum
- Elucidation of somaclonal variation rates for sorghum as a function of genotype, medium, source of explant, and time in culture
- Numerous feeding trials of sorghum and tannins, quantitating nutritional/antinutritional effects and their metabolic bases, including the largest feeding trial of tannin to individual caged steers ever reported

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A Research Development Program of the Agency for International Development, the Board for International Food and Agricultural Development (BIFAD), Participating Land-Grant Universities, Host Country Research Agencies and Private Donors

INTSORMIL INSTITUTIONS

Kansas State University
Mississippi State University
University of Nebraska
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 USAID Missions, other U S Federal Agencies, developing country National Agricultural Research Systems (NARS), developing Country Colleges and Universities, International Agricultural Research Centers (IARCs), private agencies, industry, and private voluntary organizations (PVOs) The Sorghum and Millet Collaborative Research Support Program (CRSP) is one of nine CRSPs currently in operation

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

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

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

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

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

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

Promoting demand driven processes Development of economic analysis for prioritization of research and farm-level industry evaluation, 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 pearl millet for food Research products transferred to the farm will seek to spur rural economic growth and provide direct economic benefits to consumers INTSORMIL researchers assess consumption shifts and socioeconomic policies intended to reduce effects of price collapses and address methods for reducing processing for sorghum and millet Research is aimed at reducing effects of price collapse in high-yield years and creating new income opportunities INTSORMIL socioeconomic projects measure impact and diffusion of sorghum and pearl millet technologies 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 both the U S and the developing world, especially the semiarid tropics There is international recognition by the world donor community that the developing country agricultural research systems must assume ownership of their development problems and move toward achieving resolution of them The program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits back to the U S agricultural sector and presents a win win situation for international agricultural development

Administration and Management

The University of Nebraska at Lincoln (UNL) provides the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID UNL subgrants are made to the participating U S Universities for the research projects identified in the overall research plan of the program Country project funds, managed by the ME and U S participating institutions, support collaborative research to the benefit of both the U S and country programs 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 TC, BOD, and ME institution interviewed and selected a candidate who was hired by the ME for the Associate Program Director position within INTSORMIL
- The TC and the ME finalized the RFP for a new project on Sorghum/Millet Marketing Economics
- The BOD approved a budgeting process developed by the TC This involves the TC considering PI workplans, PI budgets, PI previous annual report, discipline budget recommendation, and the TC discipline representatives justification for budget recommendations A project evaluation form has been developed for testing
- The BOD of Directors approved the EEP Rotation schedule for the period of 1998-2002

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

- INTSORMIL CRSP Directory update, INTSORMIL Publication, July, 1996
- INTSORMIL Annual Report 1996, INTSORMIL Publication No 96-1
- INTSORMIL Annual Report 1995, Executive Summary, INTSORMIL Publication No 96-2

The 1996-97 Technical Committee (TC) was elected The TC members are Dr Stephen Mason, University of Nebraska, Dr George Teetes, Texas A&M University, Dr Lloyd Rooney, Texas A&M University, Dr Darrell Rosenow, Texas A&M University, Professor David Andrews, University of Nebraska, Dr Gary Peterson, Texas A&M University, Dr Aboubacar Toure, IER/Mali and Dr Francisco Gomez, EAP/Honduras

The announcement for the International Conference on Genetic Improvement of Sorghum and Pearl Millet, in Lubbock, TX, September 23-27, 1996 was distributed world wide INTSORMIL and ICRISAT were the co-sponsors for this event with contributions from the Rockefeller Foundation, the Overseas Development Administration (ODA), the National Grain Sorghum Producers Association, the Texas Seed Trade Association, Texas Tech University and Texas A&M University There were 248 persons who participated in the conference from 38 countries

INTSORMIL partnered with the Bean/Cowpea CRSP and World Vision International for a project on technology transfer in West Africa under the West Africa NRM InterCRSP project managed by the IPM CRSP on behalf of the CRSP Council This project was initiated during this year

INTSORMIL signed MOUs with the Kenya Agricultural Research Institute (KARI), the Uganda National Agricultural Research Organization (NARO) and the Division of Agricultural Research and Extension (DARES), Eritrea during the 1996-97 time frame

Training

Training of host country scientists contributes to the capability of each host country research program to stay abreast of environmental and ecological changes which alter the balance of sustainable production systems The strengthening of host country research institutions contributes to their capability to predict and be prepared to combat environmental and ecological changes which affect production and utilization of sorghum and pearl 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 1996-97, there were 56 students from 21 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator Approximately 80% 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 16% of all INTSORMIL graduate students were women

The number of students receiving 100% funding by INTSORMIL in 1996-97 totaled 18 An additional 21 students received partial funding from INTSORMIL The remaining 17 students were funded from other sources but are working on INTSORMIL projects The number of students receiving 100% funding from INTSORMIL has dropped from a high of 71 in 1986 down to a low of 17 in 1993-94 This is, in part, due to training taking place under other funding sources, but an even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished due to reductions in our overall program budget and because of inflationary pressures

In addition to graduate degree programs, short-term training programs have been designed and implemented on a case-by-case basis to suit the needs of host country scientists Several host country scientists were provided the opportunity to upgrade their skills in this fashion during 1996-97

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, ASARECA, ROCARS, SADC and others) private industry and government extension programs to coordinate research and technology transfer efforts

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

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

Over the years, established networking activities have been maintained with ICRISAT, SADC/ICRISAT, SMIP, SAFGRAD, ICRISAT Sahelian Center, ICRISAT West Africa Sorghum Improvement Program, ROCAFREMI, EARSAM of ICRISAT, ICRISAT/Mexico, CIAT and CLAIS of Central and South America There has been excellent collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training INTSORMIL currently cooperates with the ICRISAT programs in East, Southern, and West Africa, and the ROCAFREMI (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 plans to strengthen linkages among the NARS with which it collaborates, 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 have 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 improving sorghum and pearl millet production in developing countries and in the United States in sustainable ways

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 genes for 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, Eastern Africa, and Southern Africa)
* Midge and Greenbug resistance (Latin America)
* Downy mildew resistance (Latin America and Botswana)
* Anthracnose resistance (Latin America and Mali)
* Charcoal rot and lodging resistance (Africa and drier areas of Latin America)
* Head smut and virus resistance (Latin America)
* Foliar disease resistance (for all host countries)
* Improved grain quality characteristics for food and industrial uses (for all host countries)

The hybrid sorghum success story in Sudan traces to ICRISAT/INTSORMIL/ARC collaboration in which they developed, produced seed, and popularized the first hybrid sorghum, Hageen Dura-1 (Tx623 × K1567) for this country The female line Tx623 was used due to its wide adaptation, high yield potential and drought resistance It currently is produced on about 12% of the sorghum area in the Sudan Gezira Irrigation Scheme, the largest in the world under one management 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 Central America/Honduras sorghum program is improving sorghum research and production throughout the region through research, training, and outreach activities Research based in Honduras is extended throughout the region in both the maicillo criollo enhancement program and hybrid performance testing Small-scale hillside producers benefit through the maicillo criollo enhancement while larger producers through the hybrid performance test The hybrid performance test allows commercial industry and producers access to unbiased yield data and comparison of hybrids in the region Central America is the only location in the world where sorghum has evolved to fit the cropping systems of the steepland hillsides Collaboration with projects such as LUPE (Land Use Productivity Enhancement) allows hillside producers to see the benefits of a total management package for improved sorghum production 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 land race custodians will care for this germplasm as they have cared for maicillo The creation of enhanced maicillo cultivars and their subsequent deployment on-farm, is not only intended to increase genetic diversity in situ, but to stave off replacement of maicillos by introduced cultivars There are four improved dwarf maicillo varieties ready for release which will stabilize sorghum production through stress resistance and excellent quality grain characteristics

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 In 1994, seventy six percent of the sorghum was utilized for animal consumption and 17% for human consumption in Honduras 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

Researchers of the INTSORMIL CRSP have developed 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 kg ha ^{1}) 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 Niger 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 pests 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 in order to permit the establishment of a suitable market, and the hybrid should be readily producible Results of Regional Trials indicate a wide adaptation of NAD-1 in other countries of the region indicating the opportunity for an international market The experience of developing a private seed industry in Niger would be immediately valuable to other countries of the region with the production and marketing of hybrid seeds as they realize superior hybrids from their research

Through the integrated cooperation of sorghum breeders and food scientists, we now understand many of the factors necessary to improve the nutritional value of sorghum locally processed in villages Sorghum flour is less digestible than most cereal flours unless it is processed using local village procedures which have evolved over hundreds of years We now understand the scientific reasons why processing is important This knowledge will help modify and improve the traditional processing methods and to develop improved processing methods for utilization in other countries in the world where sorghum is used as a feed for food grain The 1996 annual report noted for the first time that a genetic solution may be possible for the digestibility problem In 1996-97, Dr Bruce Hamaker, INTSORMIL scientist in the Food Science Department at Purdue University, identified modified sorghum lines with a high protein digestibility trait that have good fill of vitreous endosperm and improved milling characteristics compared to softer grains

The INTSORMIL goal for the parasitic weed, *Striga*, is to exploit the unique life cycle and parasitic traits of *Striga*, especially the chemical signals required for germination, differentiation, and establishment The genetic inheritance the low production of the *Striga* germination stimulant in SRN39 has been identified The low production of the germination stimulant in this line is inherited as a single nuclear, recessive gene which is largely additive INTSORMIL project PRF-213 also has reported on the development of an in vitro assay for post-infection *Striga* resistance This assay will allow for identification of genetic variants that discourage infection of *Striga* as a hypersensitive reaction where penetration is followed by necrosis, or slowed development of the parasite after penetration, as well as incompatibility resulting in stunted growth or eventual death of the parasite It was reported in 1996 that eight tons, one ton each of eight high-yielding *Striga*-resistant food grain sorghum varieties were released by Purdue University to the PVO, World Vision, for use in nine countries in Africa During the first eleven months of operation, these *Striga*-resistant food quality sorghums have been tested on field stations or in farmers fields, or both, in the following countries Ghana, Senegal, Mali, Niger, Sudan, Rwanda, Mozambique, and Eritrea The Ethiopian Sorghum Improvement Program has selected two of the eight varieties for large scale seed multiplication and dissemination in 1998

Excellent progress has been made in Mali to develop white-seeded, tan-plant guinea cultivars Emphasis is 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 Two new lines were selected in 1995 for on-farm testing in the rainy season of 1996 Grain of N'tenimissa will be increased on about five ha in 1996 for use in utilization and value-added product development The PVO, World Vision, distributed N'tenimissa and *Striga* resistant cultivars in 20 on-farm trials in 1996-97 In Northern Mali, CARE is cooperating with IER and testing new sorghum cultivars at about 20 sites World Neighbors has provided improved cultivars of millet and sorghum with a package of improved production technologies to more than 20 communities in the Segou area of Mali

In Mali, lines developed by Dr Bretoudeau at the Agricultural School at Katiabougou, and evaluated in a 32-line Advanced Early Test produced the highest yield These lines have good grain milling qualities and will be evaluated in the IER Food Quality Laboratory

Sustainable Production Systems

In agronomy and soil/crop management, a major INTSORMIL impact has been understanding the soil/cropping system/genotype interactions Research in Niger has shown small and large production practice differences on pearl millet grain yield production, dry matter accumulation, and nutrient uptake Research results support recently published recommendations of 20,000 hills/ha, 40 kg ha ^{1} nitrogen and 18 kg ha ^{1} phosphorus for optimizing pearl millet grain yield , even in dry years In Mali, research indicates pearl millet/cowpea rotations resulted in the highest grain yield, stover nitrogen concentration, and agronomic use efficiency of nitrogen 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 Crop residue treatments had no effect on grain yield, but residues left on the surface had greater soil phosphorus and potassium levels than with residue removal or incorporation after five years Cropping increased soil pH and carbon, but decreased potassium and cation exchange capacity INTSORMIL has supported IER scientists who have worked in cooperation with the PVO, World Neighbors, and the Malien Extension Service(PNVA) over the past five years to extend technologies developed by IER World Neighbors workers report wide adoption of early-season grain sorghum and pearl millet cultivars, improved intercropping practices, and improved manure management through animal corralling and composting with crop residues

Sustainable Plant Protection Systems

In crop protection, a wide range of sources of resistance to 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*

Several *Striga* resistant lines, from Purdue University, evaluated in Mali showed good *Striga* resistance, but had inferior grain quality compared to local cultivars Work is continuing to improve the grain quality of these lines

F_3 progeny of the cross (Malisor 84-7 * #-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 experiment 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 conditions

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

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

The INRAN/INTSORMIL pathologist from Niger is in long term training at Texas A&M University He is conducting field trials and laboratory experiments on acremonium wilt of sorghum This research is part of the work for the Ph D degree Field trials were conducted at the Konni Research Station and in farmers fields His research focuses on the association between nematodes and acremonium wilt

In Honduras, ergot appeared and data was obtained on the level of disease in selected nurseries and collateral hosts Similarly, INTSORMIL scientists helped organize meetings on ergot in Brazil in collaboration with ICRISAT and in collaboration with the National Grain Sorghum Producers in Amarillo TX The advent and rapid spread of ergot forced INTSORMIL scientists to focus on the problems of management of this disease As of June 30, 1997, the disease had spread throughout southern Texas and as far north as Victoria and west to the San Antonio area The DNA fingerprinting of head smut isolates from maize and sorghum indicate that differences among these fungi are much greater than those within, suggesting parallel evolutionary development

Pearl millet head miner (*Heliocheilus albipunctella*) or MHM is a serious insect pest of West Africa, and infestation sometimes approaches 95% with a collective grain loss of 60% MHM has been found to be an excellent candidate for control strategies emphasizing effective natural enemies, i e , biological control MHM supports a relatively large guild of natural enemies, it occupies a predictable habitat in an ecosystem with relatively consistent annual presence, and has one generation per year Two major predators and two commonly encountered parasites have been identified and are being studied During 1995/1996, two NARS scientists from West Africa were admitted as graduate students in the Department of Entomology at Texas A&M University In 1996-97 they began their graduate degree research at the ICRISAT Sahelian Center Their research objectives and results will build on findings for MHM biological control reported by INTSORMIL scientists in 1994, 1995 and 1996 Annual reports When this research is complete, the key mortality sources, including natural enemies of MHM, will be identified and methods of manipulation will be described for those that can be effectively managed for optimal mortality to MHM populations The INTSORMIL MHM researchers continue to work closely with other pearl millet scientists of the West Africa ROCAFREMI millet network INTSORMIL participated in the three ROCAFREMI network meetings during this program year

A bacterial disease of pearl millet first observed in Southern Zimbabwe in 1995 and tentatively identified as *Pseudomonas syringae* by D Frederiksen at the University of Zimbabwe was later identified as *Pantoea agglomerans* by D Frederickson Several sorghum disease nurseries, other nurseries, selected sorghums, and advanced generation breeding germplasm developed or introduced in conjunction with INTSORMIL collaborators were evaluated at Sebele Botswana Cultivars with good sugarcane aphid resistance and good agronomic characteristics were identified and identified for further evaluation

In Central America, sorghum and maize are damaged each year by soil-inhabiting insects, stem borers and panicle-feeding insects that contribute to reduced yields of both crops on subsistence farms in Honduras, as well as in other countries in Central America, however, the major insect pest constraint to these crops is foliage feeding insects The pest complex has been identified by INTSORMIL project MSU-205 to consist principally of three armyworm species and a grass looper Insect pest management tactics have been investigated as independent control practices on subsistence farms in southern Honduras Recommendations for planting dates, weed control and insecticide applications to manage the lepidopterous defoliators have been developed This information will assist subsistence farmers in Honduras and surrounding countries with similar insect constraints in producing grain crops with increase yield with minimum cost for pest control with reduced risk to human health

Crop Utilization and Marketing

Many quality and utilization studies were done in the food quality laboratory in Sotuba, Mali, including evaluation of grain from yield trials In general, the local guinea type cultivars and checks and the Bretaudeau mutation-derived, true guinea lines of Dr Bretaudeau had the best quality, based on decortication yield and grain hardness In laboratory-scale studies with GAM (Generale Alimentaire du Mali, the major bread and cookie producer in Bamako) cookies made with 5% and 10% N'tenimissa flour (substituted for flour from imported wheat) were good quality taste and texture Bread made by GAM with 5-10% sorghum flour was acceptable and was preferred by consumers over a wheat/corn flour mix There was some concern about black specks in the flour from the N'tenimissa grain produced under open pollination conditions The major constraint to increased utilization of the flour from white tan-plant sorghums in various products is the lack of 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 "Crunch" was made from sorghum, and the varieties of Wassoulou and Lakaheri produced superior crunch compared to N'tenimissa Some womens associations and small entrepreneurs are processing crunch for local markets

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 The processing unit consists of a decorticator/mill, agglomerator/siever (designed by CIRAD, France), steamer, solar drier, and packaging sealer This equipment is being used for research purposes, and also as a demonstration and testing unit to encourage local entrepreneurs to commercialize millet or sorghum couscous A commercial-type product will also be tested in the market place Cultivars of sorghum and millet have been identified that make good quality couscous Initial efforts have been made to bring in entrepreneurs to use the unit and then to market test the couscous resulting from those efforts

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 Genetic markers co-segregating for greenbug resistance in sorghum were detected on four separate linkage groups Two genetic markers are linked to greenbug biotype C resistance, three to biotype E, two to biotype I and one to biotype K resistance Efforts to assess the genetic diversity among populations of greenbug have been initiated as companion research to the plant biotech nology research Agronomically viable greenbug biotype I parental lines were selected 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 Sorghum midge resistance in sorghum is caused by early (during day) flowering spikelets with glumes that tightly close before ovipositing sorghum midges are in the field Germplasm resistant to sorghum midge, developed through INTSORMIL support, has served as the foundation for many similar breeding programs throughout the world Three female (male sterile) sorghum midge-resistant parental lines were released to commercial seed companies Seven sets of the lines were distributed under a pre-release memorandum to private seed companies (six U S and one Guatemalan) for evaluation in 1997 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 These will be the first sorghum midge resistant A/B pairs with the traits needed to produce commercially acceptable resistant hybrids

Materials from the INTSORMIL/USDA/Texas A&M University Sorghum Conversion Program and selected breeding cultivars from other projects are evaluated regularly for resistance to internationally important diseases and insects in a cooperative/collaborative program throughout the sorghum growing world The conversion program consists of substituting a recessive maturity gene for a dominant one and either two or three recessive height genes for dominant ones Backcrossing is done until the short, photoperiod converted line looks like the tropical line when grown in the tropics except for being shorter This allows introducing exotic germplasm from the tropics with potentially desirable characteristics for utilization in the temperate regions of the world Forty fully converted exotic lines and 50 partially converted bulks from the conversion program were released in 1996 The male sterile (A-line) of five new female parental lines were distributed to private companies through a pre-release materials transfer agreement Several additional A-B pairs and R lines were selected for release as germplasm stocks These lines contain various desirable traits, including resistance to downy mildew, head smut, grain mold/weathering anthracnose, charcoal rot, both pre- and post flowering drought resistance food type grain quality, and lodging resistance

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 1996-97 new lines were identified with improved grain quality where vitreous central portion of the grain was more filled out Milling and food qualities of the modified, vitreous-core sorghum lines with the high protein digestibility trait are being examined

INTSORMIL project UNL-218 released three sorghum seed parents in the U S for private sector use and eight more are being prepared for release Three pearl millet seed parents and three restorer parents are also being prepared for release

Sustainable Production Systems

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 Western Nebraska has lower rainfall and a shorter growing season than Eastern Nebraska In Western Nebraska, pearl millet yielded less than grain sorghum at early planting dates, but more at later planting dates Early planting increased pearl millet yield 10 to 15% and grain sorghum by 72% Narrow row spacing produced higher yields for both crops, but the increase of 26% for grain sorghum was much greater than for pearl millet with 6-10% increase In Eastern Nebraska planting date had a small effect on grain yield of both crops across very different years environmentally and soil types Narrowing rows increased yields of both crops, but less than in Western Nebraska

Sustainable Plant Protection Systems

Disease evaluation studies are conducted primarily in large research nurseries in South Texas Several uniform nurseries are grown in locations where sorghum/millet diseases are important These include the International Sorghum Anthracnose Virulence Nursery (ISAVN), in collaboration with ICRISAT, the Uniform Head Smut Nursery (UHSN), the Sorghum Downy Mildew Virulence Nursery (SDMVN), the International Virus Nursery (ISVN) , and also a uniform nursery for grain mold (GWT) 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 researchers have developed a dot immunobinding assay (DIA) to distinguish different bacterial pathogens of sorghum and millet The test is easy to perform, inexpensive requires limited equipment and chemicals, and was designed with LDC laboratory conditions in mind It has been shown that the causal agent of bacterial leaf streak is seedborne and can remain viable in the seed for more than two years

International collaborative research programs with NARS and ICRISAT scientists have resulted in the development 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 to develop and validate sorghum plant and sorghum midge dynamics computer models

Significant advances were made in developing the technology to allow farmers to manage 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 In 1996-97 a survey was conducted to assess the extent of use of IPM by sorghum growers in Texas These data will be valuable in determining research and educational efforts needed to increase IPM use by sorghum growers, and document the extent of IPM use in sorghum in compliance with governmental goals of having IPM approach used on at least 75% of all crop acres

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

Crop Utilization and Marketing

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

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

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 ab sence 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 The food hybrids are also in high demand in the export market

The structure and processing properties of pearl millet have 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 pearl 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

Mycotoxins such as fumonisins, fusaric acid and moniliformin are produced by *Fusarium* spp commonly recovered from sorghum These compounds are hazardous to both humans and domestic animals These compounds may be produced simultaneously by the same strain under field conditions, and may interact synergistically to increase the risk beyond that posed by the individual mycotoxins alone Two biological species within *Fusarium* section *Liseola* were examined for production of fumonisins, moniliformin and toxicity to ducklings In general members of the A population produced high levels of fumonisins (up to 6 200 µg/g) but low levels of moniliformin (less than 175 µg/g), while members of the F mating population produced low levels of fumonisins (less than 40 µg/g) and high levels of moniliformin (up to 10,300 µg/g) The duckling toxicity of the two strains were similar, however, and the level of either toxin by itself was not strongly correlated with duckling toxicity We think it is likely that the members of both of these mating populations produce additional toxins that have yet to be chemically identified These toxins may interact synergistically with other compounds to induce the observed duckling toxicity Since the most common *Fusarium* spp associated with sorghum does not produce the fumonisin mycotoxin, the possibility that sorghum is preferable to maize as a feed and food whenever fumonisin toxicity is a potential problem, e g , feed for horses and swine, needs further investigation

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 U S and in developing countries Breeding for resistance to *Fusarium* associated diseases is limited because the strains responsible for disease often cannot be accurately identified and used repeatedly in field challenges

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

Research Approach and Project Output

Research Methods

Sexual crosses and mating population identification Standard tester strains from each of the six mating populations of *Gibberella fujikuroi* were used as one of the parents in all of the crosses Crosses were made on carrot agar following standard protocols Field isolates were used as males with the standard tester as the female parent Fertile crosses produced perithecia that exuded a cirrus of ascospores Strains used and their origin are listed in Tables 1-3

Chemical assays 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 the corn meal 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

Table 1 Production of fusaric acid by strains from *Gibberella fujikuroi* (*Fusarium* section *Liseola*)

Strain	Fusaric acid (µg/g)	Original host	Geographic origin	Mating type
A 00102	260	Sorghum	California, USA	A$^+$
A 00149	760	Maize	California, USA	A
A 00488	160	Maize	Transkei South Africa	A
A 00501	340	Maize	Kansas USA	A$^+$
A 00516	210	Maize	Kansas USA	A
A 00524	98	Maize	Kansas USA	A
A 00606	160	Maize	Kansas USA	A
A 00697	97	Maize	Kansas USA	A
A 00999	250	Maize	Indiana, USA	A$^+$
A 02952	240	Sorghum	Arkansas USA	A
A 03823	100	Banana	Turkey	A
A 04426	320	Banana	Smoeng Thailand	A$^+$
B 01722	200	Sorghum	Laguna, Philippines	B
B 01728	130	Sorghum	Laguna, Philippine	B
B 03828	140	Cattleya	Germany	B$^+$
B 03852	70	Lab cross		B$^+$
C 01993	1080	Rice	Taiwan	C$^+$
C 01994	520	Rice	Taiwan	C
C 01995	600	Rice	Taiwan	C
C 01996	420	Rice	Taiwan	C$^+$
D 00502	120	Maize	Kansas USA	D$^+$
D 00637	490	Maize	Kansas USA	D
D 00666	250	Maize	Kansas USA	D
D 00875	67	Sorghum	Kansas USA	D$^+$
D 02877	270	Sorghum	Missouri Kansas	D
D 02894	100	Maize	Kansas USA	D
D 02945	130	Sorghum	Mississippi USA	D
D 02959	520	Tobacco	South Carolina USA	D
E 00434	140	Maize	Kansas USA	E$^+$
E 00731	68	Maize	Kansas USA	E$^+$
E 00990	320	Maize	Illinois USA	E
E 01583	230	Maize	Beijing China	E
F 00728	350	Sorghum	Kansas USA	F$^+$
F 00921	150	Sorghum	Kansas USA	F
F 00965	81	Sorghum	Kansas USA	F$^+$
F 01051	320	Sorghum	Kansas USA	F
F 01054	110	Sorghum	Kansas USA	F
F 01183	500	Sorghum	Kansas USA	F$^+$
F 01377	200	Sorghum	Kansas USA	F
F 03869	180	Sorghum	Natal South Africa	F

Duckling toxicity tests Lyophilized fungal conidia were suspended in sterile water and used to inoculate 400 g of

Table 2 Fumonisin and moniliformin production and duckling toxicity of strains belonging to *Gibberella fujikuroi* mating population A

Strain	Mating type	Female fertile?	FB$_1$[a] (µg/g)	FB$_2$[b] (µg/g)	FB$_3$[c] (µg/g)	Mon[d] (µg/g)	Toxicity index[e]	Host	Geographic origin
A 00102	A$^+$	Yes	1600	330	400	ND[f]	260	Sorghum	California, USA
A 00149	A	Yes	6200	1800	2300	ND	160	Maize	California, USA
A 00488	A	Yes	2200	670	400	ND	230	Maize	Transkei South Africa
A 00489	A	No	120	15	20	ND	3000[g]	Maize	Transkei South Africa
A 00501	A$^+$	No	470	40	140	ND	130	Maize	Kansas USA
A 00552	A	Yes	380	70	200	ND	120	Maize	Kansas USA
A 00999	A$^+$	Yes	1000	240	500	ND	310	Maize	Indiana USA
A 01029	A	Yes	1600	530	470	ND	190	Maize	South Carolina USA
A 01660	A	No	2500	530	310	ND	90	Maize	Beijing China
A 01811	A	No	45	5	10	170	1500	Maize	Nebraska USA
A 02889	A$^+$	Yes	330	65	150	ND	240	Maize	Ohio USA
A 02903	A	Yes	45	10	15	ND	3100[h]	Maize	North Carolina, USA
A 02949	A	Yes	2100	440	300	ND	180	Maize	Mississippi USA
A 04367	A	Yes	2600	610	780	ND	160	Maize	Assyut, Egypt
A 04426	A$^+$	Yes	75	5	60	65	1000[g]	Banana	Smoeng Thailand
A 04516	A$^+$	Yes	Tr[i]	ND	ND	180	400	Maize	Kathmandu Nepal
A 04796	A$^+$	No	230	40	65	ND	150	Maize	Transkei South Africa
A 04801	A$^+$	No	2900	910	580	ND	190	Maize	Transkei South Africa
A 04802	A	Yes	1700	400	480	ND	100	Maize	Transkei South Africa
A 04803	A	No	3200	680	1400	ND	110	Maize	Transkei South Africa

FB$_1$ Fumonisin B$_1$
[b] FB$_2$ Fumonisin B$_2$
FB$_3$ Fumonisin B$_3$
[d] Mon Moniliformin
The toxicity index was calculated as follows mean day of duckling death x grams of grain consumed Unless indicated otherwise all four ducklings in each treatment group died All four ducklings in the control group survived for the 14 day term of the test (toxicity index 28 000)
[f] ND Not detected (<1 µg/g)
[g] Three of four ducklings died
[h] Two of four ducklings died
Tr Trace (1 2 µg g) Usually indicates a high background level in uninoculated control grain

sterilized maize kernels in 2-liter fruit jars Cultures were grown for 21 days at 25°C and then dried overnight at 45°C before being ground to a fine powder in a laboratory mill This moldy meal was mixed 1 1 with commercial chicken mash and fed ad lib to groups of four 1-day-old Pekin ducklings for up to 14 days Control diet substituted milled maize from jars that were not inoculated with a *Fusarium* strain The ducklings and their feeds were weighed at the beginning of each experiment, and the total feed intake value was calculated from the amount of feed remaining at the end of the test Mortality was recorded daily, and the mean day of death was calculated from the numbers of ducklings that died on different days Cultures that caused the death of three or four of the four test ducklings were considered toxic A toxicity index was calculated by multiplying the amount of feed consumed (in grams) by the mean day of death to obtain an inverse measure of toxicity for the cultures

Research Findings

The filamentous ascomycete *Gibberella fujikuroi* (anamorphs in *Fusarium* section *Liseola*) consists of at least six distinct biological species often referred to as mating populations The biological species designated A was collected primarily as a pathogen on maize from temperate regions Mating population D is found on maize, rice, sorghum, and many other hosts in both temperate and tropical regions Mating population F is primarily an endophyte of sorghum, and is found with global distribution Genetic evidence from these mating populations (e g , vegetative compatibility group analysis) is consistent with the hypothesis that there is significant genetic variation within at least some of these species

Fusaric Acid Production by Members of Fusarium Section Liseola (Gibberella fujikuroi)

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

We tested 41 strains representing the six different biological species for their ability to produce fusaric acid (Table 1) All of the strains examined could produce fusaric acid in amounts ranging from 67-1080 µg/g Of the 70 iso-

Table 3 Fumonisin and moniliformin production and duckling toxicity of strains belonging to *Gibberella fujikuroi* mating population F

Strain	Mating type	Female fertile?	FB_1[a] (µg/g)	FB_2[b] (µg/g)	FB_3[c] (µg/g)	Mon[d] (µg/g)	Toxicity index[e]	Host	Geographic origin
F 00769	F	No	7	Tr[f]	ND[g]	1700	70	Sorghum	Mississippi USA
F 00779	F	Yes	30	5	5	880	180	Sorghum	Arkansas USA
F 00965	F+	No	ND	ND	ND	3000	150	Sorghum	Kansas USA
F 00978	F+	No	ND	ND	ND	5400	35	Sorghum	Missouri USA
F 01183	F+	No	ND	ND	ND	220	730	Sorghum	Kansas USA
F 01377	F+	Yes	5	ND	ND	800	110	Sorghum	Kansas USA
F 01540	F	Yes	Tr	ND	ND	85	4400[h]		Lab cross
F 01733	F	No	Tr	ND	ND	140	450	Sorghum	Laguna Philippines
F 02897	F+	No	Tr	ND	ND	290	210	Sorghum	Ohio USA
F 03868	F	No	Tr	ND	ND	2000	110	Sorghum	Natal South Africa
F 03869	F	No	Tr	ND	ND	10 000	84	Sorghum	Natal South Africa
F 03872	F	No	Tr	ND	ND	1300	110	Sorghum	Natal South Africa
F 03882	F+	No	Tr	ND	ND	170	540	Sorghum	Natal South Africa
F 03883	F+	No	Tr	ND	ND	200	390	Sorghum	Natal South Africa
F 03884	F+	No	Tr	ND	ND	870	49	Sorghum	Transvaal South Africa
F 03885	F+	No	Tr	ND	ND	130	130	Sorghum	Transvaal South Africa
F 04084	F+	No	ND	ND	ND	4000	64	Peanut	Texas USA
F 04092	F+	Yes	ND	ND	ND	320	3300[i]		Lab cross
F 04093	F	Yes	ND	ND	ND	1400	94		Lab cross
F 04440	F+	No	Tr	ND	ND	1400	80	Banana	Sing Buri Thailand

FB_1 Fumonisin B_1

[b] FB_2 Fumonisin B_2

FB_3 Fumonisin B_3

[d] Mon Moniliformin

The toxicity index was calculated as follows mean day of duckling death x grams of grain consumed Unless indicated otherwise all four ducklings in each treatment group died All four ducklings in the control group survived for the 14 day term of the test (toxicity index 28 000)

[f] Tr Trace (1 2 µg g) Usually indicates a high background level in uninoculated control grain

[g] ND Not detected (<1µg/g)

[h] One of four ducklings died

Three of four ducklings died

lates examined, 12 produced less than 100 µg/g, 48 produced 101-500 µg/g (moderate producers), and 10 produced more than 500 µg/g (high producers) Members of mating population C produced the most fusaric acid (range, 420-1,080 µg/g, mean = 590 µg/g) Mating population A's range was similar in size (97-760 µg/g), but the mean was much lower (xx0 µg/g) Mating population D had a range (67-520 µg/g) and mean (240 µg/g) similar to that for mating population A The means for the other mating populations were somewhat lower (B - 140 µg/g, E - 170 µg/g, and F - 236 µg/g), and their ranges (B - 70-200 µg/g, E - 69-320 µg/g, and F - 81-501 µg/g) more compressed Isolates recovered from sorghum (range 67-501 µg/g) were representative of the mating populations as a whole

Fusaric acid is unusual in that it is synthesized by all of the *Fusarium* species in the *Liseola* section as well as species outside the section such as *F crookwellense*, *F heterosporum*, *F napiforme*, *F oxysporum*, *F sambucinum*, and *F solani* Most mycotoxins produced by *Fusarium* species are produced by only one, or a very few closely related species Most *Fusarium* strains from sorghum probably synthesize fusaric acid, and fusaric acid has been universally detected in relatively few sorghum grain samples that have been analyzed for it However, the overall presence 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

Analysis of the A and F Mating Populations for Duckling Toxicity and Production of Fumonisin and Moniliformin

Fumonisins and moniliformin are both reported to be produced by some strains of *Fusarium moniliforme*, and many strains have been described as acutely toxic to ducklings This morphological species is known to encompass two different biological species (the A and F mating populations of *Gibberella fujikuroi*) that are genetically discrete and do not interchange genetic information with one another We selected 20 strains from each of these mating populations to determine if any of the differences ascribed to different strains of *F moniliforme* could be associated with either mating population

Nineteen of the 20 strains from the A mating population were toxic to ducklings These strains are most commonly recovered from maize, but can also be found occasionally on banana, fig, muskmelon, pine, rice, sorghum and sugarcane The one nontoxic strain (2903) produced low levels of fumonisins and no detectable moniliformin This strain does not produce pigmented perithecia and appears to be blocked in the synthesis of melanin and related secondary metabolites Strain 4516 produced no more than trace levels of fumonisin and a little (175 µg/g) moniliformin and was toxic to ducklings The statistical correlation between duckling toxicity and fumonisin production in the A mating population was relatively weak (r^2 = -0 43) Only 3/20 strains produced moniliformin, and those only in relatively small amounts In summary, most isolates in the A mating population produce significant levels of fumonisin, but few produce moniliformin, and the observed toxicity to ducklings cannot be attributed to either fumonisin or moniliformin alone or to synergism between the two toxins

Fifteen of the 20 strains in the F mating population were originally isolated from sorghum Nineteen of these 20 strains were toxic to ducklings The one nontoxigenic strain (1540) produced low levels of moniliformin and a trace of fumonisin B_1 This strain cannot be distinguished morphologically from the other strains of this mating population and was one of the parents of the cross from which strains 4092 and 4093 were derived The correlation between moniliformin production and duckling toxicity was weak (r^2 = -0 27) and was not statistically significant Three of the 20 strains produced more than a trace of fumonisins (5-40 µg/g), but all levels were quite low In summary, most isolates in the F mating population produce significant levels of moniliformin, but few produce fumonisins, and the observed toxicity to ducklings cannot be attributed to either fumonisin or moniliformin alone or to synergism between the two toxins

The low levels of correlation between toxin production and toxicity are troubling, especially if the hypothesis that these toxins are responsible for the observed toxicity is correct Duckling toxicity tests are normally used as preliminary screening tests for toxicity only, and variability and lack of reproducibility are not uncommon However, the agreement between toxin production and duckling toxicity is usually better than that observed in this study For this reason, we think that it is likely that additional compounds produced by the fungal isolates play a significant role, either singly or synergistically, in the duckling toxicity that we observed In a preliminary study, unique peaks missing in extracts of strain 2903 were identified by HPLC in extracts of strain 4516 but the compound(s) responsible for these peaks have not been chemically identified and have not been tested for toxicity

In conclusion, strains of the A and F mating populations of *G fujikuroi* do not differ in their acute toxicities to ducklings, but they do differ markedly in their abilities to produce fumonisins and moniliformin It is likely that members of both mating populations produce additional metabolites that are toxic to ducklings and remain to be isolated and chemically characterized

Networking Activities

Editorial and Committee Service

- Editorial Board of Applied and Environmental Microbiology
- Associate Editor and Editorial Board of Mycologia
- Member of the International Society for Plant Pathology, *Fusarium* Committee
- Editor and organizer of the Genetics session of the Paul E Nelson Memorial Symposium

Research Investigator Exchange

- Dr Leslie spent one month at the Universidad Nactional de Rio Cuarto, Rio Cuarto, Argentina as a visiting professor teaching a condensed course on Fungal Genetics for graduate students and Faculty in the southern cone region of South America

Seminar Workshop and Invited Meeting Presentations

- Myco Pharmaceuticals, Cambridge, MA
- Laboratorio Tecnologico del Uruguay, Montevideo, Uruguay - 6/96
- Mycological Society of America Annual Meeting, Indianapolis IN - 7/96
- Abbott Laboratories, North Chicago, IL - 9/96
- Dept of Plant Pathology, University of Bari, Bari, Italy - 10/96
- Dept of Microbiology, University of the Free State, Bloemfontein, South Africa - 10/96
- Stellenbosch Branch, South African Society for Plant Pathology, Stellenbosch, South Africa - 10/96
- Dept of Microbiology, Universidad Nacional de Rio Cuarto, Rio Cuarto, Argentina - 11/96

Long-Term Laboratory Visitors

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

Fusarium Cultures Provided

- S Danielson, CATIE, Turrialba Costa Rica
- Dr L Hornok, Agricultural Biotechnology Center, Institute for Plant Sciences, Godollo, Hungary
- Dr W Gams, Centraalbureau voor Schimmelcultures, Baarn, The Netherlands
- Dr C J Kedera, KARI, Nairobi, Kenya
- Dr W A J de Milliano, S & G Seeds, B V , Enkhuizen, the Netherlands

- Dr H I Nirenberg, Biologische Bundesantsalt für Land- und Forstwirtschaft, Berlin, Germany
- Dr J Chelkowski, Institute of Plant Genetics, Polish Academy of Sciences, Poznan, Poland
- Dr W F O Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa
- Dr S C Jong, American Type Culture Collection, Rockville, Maryland
- Dr Maya Piñeiro, Mycotoxin section, Laboratorio Tecnologico del Uruguay, Montevideo, Uruguay
- Dr K A Seifert, Agriculture Canada, Ottawa, Ontario, Canada
- Dr Claude P Seletrinnikoff, University of Colorado Health Sciences Center, Denver, CO
- Dr Charles Bacon, USDA Russell Research Center, Athens, GA
- Drs R D Plattner, A E Desjardins and K O'Donnell, USDA National Center for Agricultural Utilization Research, Peoria, IL
- Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, KS
- Dr J S Smith, Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS
- Drs R W Bowden, L E Claflin and D J Jardine, Department of Plant Pathology, Kansas State University, Manhattan, KS
- Dr R L James, USDA Forest Service, Coeur D'Alene, ID
- Dr G Carugati, Diaspa, S P A , Corana, Italy
- Dr D Gilchrist, Dept of Plant Pathology, University of California, Davis, CA
- Dr Y -H Lee, Department of Agricultural Biology, Seoul National University, Suwon, Korea
- Dr T C Harrington, Dept of Plant Pathology, Iowa State University, Ames, IA
- Dr R C Ploetz, Tropical Research and Education Center, University of Florida, Homestead, FL

Publications and Presentations

Abstracts

Leslie J F and K K Klein 1996 Hermaphrodite frequency and the frequency of sexual reproduction in fungal populations Inoculum 47(3) 18

Arjula, V , and J F Leslie 1996 Construction of ' near isogenic lines in *Fusarium moniliforme* (*Gibberella fujikuroi* mating population A) Phytopathology 86 S103

Zeller K A and J F Leslie 1996 Some mutants that overcome vegetative incompatibility in *Fusarium moniliforme* (*Gibberella fujikuroi* mating population A) Phytopathology 86 S32

Journal Articles

Bacon C W J K Porter W P Norred and J F Leslie 1996 Production of fusaric acid by *Fusarium* species Applied and Environmental Microbiology 62 4039 4043

Huss M J C L Campbell D B Jennings and J F Leslie 1996 Isozyme variation among biological species in the *Gibberella fujikuroi* species complex (*Fusarium* section *Liseola*) Applied and Environmental Microbiology 62 3750 3756

Leslie J F 1996 Fungal vegetative compatibility Promises and prospects Phytoparasitica 24 1 4

Leslie J F 1996 Genetic problems in some *Fusarium* species Sydowia 48 32 43

Leslie J F and K K Klein 1996 Female fertility and mating type effects on effective population size and evolution in filamentous fungi Genetics 144 557 567

Leslie J F W F O Marasas G S Shephard E W Sydenham S Stockenström and P G Thiel 1996 Duckling toxicity and the production of fumonisin and moniliformin by isolates in the A and F mating populations of *Gibberella fujikuroi* (*Fusarium moniliforme*) Applied and Environmental Microbiology 62 1182 1187

Leslie J F and K A Zeller 1996 Heterokaryon compatibility in fungi More than just another way to die Journal of Genetics 75 415-424

Plattner R D A E Desjardins J F Leslie and P E Nelson 1996 Identification and characterization of strains of *Gibberella fujikuroi* mating population A (*Fusarium moniliforme*) with rare fumonisin phenotypes Mycologia 87 416 424

Xu J R and J F Leslie 1996 A genetic map of *Fusarium moniliforme* (*Gibberella fujikuroi* mating population A) Genetics 143 175 189

Xu J R and J F Leslie 1996 Strain genotypes of *Gibberella fujikuroi* mating population A (*Fusarium moniliforme*) mapping population Fungal Genetics Newsletter 43 61 65

Books and Book Chapters

Leslie J F 1996 Introductory biology of *Fusarium moniliforme* In Fumonisins in Food (L S Jackson J W DeVries and L B Bullerman eds) pp 153 164 Plenum Press New York 399 pp

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-210B

Larry E Claflin
Kansas State University

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Dr Mitch Tuinstra, Department of Agronomy, Kansas State University, Manhattan, KS
Mr Girma Tegegne, IAR, Nazreth Research Station P O Box 436, Nazreth, Ethiopia
Dr John Leslie, Department of Plant Pathology, Kansas State University, Manhattan, KS
Dr Darrell Rosenow, Texas Agricultural Experiment Station, RR 3, Box 219, Lubbock, TX
Dr G A Odvody, TAM Research and Extension Center, Route 2, Box 589, Corpus Christi, TX 78406

Summary

Sorghum germplasm with immunity to *Sporosorium sorghi* includes B35-6, Sureño, and SC414 BTx623 was used as the susceptible parent to determine the inheritance of resistance to covered kernel smut Progenies of the initial cross (F_1) of Sureño X B35-6 and SC414 × BTx623 favored dominance of resistance Sureño × BTx623 showed an incomplete dominance of resistance Data from F_2 plants suggests that Sureño and B35-6 possess the same gene for resistance but is different than the resistant gene in SC414 The trait is simply inherited and can easily be incorporated in sorghum cultivars having desirable agronomic characteristics but are susceptible to covered kernel smut

Objectives, Production and Utilization Constraints

Objectives

- Determine the causal agent(s) of pokkah boeng disease of pearl millet and grain sorghum
- Ascertain the potential of plant growth promoting fungi in sorghum production
- Research several epidemiological parameters of ergot (*Claviceps africana*) disease of grain sorghum while on a sabbatical leave in Mexico
- Determine the inheritance of resistance to covered kernel smut (*Sporosorium sorghi*)

Constraints

Pokkah boeng disease is observed every year in all sorghum production areas of the world and the cause has been attributed to chemical injury, calcium deficiency and a fungal pathogen, *Fusarium subglutinans* Pokkah boeng is also known as "rat tail" or "onion leaf" and is a Javanese term describing a malformed or distorted top Leaves of susceptible plants are deformed or discolored near the top of the plant In some instances, the leaves become so wrinkled they are unable to unfold properly, resulting in a plant with a ladder-like appearance In extreme cases, infection progresses from the leaves and sheath into the stalks, causing death of the tops Sometimes both the stalks and the leaves display "knifecut" symptoms (narrow, uniform, transverse cuts which look like the tissue was sliced with a sharp knife) It is unknown if the causal fungus of pokkah boeng is soil-, seed- or windborne Transmission of the causal agents with propagative materials taken from diseased plants may occur occasionally, but this appears to be of limited economic importance Dissemination probably occurs by both soil and seeds and also to a certain degree by airborne spores Dormant perithecia on plant debris are the likely primary sources of inoculum

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

Ergot was only a problem in grain sorghum in Africa and Asia prior to 1996 when the disease was first detected in Brazil and Argentina In 1997, the disease spread to Colombia, Honduras, Mexico, numerous islands in the Caribbean, and, very recently, in Central and South Texas This poses profound implications for the sorghum industry in North America Losses due to ergot may be attributable to actual reduction in grain yields, loss of export markets of seed and feed grains to those countries where ergot has not been reported Loss of germplasm and or hybrid seed increases in winter nurseries where ergot was detected and quarantine regulations prohibit return of the grain into the U S Grain sorghum is used as a human food in numerous countries and may be the only food staple available in those areas where drought is a common occurrence, and ergot contamination of such grain could result in extensive hunger

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

Research Approach and Project Output

Research Methods

Two sorghum hybrids, Pioneer 8601 and Pioneer 8379 courtesy of Pioneer Hi-Bred International, one sorghum cultivar, Malisor 84-7 (Courtesy Dr Darrel T Rosenow, Texas A&M University, Lubbock Texas) and a millet cultivar, Serere 3A (Courtesy William D Stegmeier, Kansas State University, Hays, Kansas) were utilized Seeds were disinfested to eliminate microbial flora prior to planting by soaking them in distilled water for 5 min at 60 C in a water bath Seeds were further disinfested by placing them in 10% NaOCl for 2 min, rinsed in distilled water, then dried under a laminar flow hood Ten seeds of each sample were plated on potato dextrose agar (PDA) to ascertain the presence of seedborne microorganisms Treated seeds were planted in pots (200 cm^3) containing autoclaved soil

Three strains of *F subglutinans*, 210-9T, PS1, and D26 and one of *F proliferatum*, D28, were used At the 6 to 8 leaf stage of growth, plants were inoculated with 100 µl of a spore suspension containing about 10^6 conidia/ml The inoculum was placed in the whorl with a syringe and distilled water was used as a control

At physiological maturity, three inoculated plants were removed from the pots and pieces of tissue (ca 2 mm^3) were taken from roots and stalk tissues and plated on NS medium at 25C for 3 to 5 days *Fusarium* colonies were transferred to carnation leaf agar (CLA) amended with 6% KCL for identification after three days of incubation at 25 C Ten colonies from each isolation were examined under the microscope and the percentage recovery of the putative species recorded

Field Evaluations

Two methods of inoculation were compared in 1995 and 1996 at the Rocky Ford Experimental Farm, near Manhattan, Kansas In 1995, seeds of the sorghum cultivar Malisor 84-7, Pioneer 8601, and Pioneer 8379 were disinfested as previously described and planted in a completely randomized block design with three replications The experiment was repeated in 1996 using the same sorghum hybrids and the cultivar, SC155 In a separate experiment, seeds of the cultivars SC414-12E SC155 and Malisor 84-7 (1995) and 23 sorghum accessions from the All Disease and Insect Nursery (ADIN) (1996) were disinfested and used to investigate the effect of pokkah boeng disease on sorghum plant heights and grain weight The design used was a randomized complete block with three replicates Plots were fertilized with ammonium nitrate applied at a rate of 97 6 kg ha ^{1} Single-row plots were spaced 76 5 cm apart and 5 m in length with plants spaced 10 2 cm apart in the row Plants were thinned to one plant per hill after four weeks

To investigate the effect of pokkah boeng disease on sorghum plant heights and grain weight, a spore suspension (100 µl) containing 10^6 conidia/ml of *F proliferatum* (strains D28 and PS5) and *F subglutinans* (strains D27 and PS1) was placed into the whorl of plants with a syringe at the 6 to 8 leaf stage of growth in 1995 In 1996, *F proliferatum* (strain D28) and *F subglutinans* (strain D27) were used

Plant Growth Promoting Treatments

One strain each of *F subglutinans* (PS2), *Gibberella fujikuroi* (MTC), and *F proliferatum* (HGH), (Courtesy Lu Ming, Kansas State University) were used in this study They were chosen based on their performance in the bioassays and other tests Single-spored cultures of these strains were grown on complete medium in petri dishes (15 x 100 mm) for five days Spores were dislodged with a pipette containing distilled water, dilution series were made and a final concentration of 10^4 spores/ ml was used Seeds were covered with the fungal suspension in a beaker and gently shaken to ensure even coverage They were air-dried overnight in a laminar flow hood

Experimental Design

The experiment was divided into two blocks, one block received 102 15 kg of nitrogen (34-0-0) per ha and the other block was untreated In each block, seeds of the two sorghum hybrids were dressed with the eight treatments and planted at two depths, 2 5 and 5 cm Treatments and planting depths were completely randomized within the blocks and each treatment was replicated four times Each treatment combination was planted in single row plots 6 1 m long and the distance between hills in a row was 11 4 cm, with one seed per hill

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 conidia will be determined by evaluating longevity of the spores with and without honeydew under various temperature and relative humidity regimes 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

Germplasm reported to be resistant to ergot will be evaluated under conditions in Mexico, providing that the accessions are not photoperiod sensitive

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 Mexico Koch's postulates will be used as to identify those susceptible

Inheritance of Resistance to S sorghi

Seeds of true breeding varieties and crosses used were supplied by Dr Paula Cox, Department of Agronomy, Kansas State University Immune cultivars were B35-6, SC414, and Sureño The susceptible parent was BTx623 Crosses were made between resistant and susceptible accessions to determine the dominance of susceptibility or resistance, and between resistant accessions to determine if they possess the same genes Crosses between resistant varieties were SC414 × Sureño, SC414 × B35-6, and Sureño × B35-6 Crosses between resistant and susceptible varieties consisted of B35-6 × TX623, SC414 × TX623 and Sureño × TX623

F_1 seed was increased to produce the F_2 generation To produce the F_3 generation of the crosses between resistant and susceptible varieties, F_2 seed was grown in the greenhouse in 1995 As soon as the heads of the F_2 plants emerged and before anthesis they were covered with paper bags to prevent outcrossing The F_3 seed was harvested in May, 1995 and stored in paper bags until sown in the field

Seed Inoculation

Seeds were sterilized prior to inoculation by soaking in a mixture of formalin water (1 3, v/v) for one hour, followed by a wash in running tap water for 30 minutes and then air dried for 12 hours at room temperature The method of infestation of F_1, F_2, and F_3 seeds with teliospores of *S sorghi* varied The F_1 and F_2 seed was infested with partial vacuum The F_3 seed was infested by adding a small quantity of teliospores in a planting cup and then shaking to ensure a uniform distribution The source of teliospores was smutted sorghum heads from the previous season

Planting

Seeds were planted within several hours after the teliospores were added The cross B35-6 × BTx 623 consisted of 33 F_3 lines, Sureño × BTx 623 resulted in 38 F_3 lines, and 41 F_3 lines were from SC414 × BTx623 F_3 lines were machine planted in three meter rows spaced 76 cm apart at the Rocky Ford Experimental Farm, Manhattan, KS in June, 1995 To study inheritance of resistance (segregation) in the F_2 generation, F_2 seed of all crosses were grown in the greenhouse in pots during the winter of 1996 At least eight seeds were planted per pot Plants were thinned at the three-four leaf stage of growth and number of plants per pot varied from three-five depending on the size of the pot Insufficient seed from all crosses was a problem, and therefore dominance of resistance or susceptibility was determined in only one cross, Sureño × BTx623 All crosses were compared to the parental varieties

Research Findings

Colonization by *F proliferatum* and *F subglutinans* occurred in the basal, middle, and uppermost nodes *F proliferatum* was recovered from 58 2% of the sorghum accessions, whereas *F subglutinans* was recovered from only 29 8% Recovery of *F proliferatum* was much higher in 1996 (100%) than in 1995 (47 8%) on the 23 sorghum accessions tested, whereas recovery of *F subglutinans was the same in both years Furthermore a high percentage of F proliferatum* was recovered from control plants, some of which exhibited pokkah boeng symptoms in 1996 (34 8%) *F subglutinans*, was recovered from control plants only once

Cultivar SC155 was more susceptible than other accessions Mean recovery of the four cultivars varied from 30 to 48% with *F proliferatum* , and from 17 to 22% with *F subglutinans* In Kansas, *F proliferatum* is recovered more commonly than *F subglutinans*

Heights and fresh weights of young plants were measured at the 5-leaf stage (stage 2 of sorghum development) Differences between sorghum hybrids, planting depths, fertilizer regimes, and treatments were significant at $P < 0\ 05$ Plants in fertilized plots and planted at 5 cm were taller than those in unfertilized plots planted at 2 5 cm Differences between treatments for the fresh weight accumulation were not substantial Fresh weight depended on planting depths, 5 cm being better than 2 5 cm, and the hybrid used Grain yield depended more on fertilizer and sorghum hybrids than on treatments However, there was a tendency for *G fujikuroi* to produce more with the higher yielding hybrid, Pioneer 8379, than the other treatments Fungal dressings were better than pure GA_3 for early stand enhancement, which suggest that the stimulatory substance probably remained on the surface of the seeds longer than GA_3

In summary, strains of *Fusarium subglutinans* and *F proliferatum*, with growth promoting properties in lettuce and rice bioassays, did not show substantial performance in the field experiment Even if other growth promoting substances influenced bioassays results, commercial Ga_3 applied at 10 ppm/2000 seeds of sorghum substantially did not improve either stand establishment or grain yield By contrast, dressing with spore suspensions was better than commercial Ga_3 for early stand enhancement There was no direct relationship between promoting sorghum growth by these strains of *Fusarium* and pokkah boeng incidence, which was very low and caused more often by *F proliferatum* than other strains

Covered Kernel Smut Reaction of Parents

Resistant parents remained immune to *S sorghi* under field and greenhouse conditions Incidence of covered kernel smut was significantly higher in the susceptible parent, BTx623, in the greenhouse (71 1%) than in the field (2 3%)

Reaction of F_1 Progenies

F_1 progenies of the crosses Sureño × B35-6 and Sureño × BTx623 favored dominance of resistance Dominance was incomplete in the cross Sureño × BTx623 Reaction of other F_1 progenies to covered kernel smut could not be determined due to limited seed stocks

Reaction of R × R F_2 Progenies

Variability existed in smut reactions among crosses of resistant (R) by resistant (R) varieties F_2 progenies of B35-6 × Sureño were free of disease Only two plants were diseased out of a total of 47 plants in the cross, SC414 × B35-6 Although not anticipated, 26% of the F_2 progenies of Sureño × SC 414 were diseased

Reaction of F_3 Lines

Conditions for smut infection were not as conducive under field conditions, as shown by the low incidence (2 3%) of infection in the susceptible parent However, all F_3 lines of the crosses were more diseased than the susceptible parent (BTx623), with 6 15% in the F_3 lines of Sureño × BTx623, 3 80% in the F_3 lines of SC414 × BTx623, and 3 67% in the F_3 line of B35-6 × BTx623 Differences in covered kernel smut incidence in the susceptible parent (BTx623) in both greenhouse and field experiments were probably due to variability in the effectiveness of inoculation methods and also to environmental differences

F_1 progenies of Sureño × BTx623 showed an incomplete dominance of resistance Casady obtained similar results in F_1 plants of Combine kafir 60 (S) × Spur feterita (R) and Pink kafir (S) × Spur feterita (R) Seed from F_1 plants of the other resistant × susceptible crosses were not available, therefore no conclusion could be reached about the reaction of their F_1 progenies to *S sorghi*

A 3 1 ratio of resistant to susceptible plants was obtained in F_2 populations of SC414 × BTx623 The calculated chi-square value of 1, $p = 0\ 50 - 0\ 10$, indicated that the hypothesis of a 3 1 ratio of resistant to susceptible plants was applicable in this situation, thus suggesting the segregation of a single gene pair under the prevailing environmental conditions with our isolates of *S sorghi* A poor fit of the 3 1 ratio of resistant to susceptible plants was obtained in the F_2 population of Sureño × BTx623, indicating incomplete dominance, probably because of incomplete resistance in the parent Higher smut incidence in the F_1 progeny of Sureño × BTx623 was a further indication of the incomplete dominance of the resistant parent

The diseased F_3 lines were classed as susceptible because it was impossible to separate segregating and homozygous susceptible lines Therefore, a 1 3 ratio for homozygous to segregating classes was assumed, and the chi-square values were calculated on this basis The chi-square and probability values indicated a close fit to a 1 3 ratio for the F_3 families of SC414 × BTx623 and Sureño × BTx623, respectively These results are in good agreement with those of the F_2 families of each respective F_3 family, thus confirming the operation of a single gene No conclusion could be reached on the inheritance mechanism in the F_3 of B35-6 × BTx623 because of the small sample size

Data from the F_2 plants of B35-6 × SC414, B35-6 × Sureño, and Sureño × SC414 suggests that Sureño and B35-6 possess the same gene for resistance to *S sorghi* and was different from the gene found in SC414 Therefore, in breeding sorghum for resistance to *S sorghi*, it is immaterial whether Sureño or B35-6 is used as the resistant parent because both have the same gene The two resistant genes can also be pyramided into one plant It still remains to be determined whether the genes controlling resistance in B35-6 and SC414 occur in dominant or recessive form

This simple mode of inheritance for genes to *S sorghi* suggests that resistance can be easily transferred to susceptible sorghum cultivars having desirable agronomic characteristics

The reaction of F_1, F_2, and F_3 plants in crosses where seed was unavailable, or where the sample size was too small to make a definite conclusion, needs to be determined or repeated with large sample size Because of the diversity of grain sorghum germplasm and occurrence of physiologic races of *S sorghi*, further research is needed to quantify these results

Networking Activities

Workshops

- Attended the Global Conference on Ergot of Sorghum at Sete Lagoas, Brazil June 1-7, 1997
- Participated and attended the All Africa Crop Science Meeting in Pretoria, SA Jan 12-16, 1997

Research Investigator Exchanges

- Egypt Visited ARS facilities in Giza, Egypt Jan 4-7, 1997 Assistance was provided on evaluation of onion and garlic extracts as a biological control agent for common smut of sorghum Immunofluorescent microscopy and preparation of specimens was taught to several scientists in the section
- Ethiopia Evaluated biological control agents, such as animal urine and an extract from a corm of the bosha plant Finalized future collaborative plan of work with Mr Girma Tegegne during the time interval of Jan 7-11, 1997 Mr Tegegne worked in my laboratory from Sept 27-Oct 3, 1997
- Numerous contacts were made with international scientists at the Principal Investigators Conference Sept 20-22, 1996 and the International Conference on Genetic Improvement of Sorghum and Pearl Millet (Sept 22-27, 1996 at Lubbock TX

Research Information Exchange

Assistance Given

- Reprints of pertinent journal articles, antisera, bacterial cultures, and nitrocellulose paper, and immunofluorescent slides were furnished to Institute of Maize, Sorghum and Sugarcane Diseases in Giza, Egypt
- Manuscripts, fuses for a microscope, and exchange of microscope tunnel camera adapters were provided to Mr Tegegne in Ethiopia

Publications and Presentations

Abstracts

Nzioki H S L E Claflin and B A Ramundo 1996 Comparison of covered kernel smut *Sporisorium sorghi* isolates from different geographic regions by isozyme analysis Abstr 503A P S58 Amer Soc Of Phytopath

Nzioki H S L E Claflin and B A Ramundo 1996 Comparison of inoculation techniques for screening grain sorghum to kernel smut *Sporisorium sorghi* Abstr 508A P S59 Amer Soc Of Phytopath

Claflin L E and B A Ramundo 1996 Evaluation of all disease and insect nursery sorghum germplasm for susceptibility to covered kernel smut Abstr 537A P S63 Amer Soc Of Phytopath

Journal Articles

Muriithi L M and L E Claflin 1997 Genetic variation of grain sorghum germplasm for resistance to *Pseudomonas andropogonis* Euphytica (In Press)

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-205

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Summary

The major insect pest constraint to production of sorghum and corn in Honduras is 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 Studies on aspects of the biology, ecology, behavior and population dynamics of the armyworm species in this complex have identified the role of these insects in crop production systems in Honduras Research emphasis of MSU-205 during the 1996 growing season in Honduras considered the role of natural enemies (parasites) of the lepidopterous pests as regulatory agents in order to assess their significance in biological control Less than two percent of the armyworm population on sorghum and corn was parasitized by insects during the early part of the growing season when the crops are most vulnerable to insect damage A nematode, Hexameris sp , parasited 0 to 68% of the armyworms, but the larvae were still able to cause extensive damage to the crops Weed infestation did not influence parasites or parasitization of the lepidopterous defoliators in a significant way This information indicated the limited role that biological control might play in developing intergrated insect pest management strategies for the lepidopterous caterpillars on sorghum and corn in this agricultural ecosystem in southern Honduras and may possibly relate to other areas in Central America with similar insect pest constraints to productions of these grain crops in similar agricultural environments

Objectives, Production and Utilization Constraints

Objectives

- Determine the influence of specific weed management practices on lepidopterous insect pests in the "langosta" complex and natural enemy parasite populations on production farms in southern Honduras- a continuation of 1996 investigations

- Complete extensive survey of subsistence farmers to determine variations in sorghum and corn production practices in southern Honduras, this information is to be used in recommending specific insect pest management systems for the different cropping practices employed in the area

- Initiate studies to determine feeding preferences and performances (developmental rates) of *Metaponpnaumata rogenhoferi* a lepidopterous defoliator in the "langosta" complex, on sorghum, corn, and sicklepod, a preferred weed species prevalent in production fields in southern Honduras

- Publish scientific paper on the "Langosta Complex and Management Strategies" in Ceiba (the scientific and technical journal of Zamorano), and a second popular article to be published by Zamorano for distribution throughout the sorghum and corn production areas in Honduras

- Extension of MSU-205 activities into Nicaragua
- 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, publish scientific information, travel to host countries

Constraints

Ninety percent of the sorghum acreage in southern Honduras is intercropped with corn because of adverse environmental and agronomic conditions In this area, tall, photoperiod sensitive, low yielding sorghum,, called “maicillo criollo” are intercropped with corn If the corn crop is lost to drought, farmers substitute sorghum for corn to feed their animals and family Thus, sorghum is an insurance crop during dry years when the corn crop fails, which occurs in three of every five years More than 40% of the sorghum harvested in southern Honduras is destined for human consumption

The lepidopterous “langosta” pest complex is considered by subsistence farmers to be the principal threat to their sorghum-corn crop during the early period of crop development Biological and ecological studies have been conducted in MSU-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 corn Noncrop plant “source habitats” and crop plant “sink habitats have been identified and the biotic potential of the species in the crop production systems has been determined Crop mortality factors have been partitioned in limited studies in sorghum-corn intercropped systems in southern Honduras, with insects accounting for 65% of the mortality to the crops

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

Alternative insect pest management practices (limiting insecticide use) which are practical for use by the subsistence farmer have been evaluated in MSU-205 Investigations have been further designed to elucidate specific aspects of langosta pest management tactics previously identified as practical for control of the species in this lepidopterous complex that limit crop production The sorghum breeding program with EAP is designed to develop improved maicillo varieties and photoperiod sensitive hybrids MSU-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

Research Approach and Project Output

A-B Research Methods and Research Findings

Honduras

Influence of Weed Management Practices on Lepidopterous Defoliator and Natural Enemy (parasites) Populations and Levels of Parasitization

Noncrop vegetation in and around intercropped sorghum and corn provides a source of food for the langosta Lepidoptera, as well as adult natural enemy parasites Wild plants and flowers provide a source of nectar and pollen The relationship of sorghum, corn and noncrop vegetation with the lepidopterous pests and their natural enemy parasites in intercropped sorghum and corn production systems is under investigation in southern Honduras Weed management in and around intercropped fields affects the populations of plants that support the pests and parasites and ultimately the levels of natural control of the lepidopterous pests

The diversity and density of weed species and lepidopterous pest species as well as age structure and temporal occurrence of these pest organisms in production fields has been investigated Levels of parasitization of the langosta Lepidoptera were recorded in the various weed management system treatments on production farms This information will be used to assess the value of naturally occurring parasites in control of lepidopterous pests on sorghum and corn The influence of preplant and delayed weed control after planting (the latter as recommended by MSU-205) will be assessed against the benefits received from parasite-weed relationships in regard to langosta management in southern Honduras

Preliminary data suggests that insect parasitization of larvae (less than 2%) has little beneficial effects in managing populations of the langosta Lepidoptera on sorghum and corn during the early part of the growing season (Table 1) The large early season infestations of *M rogenhoferi*, black armyworm, and fall armyworm resulted in extensive damage, as much as 100% crop destruction, to the early plantings of intercropped sorghum and corn There was little appreciable reduction in populations due to parasite mortality Weed infestations did not appear to influence parasites and parasitization of these lepidopterous defoliators in a significant way Not until mid- to late season were insect parasites recorded on sorghum and corn in small and insignificant numbers A nematode parasite of the larvae (0 to 68% parasitization) was the most prevalent of the species attacking the armyworms (Table 1) and does not appear to be associated with weed infestations Even at this level of parasitization, the armyworms, predominately fall armyworm, caused extensive damage to the larger crop plants

Survey of Subsistence Farmers to Determine Variations in Sorghum-corn Production Practices

Specific insect pest management systems can be designed and recommended for crop production practices in specific regions According to statistics, 52% of the sorghum produced in Honduras comes from the southern area of the country, and 95% of this total is produced by subsistence farmers on small farms with marginal soils, using local landrace sorghum, and local early-maturity corn cultivars

Table 1 Parasites recorded from the lepidopterous larval complex ("longosta") collected on sorghum and corn in the field in southern Honduras 1997

Insect host	Parasite	Percent parasitization
Spodoptera frugiperda	Nematode	
(fall armyworm)	*Hexameris* sp	0 68
	Insects	
	Ichneumonidae	
	Chelonus insularis (Cresson)	2
	Unidentified (2 spp)	<1
	Tachinidae	
	Archytas sp	<1
	Lespesia (2 spp)	<1
M rogenhoferi	Nematode	
	Hexameris sp	<1
	Insects	
	Ichneumonidae	
	Unidentified	<1
	Tachinidae	
	Lespesia	<1
S latifascia	Nematode	
(black armyworm)	*Hexameris* sp	low
	Insects	
	Tachinidae	
	Archytas	3 5

Biotic and abiotic factors influencing the crop production systems in this area have caused reductions in sorghum yield per hectare, from 0 93 metric tons in the 70's to 0 85 metric tons in the 80's, with an annual decreasing rate of 2 3% Among these factors, which could be manipulated by subsistence farmers, include the lepidopterous defoliators, weed complex, plant diseases, soil insects, soil fertility, soil moisture, seed quality, seed germination, and use of pesticides These factors are closely related to the planting system used by the farmers during the growing season

There are four types of planting systems currently used by subsistence farmers in southern Honduras "aporque" or sorghum planting delayed one month after corn planting, "surco alterno" or corn and sorghum planted at the same time in alternate rows, "golpe alterno" or corn and sorghum planted at the same time in alternate hills, and "casado" or corn and sorghum planted at the same time in the same hill There are important differences among these planting systems with respect to corn/sorghum interspecific competition in the field The ranked order of competition between corn and sorghum in the planting systems is as follows (from least to greatest competition) 1 aporque, 2 surco alterno, 3 golpe alterno and 4 casado Interspecific competition can reduce overall yield up to 60% The planting system used will influence agronomic tactics (corn and sorghum varieties, planting date, fertilization, weeding systems, etc) and pest control tactics (seed treatment, herbicides, insecticides, number of sprays per season, etc) The objectives of conducting a survey of planting systems used by subsistence farmers in southern Honduras were to identify the most popular systems, to quantify the agronomic and entomological implications of use and to correlate the results with previous information obtained from other field investigations in the area

A survey of planting systems was conducted during the months of July and August, 1996 in ten locations in the Department of Valle in southern Honduras (coordinates ca 13° 31'N, 87° 43' W) The survey was composed of 11 questions and lasted an average of 20 minutes per farmer A total number of 114 farmers (5 women and 109 men) were interviewed and answers were tabulated in categories Totals and percentages were calculated

The 114 farmers were located in 10 different locations in the area Eighty six farmers described themselves as "hill farmers", while 28 of them plant their crops on the plains All the farmers produced corn and sorghum using intercropped systems, and together occupied a total area of 155 ha This was an average production area of 1 3 ha per farmer Of the 155 ha of intercropped corn and sorghum production, 105 ha were in the "hills" and 51 ha on the "plains" The average farm in the hills was only 1 2 ha compared to 1 8 ha for a farm on the plains On average, farms located on the plains are 67% larger than farms in the hills

“Casado” was the predominant planting system used (52% of the farmers), “surco alterno ’ was second (28%), aporque was third (17 6%) and golpe alterno was fourth (1 8%) Of 86 farmers that produce their crops in the hills, 56 used casado (65 1%), 27 used surco alterno ’ (31 4%), 2 used “golpe alterno” (2 3%) and one used “aporque” (1 2%) Of 28 farmers that produce their crops on the plains 19 used aporque (67 9%), 5 used surco alterno (17 8%) 4 used “casado” (14 3%), and none used “golpe alterno”

A major portion of the farmers (108 of 114 in this survey) use their own early maturity corn and landrace sorghum varieties and only six farmers are currently using the hybrid corn and enhanced landrace sorghum recommended by the INTSORMIL program These six farmers deposit 4 7 corn seeds per hill and 6 5 sorghum seeds in the same hill The high amount of seed used is intended, in part, to solve problems due to low percent germination, loss of stand during seedling stages by cutworms and defoliators, and uncertainty about the beginning of the rainy season Most farmers plant sorghum and corn as soon as the rainy season begins The month of May is generally considered to be the time to plant these grain crops in southern Honduras Only 3 5% of the farmers will plant in April and 10 5% will plant in June Of those farmers that usually plant during the month of May, 60 2% try to plant during early May, 36 7% during mid-May, and 3 1% in late May

The key insect pests were identified for each region included in the survey - the hills and coastal plains The langosta were identified by most farmers as the principal insect pest constraint to production, although termites, ants and grasshoppers were also identified as pests by many farmers The key insect pests in each of the four intercropped sorghum-corn planting systems in the hills and on the plains were fall armyworm and *Metaponpneumata rogenhoferi*

Insecticides are applied more often to intercropped sorghum-corn plantings in southern Honduras than previously reported Eighty one percent of the farmers interviewed used insecticides, the other 19% cannot afford the cost of these materials Seventy nine and 86% of the farmers in the hills and on the plains, respectively, use insecticides Farmers in the hills will apply 1 to 6 insecticide applications during the crop growing season on the coastal plain farmers use 2 to 5 insecticide applications Seed treatment insecticides and use levels in both hills and coastal plain were identified The extensive use of specific insecticides from one year to the next could result in insecticide resistance to these chemicals

Herbicides, also are used by more farmers than expected Ninety-eight percent of the farmers in the hills use herbicides, whereas only 18% of the farmers on the coastal plain use these chemicals to manage weeds The survey identified the most often used herbicides, as well as insecticides and alternative weed management practices used in both regions of crop production

Metaponpneumata rogenhofera Feeding Preferences and Developmental Rates on Sorghum Corn and Sicklepod a Preferred Broadleaf Weed Species

In many years, *M rogenhoferi* may be the most damaging species in the langosta complex, in other years, it may appear only as a contributor to crop destruction by these lepidopterous defoliators This insect has not been investigated by entomologists, therefore the literature is virtually void of reference to the species The MSU-205 project has studied aspects of the biology, ecology and behavior of *M rogenhoferi* in field and laboratory investigations (previous annual reports) Some host plant feeding preference and host suitability studies, as well as studies on diapause have been completed The biological and ecological relationships of this species, in association with crop plants and noncrop vegetation, have been investigated to elucidate the specific factors responsible for the occurrence of devestating populations of this defoliator pest at various times in Honduras This biological information is useful in understanding the role of crop and noncrop plants, as well as survival potential of this species This type of biological information is necessary for designing successful insect pest management methods for the complex of defoliators that is the principal insect pest constraint to sorghum and corn production in many regions in Central America

In 1997, the rainy season in Honduras was delayed until the early part of June, thus farmers planted their sorghum and corn crops about one month later than usual The small amount of rainfall in late April encouraged some farmers to plant after these early, brief rains These rains stimulated termination of diapause in some *M rogenhoferi* pupae and activity of the black armyworm and fall armyworm in the southern region of the country *M rogenhoferi* constituted the greatest component of the langosta complex during May The early planted crops were completely destroyed by the insects, requiring replanting

Additional field and laboratory studies were initiated in 1997 to determine the relative suitability of sicklepod compared to sorghum and corn, to serve as a host plant for *M rogenhoferi* feeding and development to adult Sicklepod was observed to be the principal host plant for *M rogenhoferi* during April and May in southern Honduras A small number of *M rogenhoferi* larvae collected in the field developed through two generations on sorghum, corn and sicklepod in the laboratory, the same was observed on sicklepod in field cages in the study area Most of the larvae of the second generation that developed to pupae in the laboratory on the three host plant species appeared to be in diapause This seems to confirm our previous observations that this species enters a pupal diapause after one or two generations on suitable host plants in southern Honduras The few insects that emerged after the second generation in the laboratoy laid eggs, indicating that not all M rogenhoferi entered diapause after one or two generations in the laboratory In the field cages, the insects developed through two generations on sicklepod and appeared to remain in a pupal dispause This information suggest that M rogenhoferi may experience an obligatory diapause under field conditions in southern Honduras This is the first entomological information available on this aspect of the dynamics of this species and provides useful insights in regard to annual occurrence of this species in Honduras

Observations on developmental rates of M rogenhoferi in the laboratory at 28°C indicated larvae development to adult on sicklepod to be 26 0 days, on maize 29 5 days and 34 5 days on artificial diet (prepared for fall armyworm) Pupal weights were highest for insects fed artificial diet and lowest for insects fed sicklepod Most pupae (>95%) did not complete development to the adult stage, particularly on sorghum and corn The few females that developed to the adults mated and laid eggs These data corroborate earlier reports (MSU-205) that the grain crops appeared to be sink habitats for this armyworm species That is, the insect had difficulty in developing through the life stages to adults on curtain host plants, thus the population does not build at any appreciable rate on these hosts It is the first generation and possibly part of the second generation that causes most of the damage to sorghum and corn early in the crop growing season

Publication of Langosta Scientific Paper in Journal and Popular Article for Distribution in Agricultural Communities in Honduras

Research results on the lepidopterous defoliator complex on sorghum and corn in southern Honduras has been summarized in manuscripts for publication The paper has been submitted and accepted by the international journal, Ceiba The popular article will present information on seasonal occurrence of the pests, 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, chemical control, recommendations for insect pest management strategies, and benefits to farmers The popular article has been prepared by the PI and co-authors, submitted to EAP (Zamorano) to be published in suitable form with pictures to capture the attention and interest of the farmers This publication is in final stages of production and is focused on, and will promote, the use of crop production practices for management of the lepidopterous defoliators on sorghum

Extension of INTSORMIL MSU-205 Activities into Nicaragua

The PI traveled to Nicaragua in June to discuss the extension of MSU-205 activities in that country in 1998 This is as recommended and also discussed previously in an effort to include research involvement in other areas in Central America than Honduras Dr Lopez and Dr Hruska were very supportive of this effort Visits with personnel in EAP, hillside agriculture group located at Esteli, INTA (Esteli), CNIA (Managua), UNA (Leon) and UNAN (Leon) proved to be very encouraging in regard to active collaboration Personnel at each location expressed interest in collaboration with administration at each location prepared to provide space in facilities, participation in research activities, and training A student (graduate of EAP and Nicaraguan) has been selected and accepted to begin his M S academic program at Mississippi State University in August of this year and to conduct research in Nicaragua between May and August, 1998-99 A second student (Nicarguan) will be brought into MSU-205 to become involved in research in the coastal region of Nicaragua to evaluate the insect pest constraints to sorghum production and insect pest control problems in this region The second student will be accepted to enter the program in May 1998

Consult With and Review IAR Entomological Research Program on Sorghum in Ethiopia (INTSORMIL Purdue University Project)

MSU-205 PI (Pitre) corresponded with the INTSORMIL/ Horn of Africa Coordinator (Dr Gebisa Ejeta, Purdue University) and 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) the economic impact of the insect pests on crop 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 contraints 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 and Corn for Control of Stem and Whorl Feeding Insect Pests

A select group of insecticides were evaluated for control of chinch bugs and fall armyworm on sorghum and corn Insecticides were applied at various rates of application and applied in various amounts of water to plants of various sizes (planted on different dates) The efficacy of materials was recorded on chinch bugs and armyworms of various instars to determine activity of the insecticides against larvae of various ages and sizes This data has not been properly analyzed, but when done, the information will be useful in recommendations for control of the indicated pests on sorghum and corn stems (stalks) and in the whorl

Direction of Graduate Students in INTSORMIL Program Publication of Scientific Papers and Travel to Host Countries

The PI (Pitre) directed the INTSORMIL research activities of three graduate students, prepared papers for publication of INTSORMIL research in scientific journals, and traveled to Honduras and Nicaragua to work with collaborators and graduate students

Networking Activities

Germplasm and Research Information Exchange

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 the students for research expenses while in Honduras

Publications and Presentations

Journal Articles

Castro M T H N Pitre and D H Meckenstock 1996 Effect of intercropping sorghum and maize on Neotropical cornstalk borer Diatraea lineolata (Lepidoptera Pyralidae) in Honduras Ceiba 37 267 271

Lopez J I H N Pitre D H Meckenstock and F Gomez 1996 Evaluation of Honduran landrace sorghums for antibiosis resistance to *Spodoptera frugiperda*(Lepidoptera Noctuidae) Ceiba 37 273 280

Lopez J H N Pitre D H Meckenstock and F Gomez 1996 Evaluation of a sorghum population for resistance to fall armyworm (Lepidoptera Noctuidae) Trop Agric 73 43 48

Portillo H E H N Pitre D H Meckenstock and K L Andrews 1996 Oviposition preference of *Spodoptera latifascia* (Lepidoptera Noctuidae) for sorghum maize and noncrop vegetation Fla Entomol 79 552 562

Portillo H E H N Pitre D H Meckenstock and K L Andrews 1996 Feeding preferences of neonates and late instar larvae of a lepidopterous pest complex (the langosta in Honduras) (Lepidoptera Noctuidae) on sorghum maize and noncrop vegetation Environ Entomol 25 589 598

Role of Polyphenols in Sustainable Production and Utilization of Sorghum and Millet

Project PRF-204B
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Summary

PRF 204 is an interdisciplinary program with collaborative research projects conducted in association with LDC and other INTSORMIL scientist Research projects are implemented to characterize the nature of sorghum's defense chemicals, to elucidate the role of these chemicals in minimizing losses to birds and diseases, and to overcome their role in limiting nutritional quality In collaboration with Dr Ejeta, we develop simple laboratory assays for screening germplasm for concentration of polyphenalic compounds in various sorghum tissue

Activities in the past year have focussed on evaluating the effects of tannins on the diet of weanling steers and on characterization of the compounds responsible for bird resistance in a low tannin bird resistant sorghum line, ARK-3048 The feeding experiment has been underway and results have not been compiled yet We have however, determined that the bird resistance trait in ARK-3048 is due to an unusually high concentration of the cyanogenic gluconide, dhurrin in the milk dough stage The dhurrin concentration in the mature grain of this genotype is immeasurable, making it safe for consumption as mature grain

Objectives, Production and Utilization Constraints

- To determine the nutritional significance in diets for weanling steers of sorghum tannins and of related flavonoids in tannin-free sorghums
- To characterize chemically and nutritionally the newly discovered tannin-like pro-3-deoxyanthocyanidin, and to assess its fungicidal activity and its role in mold resistance
- To elucidate the biochemical mechanism for resistance to birds in sorghum line ARK-3048
- To train collaborators in methods of polyphenol analysis, evaluation of nutritional properties, and bird resistance in sorghum germplasm

Research Approach

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

Our activities on characterization of sorghum polyphenols continue in the same pattern as has been successful for us in the past chemical characterization as completely as possible and nutritional evaluation as appropriate We have analyzed many samples of the tannin-free sorghums that are bird resistant because in the early stages of grain development where the crop is vulnerable to bird damage, they contain the cyanogenic gluioride, dhurrin Some results are emerging from these samples

A major study that has been underway is the study on the effect of tannins in weanling steers and is being done in collaboration with the manager of Purdue's Beef Cattle Research Unit It is being done in individual stalls, with 5 different treatments, 8 cattle per treatment, for at least 120 days Tissue samples are collected regularly and weights and feed consumption are recorded weekly

Research Findings

Tannin Feeding

An extensive study on the role of sorghum tannins and other polyphenols in the diets of feeder cattle has been underway The results of feeding tannins to weanling steers appear promising and is likely to produce a major impact on the beef feeding industry, and possibly the sorghum production industry

Supplemental tannins from querbacho (sorghum tannins could not be obtained in the quantities required) are resulting in weight gains of almost 0 5 pounds per day over controls for the first seven weeks of the trial It appears that adding tannins to diets of ruminants that are growing rapidly and have a high requirement for dietary protein may diminish protein loss by rumen microorganisms It is quite plausible that dehulling high tannin sorghums and adding the hull fraction to protein-rich ruminant diets may be more effective than using whole high tannin sorghum, probably due to increased accessibility of the tannin to supplemental proteins rather than to sorghum grain components Either way, a market could develop for high tannin sorghums easier to produce than low tannin sorghums in several areas

Bird Resistance

Some African sorghums are resistant to bird damage because they contain relatively high levels of tannins, which repel birds by reducing the palatability of the grain The level of tannins in the grain is generally highest at the milk stage, which is otherwise most attractive to birds However, high levels of tannins in the mature grain lower the nutritional quality of the grain for human consumption The cultivation of high tannin sorghum varieties as a method of reducing bird damage, though successful, is done at a high nutritional cost to the consumer Low tannin sorghums are significantly more nutritious than high tannin sorghums Therefore, a shift in production to low tannin varieties would be beneficial if bird resistant types low in tannin could be identified Two bird resistant sorghums which are tannin-free and have excellent nutritional value have been found in our laboratory However further investigation showed that these two sorghum lines were also unique in that they contain the cyanogenic glucoside dhurrin in their grain Cyanogenic glucosides are common in nature and invariably the enzymes, hydroynitrile lyases and B-glucosidases, that catabolize them occur in adjacent tissue Dhurrin, a cyanogenic glucoside, is commonly found in young sorghum seedlings but is rarely found in grain The chemical characteristics of a cyanogenic glucoside fit nicely as a repellant candidate The repellant is extractable and stable in polar solvents In aqueous plant extracts cyanogenic glucosides are hydolyzed by endogenous glucosidases Hydrolysis of these compounds releases cyanide, a known respiratory inhibitor, glucose, and usually a small organic compound When dhurrin containing tissue is damaged, dhurrin becomes accessible to endogenous glucosidases and is enzymatically converted to glucose, cyanide, and hydroxybenzaldehyde

The determination of whether the bird repellant compound is a cyanogenic glucoside and whether the amount present in the sorghum line ARK-3048 could be toxic to livestock is of considerable concern We conducted studies and established the bird resistance of this sorghum line and determined its dhurrin concentration at different stages of grain development

Publications

Refereed Papers

Vogler R K G Ejeta, and L Butler 1996 Inheritance of low production of Striga germination stimulants in sorghum Crop Sci 36 1185 1191

Volger R K G Ejeta, and L G Butler 1996 Integrating biotechnological approaches for the control of striga Afric Crop Sci Journ 3 217 222

Conference Proceedings

Ejeta, G and L G Butler 1996 Biotechnological approaches for understanding mechanisms of resistance to *Striga* P 568 573 In M T Moreno et al (ed) Advances in Parasitic Plant Research Sixth International Parasitic Weed Symposium Cordoba Spain April 16 18 1996

Babiker A G T Ahmed N E G Ejeta L G Butler A Mohammed M T El Mana S M El Tayeb and B E Abdel Rhamman 1996 Chemical Control of *Striga hermonthica* in sorghum P 769 776 In M T Moreno et al (ed) Advances in Parasitic Plant Research Sixth International Parasitic Weed Symposium Cordoba Spain April 16 18 *1996*

Ejeta, G L G Butler D E Hess T Obilana and B V Reddy 1997 Breeding for *Striga* resistance in sorghum In Proc International Conference on Genetic Improvement of Sorghum and Pearl Millet Lubbock TX September 23 27 1996 University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 504 516

Butler L G G Ejeta A G T Babiker and D E Hess 1997 *Striga*-host relationships and their role in defining resistance In Proc International Conference on Genetic Improvement of Sorghum and Pearl Millet, Lubbock TX September 23 27 1996 University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 490 503

Dr Larry Butler passed away before the end of this project year The Management Entity is grateful to Dr Gebisa Ejeta for preparing this report and finalizing Dr Butler s contributions to the INTSORMIL program

Striga Biotechnology Development and Technology Transfer

Project PRF-213
Gebisa Ejeta
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Dr Dale Hess, *Striga* Specialist, ICRISAT, Mali
Dr Joel Ransom, *Striga* Agronomist, CIMMYT, Kenya
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Dr James Riopel, University of Virginia, USA
Dr H Geiger, University of Hohenheim, Germany

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 18, we report on a study of inheritance of low germination stimulant in a strong sorghum line, SRN39 Low germination stimulant in this line is inherited as a single, nuclear, recessive gene which is largely additive We also report on a development of an in vitro assay for post-infection *Striga* resistance This assay, which is currently under refinement, allows identification of genetic variants that discourage infection of *Striga* as a hypersensitive reaction where penetration is followed by necrosis, or slowed development of parasite after penetration, as well as incompatibility resulting in stunted growth or eventual death of the parasite Also reported are the results of testing of our recently released *Striga* resistant varieties in northern Ethiopia The Ethiopian Sorghum Improvement Program has selected two of our varieties for large-scale seed multiplication and dissemination in the next couple of years

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 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, and 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 objective 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, and to achieve a more effective control than is presently available
- To assess (both *ex ante* and *ex post*) 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 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 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 focussing 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

Inheritance of low production of *Striga* Germination Stimulants in Sorghum

Host plant resistance to *Striga* is a manifestation of one or more potential mechanisms *Striga* seeds require after-ripening, conditioning, and chemical stimulation before they can successfully germinate and parasitize a host Stimulation of the seeds to germinate initiates the potential host-parasite relationship One of the better understood mechanisms of resistance against *Striga* by sorghum is low production of compounds by the host roots that *Striga* seeds require as stimulants for germination Minute quantities of compounds, as low as 10 ^{16}M, exuded by host roots stimulate the conditioned *Striga* seeds to germinate Sorghum cultivars differ in the amounts of stimulant compounds that their roots produce This variation is responsible in part for the resistance against *Striga* found in some sorghum cultivars A host plant that produces low amounts of stimulants will cause fewer *Striga* seeds to germinate, and thus will be subject to less infestation The production of germination stimulants is relatively simple to assay We developed a simple and rapid agar gel assay in which we showed a close correspondence between a laboratory measure of stimulant production and field resistance in several sorghum cultivars This assay screens individual sorghum seedlings for the capacity of their root exudates to stimulate the germination of conditioned *Striga* seeds embedded in water agar We measure capacity to stimulate germination as the maximum distance from the sorghum root at which *Striga* seeds germinate Germination distance in the agar medium, therefore, is a function of stimulant production and the interactions between the host root and conditioned *Striga* seeds We also found out that there is a strong positive correlation between maximum germination distance and percentage of germinated *Striga* seeds in the agar medium

Among a collection of sorghum germplasm assembled in our program, we have established, in field tests, that sorghum cultivar, SRN39, has the strongest expression of resistance Resistance is measured as the capacity of a host plant to support fewer emerged *Striga* plants and yields more grain than susceptible crop variety when grown under *Striga* infestation The objective of our study was, therefore, to determine the mode of inheritance of stimulant production for *Striga* germination in SRN39

Crosses were made between the *Striga* resistant, low stimulant producer line, SRN39, and three high stimulant producer sorghum lines, Shanqui Red, IS4225, and P954063 F_1 progenies were selfed and also crossed back to both parents producing F_2 and backcross populations *Striga* germination tests were conducted on parental lines, F_1, F_2 and backcross generations of these crosses For each of the three crosses, significant differences between the mean maximum germination distances of the two parental cultivars were observed No significant differences existed between mean germination distances of the F_1 and reciprocal F_1 progenies, indicating absence of maternal effects in these crosses The germination distance for the three F_1 populations were greater than their respective midparent mean values suggesting partial dominance for high stimulant production Chi-square values for Mendellian F_2 segregation ratios indicated that low stimulant production in SRN39 is inherited as a single, nuclear, recessive gene which is largely additive in action These results suggest that selection for low stimulant production would be successful in generating *Striga* resistance sorghum cultivars when appropriate genetic variability is generated Work in our program has also demonstrated this concept empirically where elite low stimulant producing *Striga* resistant germplasm have been produced using our laboratory procedure

Development of an In Vitro Assay for Post-infection *Striga* Resistance

Conventional approach to selection for resistance to *Striga* has involved evaluation of sorghum germplasm in *Striga* infested plots This approach has not been widely successful because of the complexity of the biology of the host-parasite relationship and its interaction with other environmental factors *Striga* resistance in sorghum results from one or a combination of several recognized mechanisms that influence the development of parasitism An understanding of these mechanisms and the gene action associated with specific host plant reaction to *Striga* infestation are essential prerequistes for efficient exploitation of host plant resistance as a *Striga* control measure We have stated, in the past, that the lack of effective germplasm screening techniques, based on specific mechanisms of resistance, as well as the overall paucity of sorghum germplasm with strong level of *Striga* resistance, is a major bottleneck to breeding for *Striga* resistance Understanding specific mechanisms of resistance based on better appreciation of the host parasite biology can provide impetus for development of efficient screening techniques that can be used for characterizing crop germplasm for successful exploitation through conventional and/or new breeding strategies

The agar gel assay, developed in our laboratory, has been effective in screening crop germplasm with *Striga* resistance, due to low production of compounds that trigger *Striga* germination The assay was also effectively utilized in transferring gene(s) for low stimulant production into elite, broadly adapted sorghum cultivars At the moment, a reliable assay is unavailable for screening host germplasm for mechanisms of resistance beyond germination A project, currently underway in our laboratory, aims at developing simple laboratory assays for screening germplasm during early development after germination Our new assay, which is currently under refinement, allows quantification of potential problems in the infection process including a hypersentitive reaction where penetration is followed by necrosis, or slowed development of parasite after penetration, as well as incompatibility resulting in stunted growth which may cause death of the parasite following penetration We hope to utilize this assay in the screening of the large assembly of sorghum breeding germplasm in our *Striga* resistance breeding program

International Testing of *Striga* Resistant Sorghum Selections

In December 1994, we released eight *Striga* resistant sorghum cultivars and distributed them to several African countries through a collaborative partnership with World Vision International Field trials were conducted in 11 countries Senegal, Chad, Ghana, Mali, Eritrea, Mozambique, Sudan, Somalia, Rwanda, Ethiopia, and Niger World Vision recently reported on their findings in nine of the above countries According to the report, different varieties were found to be better adapted in each of these countries In general, these varieties were broadly adapted, earlier in maturity, had good response to inputs, and possessed better food quality characteristics

Seed distribution of the Purdue/INTSORMIL *Striga* resistant varieties in Ethiopia was curtailed because of bureaucratic irregularities Seed shipment intended for Eritrea was also held in the Ethiopian capital en route to Asmara, Eritrea for the same reason We have since shipped experimental quantities of seed of the eight varieties to both Ethiopia and Eritrea and testing has been underway in research plots and farmers fields in both countries We recently obtained results of testing of our varieties in two locations in Northern Ethiopia during the 1996 crop season (Table 1) The results showed that these varieties possess early maturity, tolerance to moisture stress, and *Striga* resistance - traits that make them suitable to the drier sorghum growing condition of the region On the basis of the data in Table 1 and results of observations from field plantings at other sites (data not shown), it has been recommended that seed of two of these varieties be multiplied for large scale on farm demonstration and dissemination of these varieties in Tigray province in northern Ethiopia

Networking Activities

We have provided seed of our *Striga* resistant sorghum lines to Drs Chester Foy and Brhane Gebrekidan, IPM-CRSP, for a study on integrated *Striga* management in Uganda These cultivars will be screened for tolerance to a broad range of herbicides, which would act either through the soil to prevent *Striga* attachment to the host or absorbed and innocuously translocated to the roots of the host and prevent parasitism on the crop In cooperation with weed scientists and plant breeders in the Horn of Africa region, a pilot project has also been planned on an integrated control of *Striga*, using resistant sorghum lines in combination with added nitrogen fertilization and tied ridging to conserve moisture and enhance control of *Striga* Implementation of this plan is awaiting availability of funds from INTSORMIL It is a project that would have immediate pay-off and impact and needs to be implemented as soon as resources are made available

Workshop and Program Reviews

Served as a member of the organizing committee of both INTSORMIL Principal Investigators Conference and the International Conference on the Genetic Improvement of Sorghum and Pearl Millet held in Lubbock, TX, September 1996 Presented joint papers with several colleagues at these meetings

Presented a joint paper (with L G Butler) at Sixth International Parasitic Weed Symposium, Cordoba, Spain, April 1996

Served as Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research, June 1997

Participated in African Dissertation Internship Awards Selection, Rockefeller Foundation, November 1996, and April 1997

Attended American Society of Agronomy National Meetings, Indianapolis, IN, November 1996

Research Investigator Exchange

Interactions with public, private, and international sorghum research scientists is an important function of PRF-213 The following individuals visited our program or worked in our laboratory during the project year

Dr Paula Bramel-Cox, Director, Genetic Resources Unit, International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), February 1996, and June 1997

Dr Jill Lenne, Principal Plant Pathologist, ICRISAT, July 1996

Table 1 Performance of Purdue/INTSORMIL *Striga* resistant sorghum cultivars at Sheraro, Trigray, Ethiopia

Cultivars	Days to anthesis (d)	Plant height (cm)	Grain yield (kg ha^{-1})	*Striga* count (No/7 5m^2)
P 9401	68 50	116 8	2312 01	15 5
P 9402	79 50	136 4	2174 84	37 0
P 9403	73 75	135 6	1938 84	41 0
P 9404	69 00	141 6	2360 51	13 5
P 9405	73 75	120 3	2145 50	39 2
P 9407	52 00	135 2	1106 92	108 0
SRN 39	71 00	131 7	1845 00	34 0
Local Check	86 75	253 8	1773 84	318 0

Dr Aberra Debelo, Sorghum Breeder and Program Leader, Ethiopia Sorghum Improvement Project, September 1996

Dr Abdelgabar Babiker, Sudan National Coordinator for Sorghum and Millets, September 1996

Dr Abdel Moneim Bashir El Ahmadi, Director National Seed Industry, Sudan, September 1996

Publications

Refereed Papers

Vogler R K G Ejeta and L Butler 1996 Inheritance of low production of *Striga* germination stimulants in sorghum Crop Sci 36 1185 1191

Vogler R K G Ejeta and L G Butler 1996 Integrating biotechnological approaches for the control of *Striga* Afric Crop Sci Journ 3 217 222

Conference Proceedings

Ejeta G and L G Butler 1996 Biotechnological approaches for understanding mechanisms of resistance to *Striga* P 568 573 In M T Moreno et al (ed) Advances in Parasitic Plant Research Sixth International Parasitic Weed Symposium Cordoba Spain April 16 18 1996

Babiker A G T N E Ahmed G Ejeta, L G Butler A Mohammed M T El Mana S M El Tayeb and B E Abdel Rhamman 1996 Chemical Control of *Striga* hermonthica in sorghum P 769 776 In M T Moreno et al (ed) Advances in Parasitic Plant Research Sixth International Parasitic Weed Symposium Cordoba Spain April 16 18 1996

Ejeta, G L G Butler D E Hess Tunde Obilana and B V Reddy 1997 Breeding for *Striga* resistance in sorghum In Proc of the International Conference on Genetic Improvement of Sorghum and Pearl Millet, 23 27 September 1996 Lubbock Texas USA University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 Pp 504 516

Butler L G G Ejeta A G T Babiker and D E Hess 1997 *Striga* host relationships and their role in defining resistance In Proc of the International Conference on Genetic Improvement of Sorghum and Pearl Millet 23 27 September 1996 Lubbock Texas USA University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 Pp 490 503

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 In concert with INRAN, Mr Kollo is conducting his research on factors affecting sorghum and millet stands and stalk rot in Niger during the current growing season Collaborative activities on studies for management of ergot were formulized in Brazil and are being prepared for Honduras on evaluation of ergot reaction of sorghum lines and hybrids Domestic research on head smut has permitted the development of non damaging, methods of evaluation of host reaction in the laboratory that represents the line/hybrid reaction under field conditions Mapping of host resistance genes to head smut has substantially enhanced our ability to eventually use marker assisted selection in the development of more durable resistance to this disease Head smut is important in Niger and Kenya At the same time, progress has been made in developing methods of separating populations of sorghum head smut from those attacking maize The relations among these fungi attacking these hosts are similar to many other pathogen of both hosts Arrangements for collaborative research on grain mold with ICRISAT have been prepared

Research Objectives

Honduras

- Evaluation of sorghum resistance and vulnerability to ergot

India/ICRISAT

- Continue collaboration with ICRISAT on growing, distributing, and evaluating the Sorghum Anthracnose Virulence Nursery
- Continue collaboration on ergot
- Initiate 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 performed by the Niger Sorghum Improvement Program, along with evaluation for resistance to head smut, acremonium wilt, and anthracnose

- Summarize data on the survival of spores from long smut

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

- 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 biotechnical methods

- Improve disease screening methods

- Study biology of disease epidemiology of sorghum pathogens as needed

- Organize, maintain, and distribute the international sorghum disease and pathogen identification nurseries in collaboration with ICRISAT, and with TAM-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 collaboration on the incorporation of the resistance(s) into useful cultivars Most of this work is done cooperatively with plant breeders, biotechnologists, geneticists, and entomologists in the Texas programs, but also occasionally with breeders in other states, nations (NARS), or with an International Crop Research Center, specifically ICRISAT This includes the application of such technologies to manage ergot

Collaborative Research in Niger

Unfortunately, Mr Kollo is in Niger, conducting the collaborative work and he will not be able to summarize his progress until the next annual report His research is continuing in three areas 1) Field evaluation of the importance of nematodes on yield and other diseases of sorghum such as acremonium wilt, 2) The influence of various agronomic practices on sorghum seedling survival and stalk rot of sorghum and 3) Another study similar to study #2 at a different location The practice includes rates of fertilization, dates of planting, and plant density

Domestic Research

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

Elite sorghums are also distributed and evaluated for multiple resistances in international nurseries, which also provide a means of distributing elite germplasm from different breeding programs in INTSORMIL The most widely grown is the International Disease and Insect Nursery (IDIN), a 30-entry test, followed by the All Disease and Insect Nursery (ADIN), a 70-entry test, which is composed in part of unreleased experimental materials that are evaluated in many different disease environments Both of these collections represent one of the best means of comparing germplasm from region to region Additionally, we have collected disease information on converted sorghums and, with the assistance of Dr Rosenow (TAM-222), maintain sets of anthracnose, sorghum downy mildew, and head smut resistant converted lines These specific nurseries represent valuable sources of disease resistance traits for breeding programs

Recombinant inbred populations are being developed and maintained for the mapping of selected host resistance genes to anthracnose, head smut, leaf blight, grain mold, and downy mildew Drs Jeff Dahlberg and Clint Magill have assisted in the development of these populations We are continuing to develop near-isogenic lines of Tx430 and TAM428, each possessing downy mildew resistance from four different sources Two B-line populations of the cross (BTx623 × QL3 (India)) have been developed and are considered for release Both have resistances to the causal organisms for downy mildew and head smut Both populations are immune to maize dwarf mosaic viruses 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

We grew 77 exotic sorghum lines in quarantine grow outs in 1996-97 These were from Sudan (39), India (37) and Ethiopia (1)

Sorghum Head Smut

For decades, methods of inoculating sorghum using dry spores have been challenging, or in other words, not reliable or effective However, Jairo Osorio developed a procedure using a technique that combined preparing seed and spores to permit simultaneous germination Additionally, he placed the inoculum at sites where the host was known to accept the spores With this procedure, he obtained infection levels of about 80% for susceptible lines This level of infection is equivalent to that of hypodermic inoculation methods but evaluates both meristematic and non meristematic resistance to head smut The hypodermic method bypasses non meristematic resistance Simply, the method calls for imbibing seed for 18 hr and planting the seed in soil at 40% moisture content (w/w) and covered with a 1 50 (v/v) mixture of teliospores and autoclaved soil

A major need in managing head smut resistance has been the development of durable resistance The advent of RAPDs (randomly amplified polymorphic DNA and AFLPs (amplified fragment length polymorphisms) has made the process of combining genes for resistance to head smut possible Again, Jairo Osorio demonstrated there are genetic differences between meristematic and non meristematic resistance The meristematic type of resistance was studied in segregating populations from crosses between parental lines CS3541 × RTx7078 and BTx635 × B1 F_3 families from both crosses were inoculated with sporidia of a Corpus Christi isolate of *S reilianum* The observed phenotypic ratios analyzed with the χ^2 statistic were found to fit the predictions for monogenic control of resistance, with susceptibility being dominant Bulked segregant analysis was used to target the meristematic resistance locus (*hsr*) with RAPD and AFLP markers Two RAPD markers were found linked to the resistance locus in the parental lines CS3541 and BTx635 Three additional markers (AFLPs) were identified in the chromosomal interval defined by the *hsr* locus and marker OPH-04 Two of these AFLPs flank the head smut resistance locus at 2 6 and 2 9 cM Molecular markers for head smut resistance mechanisms identified may be used in locating the disease resistance loci in the sorghum genome Additionally, tightly linked AFLPs can be converted to diagnostic co-dominant markers valuable in pyramiding resistance to head smut in sorghum

Genetic Diversity of Sporisorium reilianum the Head Smut Pathogen of Sorghum and Maize

Genetic diversity in the head smut pathogen *Sporisorium reilianum* was assessed by graduate student, Heriberto Torres-Montalvo, using anonymous RFLPs loci in the nuclear DNA of isolates sampled from two hosts in several regions of the world The objective of this study is to develop sensitive, selectively neutral genetic markers that could differentiate among isolates from each host, and use them for future studies of the population biology and epidemiology of *S reilianum* At this stage of the investigation, 10 sorghum head smut (SHS) isolates originating from USA Mexico, China, Mali and Uganda as well as 10 maize head smut (CHS) isolates from U S and Mexico were employed Two genomic libraries containing random *S reilianum* DNA fragments were constructed using one SHS isolate collected from Corpus Christ TX Two-hundred and ninety clones obtained from the libraries were used as potential probes for RFLP analysis

The six probe-enzyme combinations representing the most informative RFLP loci within each host, were used to construct multilocus haplotypes for each individual Each unique fragment or set of fragments at an RFLP locus was treated as an allele and assigned a unique number The alleles at different RFLP loci were combined in the same order for each isolate The resulting haplotype was a six-digit number for each isolate that summarized which allele was present at each RFLP locus for each isolate

A high level of variation was detected when SHS isolates were compared with CHS isolates Fifty-five percent of the probe-enzyme combinations were polymorphic Most of the differences given by the polymorphic probe-enzyme combinations between SHS and CHS hybridized to single or low copy sequences, where all the isolates within each host gave the same pattern

A lower genetic diversity was found within each host In the case of SHS, 18% of the probe-enzyme combinations tested were polymorphic among the 10 isolates For CHS, 11% showed RFLPs, most of them had only one polymorphism among the 10 isolates evaluated The high genetic diversity between SHS and CHS and the limited genetic diversity found within each host, suggests that these smuts evolved independently from a source population, and strong selection for strict host specialization has maintained their distinct lineages

Six of the probe-enzyme combinations which showed the greatest resolution (Table 1 for SHS and Table 2 for CHS) were used to construct multilocus haplotypes for each individual Each one of the selected probes displayed only two or three alleles within the isolates of each host screened Among the 10 SHS isolates, 6 different multilocus haplotypes were present, among the 10 CHS isolates, only 4 The probes selected in this study hybridized to one or few DNA

Table 1 Multilocus haplotypes of *Sporisorium reilianum* isolates from sorghum Each number represents an allele present at a nuclear RFLP locus defined by a particular probe-enzyme combination

	RFLP locus					
Isolate	pSR113 *PstI*	pSR126 *PstI*	pSR 130 *HindIII*	pSR210 *HindIII*	pSR229 *XhoI*	pSR257 *XhoI*
SfMx89	1	1	1	2	1	1
RBMx3	1	1	1	2	1	1
CoCr 3 13	3	2	1	2	1	1
Ugan 2 93	1	1	1	1	1	1
Tayl 4 18	1	1	1	1	1	1
Mali 3 91	1	1	1	1	2	2
China 101	1	1	2	2	1	1
Dane 3 3	1	1	1	2	1	1
Vict 101-4	2	1	1	1	1	1
MtMx 50	1	1	1	1	1	1

Table 2 Multilocus haplotypes of *Sporisorium reilianum* isolates from maize Each number represents an allele present at a nuclear RFLP locus defined by a particular probe-enzyme combination

	RFLP locus					
Isolate	pSR143 *HindIII*	pSR207 *HindIII*	pSR225 *HindIII*	pSR229 *HindIII*	pSR231 *XhoII*	pSR257 *XhoI*
TxMx 9 9	1	1	1	1	1	1
TxMx 8 14	1	1	1	1	1	1
QrMx 1 11	3	2	2	2	2	
QrMx 4 15	1	1	1	1	1	1
ZpMx 2 7	1	1	1	1	1	1
Lubk 6 5	1	1	1	1	1	1
Lubk 3 5	2	1	1	1	1	1
Lubk 89 1	1	1	1	1	1	1
BrBo 90 1		1	1	3	3	2
CoCr 88 1	1	1	1	1	1	1

= missing data

fragments in suitable size ranges, the polymorphisms are easily differentiated (i e , appropriate size differences), and displayed two or three alleles within the isolates of each host

The selected probes are being used currently to evaluate seven SHS and four CHS populations collected in different locations of Mexico and Texas

Sorghum Downy Mildew

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

Plant breeding graduate student, Curtis Wiltse evaluated benzothiadiazole (BTH) BTH is a synthetic chemical that induces systemic acquired resistance (SAR) in plants SAR is characterized by long lasting, systemic resistance against a broad spectrum of viral, bacterial and fungal pathogens The use of BTH as a novel disease management strategy in sorghum may have practical implications where adequate host plant resistance and chemical or cultural controls do not exist We are evaluating the efficacy of BTH as a seed and foliar treatment against downy mildew, anthracnose, and grain mold To date, our data indicates that BTH is effective in reducing disease incidence in sorghum seedlings that were inoculated with conidia of *Peronsclerospora sorghi*, the causal agent of sorghum downy mildew Experiments with anthracnose and grain mold are under testing

Sorghum Anthracnose/Sorghum Leaf Blight

Dr K Boora completed his work on mapping of anthracnose and leaf blight resistance in January 1996 and he will return to TAMU on a Rockefeller Foundation scholarship to continue preparing his work for publication in 1997-98

Collaborative Research

Honduras and Brazil Ergot

In 1995 sorghum ergot casued 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 In anticipation that the disease will continue spreading in Latin America and could threaten the seed industry in West Texas I proposed and assisted in developing a global conference on ergot in Brazil for June 1997 This Brazilian Conference was held and supported in part by the grants prepared through the American Seed Trade Association, the National Grain Sorghum Producers Board with additional underwriting from the U S seed producing companies INTSORMIL Principal Investigators in attendance included Drs L Claflin, G Odvody, R Frederiksen, and Director J Yohe Dr A Bruce Maunder Chair of the External Review Panel, also participated in the conference Essentially, all of the ergot authorities from Europe, Africa, Australia and Latin America participated in the conference Recommendations from the conference, as well as a proceedings, are being developed Dr L Claflin served on the editorial board and Dr G Odvody was elected as chair of the ongoing sorghum ergot oversight committee

A follow-up conference on ergot for members of the U S sorghum seed producers and researchers, extension specialists, as well as other news media, was held on June 11 at Amarillo, Texas Over 200 persons participated in the day long conference Proceedings from this program are being prepared

A special grant from the USDA was presented to Texas A&M University Drs Odvody and Frederiksen approved hiring Rudolfo Velasquez-Valle for a year to study chemical control of ergot Other collaborate work on minor differences in reaction to ergot are being developed

Networking Activities

Conferences attended or organized

* R Frederiksen made several trips regarding ergot These included presentations to the American Seed Trade Association, Scottsdale, AZ in June 1996 He participated in the special session on Ergot at the International Conference on Genetic Improvement of Sorghum and Pearl Millet at Lubbock, TX in September 1996, Seed Producers in Dallas, TX in January 1997, as well as a trip to Washington, D C in February 1997 to discuss ergot with members of Congress R Frederiksen traveled to Sete Lagoas, Brazil to participate in a global conference on ergot of sorghum in June 1997
* R Frederiksen represented INTSORMIL at the IPM Networking Workshop in Ethiopia in October 1996
* R Frederiksen served as a member of the Editorial Advisory Board of the African Crop Science Journal

Other Cooperating Scientists

* John Millet, Dept of Biochemistry, Texas A&M University, College Station, TX 77843
* Jesus Narro, Campo Agricola Experimental Bajio A P 113, Celaya Guanajuato Mexico
* William Rooney, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
* Ralph Waniska, Dept of Soil and Crop Sciences, Texas A&M University College Station, TX 77843

Publications And Presentations

Abstracts

Kumari S R C W Magill and R A Frederiksen Identification of molecular markers for grain mold resistance and mapping of fungal inhibiting protein genes in sorghum [*Sorghum bicolor* (L) Moench]

Journal Articles

Cui Y J M Magill R A Frederiksen and C W Magill 1996 Responses of chalcone synthase and phenylalanine ammonia lyase to fungal pathogens in sorghum Physiological and Molecular Plant Pathology 49 187 199

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 Accepted British Mycological Society

Oh B J R A Frederiksen and C W Magill 1996 Identification of RFLP markers linked to a gene for downy mildew resistance (Sdm) in sorghum Can J of Bot 74 315 317

Miscellaneous Publications

Frederiksen R A 1996 Plant Disease Management principles and strategies Workshop Latino Americano Sobre Manejo de Doencas de Milho CNPMS/EMPRAPA Sete Lagoas Brazil May 1996

Frederiksen R A 1996 IMP networking in INTSORMIL Workshop on IPM Networking in Sub Saharan Africa Institue of Agricultural Research and the IPM CRSP Addis Ababa and Nazreth Ethiopia, Oct 1996

Thakur R P R A Frederiksen D S Murty B V S Reddy R Bandyopadhyay L M Giorda, G N Odvody and L E Claflin 1996 Breeding for disease resistance in sorghum Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet Lubbock TX Sept 23 27 1996 University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 303 315

C W Magill K Boora, R Sunitha Kumari Jairo Osorio B J Oh B Gowda Yunxing Cui and Richard Frederiksen 1996 Tagging sorghum genes for disease resistance expectations and reality Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet Lubbock TX Sept 23 27 1996 University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 316 325

Dissertations

Osorio Jairo 1996 Infection of sorghum seedlings by Sporisorium reilianum (Kuhn) Clinton (Langdon and Fullerton) and molecular markers for head smut resistance mechanisms Ph D diss

Insect Pest Management Strategies for Sustainable Sorghum Production

TAM-225
George L Teetes
Texas A&M University

Principal Investigator

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

Collaborating Scientists

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

Summary

A Malian graduate student completed her Ph D degree program with project TAM-225 and returned to Mali Greenbug- and sorghum midge-resistant sorghum lines and hybrids were evaluated for resistance in collaboration with Dr Gary Peterson (TAM-223) Also, sorghums were evaluated for resistance to yellow sugarcane aphid Insect-resistant sorghum genotypes were advanced in crosses with elite germplasm Three female (male sterile) sorghum midge-resistant parental lines were released to commercial seed companies Agronomically viable greenbug biotype I parental lines were selected for release Efficacy experiments indentified insecticides effective against sorghum midge and stink bugs Resistance to sorghum midge was determined to be caused by early (during day) flowering spikelets with glumes that tightly close before ovipositing sorghum midges are in the field Genetic markers co-segregating for greenbug resistance in sorghum were detected on four separate linkage groups Two genetic markers are linked to greenbug biotype C resistance, three to biotype E, two to biotype I, and one to biotype K resistance Efforts to assess the genetic diversity among populations of greenbug were initiated as companion research to the plant biotechnology research DNA extraction protocols were modified to produce suitable restriction enzyme digestion of greenbug DNA Multiple Southern blots were completed and autoradiograms produced Thirty to 60 probes are being used to determine probe-enzyme combinations that show RFLPs suitable for screening natural populations of greenbug Failure of a corn-sorghum rotation scheme to reduce abundance of Mexican corn rootworm in corn grown after sorghum is because the corn rootworm adults oviposit in sorghum fields

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 Reporting period objectives were (1) to 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) to determine the role of insects and pathogens in kernel deterioration by applying different combinations of insecticides and fungicides, and (3) to assess the importance of panicle-feeding bugs and sorghum midge in farmers' sorghum 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 (1) to conduct field and greenhouse experiments to evaluate sorghums resistant to greenbug, sorghum midge and yellow sugar cane aphid and (2) supervise graduate student research Graduate students supervised are a 1) Malian Ph D student assessing causes of sorghum resistance to sorghum midge, 2) U S Ph D student using RFLP technology to assess genetics of greenbug resistance in sorghum, 3) U S Ph D student using RFLP/RAPD technology to assess genetic variability of greenbug and its biotypes, 4) U S Ph D student assessing the role of sorghum in the population dynamics of Mexican corn rootworm, 5) M S student from Niger researching field biology and laboratory life table assessment of millet head miner in Niger (committee co-chair) and 6) 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

Panicle-feeding bugs are potential constraints to deploying improved sorghum varieties, especially non-photoperiod sensitive, compact-panicle sorghums that yield more than currently grown, local varieties The interrelationship of damage by bugs, infection by pathogens, and reduction in grain yield and quality requires an interdisciplinary, team approach to resolve these problems Damage by bugs is exacerbated by pathogen infection that significantly increases in damaged kernels Grain damage by bugs and infection by pathogens dramatically reduce grain yield and quality and render the grain unusable for human consumption

U S

The ready availability of insecticides in the U S lessens the yield-reducing impact of insect pests, consequently insect pests in the U S constrain sorghum production in a different way than in developing countries However, insecticides result in significantly increased production costs, occurrence of secondary insect pests, insect pest resurgence, ecological disruption, and environmental contamination Sorghums resistant to aphids, sorghum midge, and panicle-infesting bugs and caterpillars would enable sorghum insect pests to be managed in a more ecologically sound way and provide a more economically and environmentally sustainable sorghum production system Insect-resistant plants provide an important foundational component to an 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 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

Research Methods

Two primary methods are used to achieve project output — collaboration and graduate student education Project outputs are divided into these research approaches

Research Findings

Collaborative Sorghum Panicle-feeding Bug Research in Mali The Principal Investigator for project TAM-225 was unable to travel to Mali during this reporting period because of other pressing obligations However, during September 1996, Dr Y O Doumbia traveled to the U S TAM-225 PI was instrumental in Dr Doumbia receiving approval to travel to the U S , and to participate in the "International Conference on the Genetic Improvement of Sorghum and Pearl Millet' in Lubbock, TX Dr Doumbia's visit to the U S provided opportunity to review past research results and plan for future collaborative research The opportunity to plan for future collaborative research was particularly important because Niamoye Yaro Diarisso was completing her Ph D degree program at Texas A&M University, and will be in Mali to participate in sorghum insect collaborative research

Also, considerable time was spent with Dr Doumbia and other IER/Malian researchers discussing the sorghum research program in Mali Two important issues were the main topics of discussion — advancing technology to Malian farmers and on-farm research relating to new technology In light of the importance of technology transfer and on-farm research TAM-225 PI prepared and submitted in July 1996 a USDA Scientific Cooperation Program proposal entitled 'Determination of Biological Characteristics of Insects Infesting Sorghum Panicles for Integrated Pest Management and Preventing Introduction from Mali into the U S ' The objectives of the proposal were to 1) assess the severity of damage by insect pests infesting panicles of local and improved sorghum cultivars in farmers' fields, 2) determine alternate and off-season host plants of insect pests infesting sorghum panicles, 3) determine biological characteristics such as overwintering ability, duration, and survival as a means to assess likelihood of introduction, and 4) identify cultural management methods including planting dates, variety phenological characters, and genetic resistance that result in suppression of the effects of sorghum panicle-infesting insect pests Benefits to Malian research and agriculture were to 1) strengthen the collaborative research effort between IER scientists in Mali and Texas Agricultural Experiment Station scientists, 2) increase the research effort on local farm agroecosystems to achieve farmer input into insect-related production constraints and to speed adoption by sorghum farmers of new technologies developed through the proposed research, 3) provide research results on the biology and management of insect pests infesting panicles to enhance an IPM approach for sorghum which is an IER research mandate, and 4) initiate a collaborative research project that provides a means to mentor the professional career of a graduate student from Mali completing her Ph D degree in entomology at Texas A&M University The proposed research encourages the application of sound science to an agricultural problem, and seeks to directly involve farmers in the research process IER benefits as an institution responsible for research to reduce production and economic constraints in Mali, and farmers benefit from the developed technology The funding status of the proposal is unknown

Technology Development and Graduate Student Research

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 C Peterson, Sorghum Breeder at the Texas A&M University Agricultural Research and Extension Center at Lubbock

Technology development Resistance to yellow sugarcane aphid of seedlings of 126 sorghums developed by Dr Peterson and 218 sorghums from DeKalb was evaluated in the greenhouse No significant resistance was detected among these sorghums Evaluated were 664 sorghums for resistance to biotype I greenbug, several of these sorghums were resistant to biotype I Thirty sorghums from Crosbyton Seed Company were evaluated for resistance to biotype E greenbug

Seven insecticidal compounds at different rates were evaluated for control of sorghum midge in the field Endosulfan controlled sorghum midge as well as pyrethroid and organophosphorous insecticides Lesser yields resulted from applications of "soft" insecticides, including Fipronil, Provado, and Spinosad Five insecticides were evaluated for control of rice stink bug in sorghum Suppression of insects was greatest in plots treated with pyrethroids

In collaboration with TAM-223 standard, annual evaluations of sorghum midge-resistant sorghum lines and hybrids were conducted during 1996 at Corpus Christi, College Station, and Lubbock, TX As in past years, sorghum midge-resistant genotypes sustained significantly less damage than susceptible genotypes Amount of sorghum midge damage and yield of resistant and susceptible sorghum genotypes were similar to previous years' results Also during 1996 multiple evaluations of sorghum midge-resistant hybrids were conducted by seed company and Extension Service personnel Differences in yield of sorghum midge-resistant hybrids compared to susceptible hybrids depended on planting date and geographical location Below, are summarized mean yield differences between susceptible and resistant hybrids for three regions in the southern part of Texas where these hybrids have the most application The table also contains a mean of the estimates for the three regions

Region	Sorghum planting date		
	Early	Two weeks later	Four weeks later
Lower Rio Grande Valley	S>R 13 7%	R>S 11 1%	R>S 1231 8%
Coastal Bend	S>R 11 6%	R>S 21 4%	R>S 875 0%
Blacklands	S>R 12 7%	R>S 16 3%	R>S 175 0%
Mean	S>R 12 7%	R>S 16 3%	R>S 760 6%

These data illustrate that when planted early (at the normal or usual time), susceptible hybrids out yield resistant hybrids by 12 7% When sorghum is planted two weeks later than normal, resistant hybrids out yield susceptible hybrids by 16 3%, and when sorghum is planted much later, the resistant hybrid out yields susceptible hybrids by 760 6% During most years 85% of sorghum would be planted early, 15% planted two weeks later, and 5% planted four weeks later These data are illustrative of the progress made to develop commercially acceptable sorghum midge-resistant hybrids, and the additional improvement required before they become acceptable to farmers for use in sorghum production as a component of IPM However, based on several years of research and genotype evaluation, three sorghum midge-resistant A-lines were released during this reporting period The A/B inbred line pairs are designated A/BTx639, A/BTx640, and A/BTx641 In hybrid combination with resistant R-lines, they resist damage caused by sorghum midge and produce grain yields almost comparable to susceptible sorghum hybrids in the absence of sorghum midges but much greater than susceptible hybrids when sorghum midges are present The lines were selected and evaluated for resistance to sorghum midge and adaptation at Corpus Christi (high sorghum midge abundance) and College Station (moderate sorghum midge abundance), TX, and for adaptation at Lubbock, TX Resistance also was evaluated at Tifton, GA (low/moderate sorghum midge abundance) Experimental hybrids were evaluated for resistance and yield at Corpus Christi and College Station Damage rating used was a 1 9 scale, where 1 = 0-10%, 2 = 11-20%, to 9 = 81-100% of kernels that failed to develop Experimental hybrids produced from the released female lines sustained significantly less damage and produced significantly more grain than susceptible hybrids Sorghum midge damage ratings of the experimental resistant hybrids usually were less and grain yield superior to resistant hybrid ATx2755*Tx2767, produced from previously released resistant parental lines Scores of sorghum midge damage to the experimental hybrids ranged from 1 3 to 3 0 and 1 0 to 3 7 at College Station, and 2 7 to 4 0 and 1 3 to 6 0 at Corpus Christi during 1995 and 1996, respectively Damage ratings of four susceptible hybrids ranged from 4 7 to 7 3 and 5 3 to 8 0 at College Station, and 8 0 to 9 0 and 8 3 to 9 0 at Corpus Christi during 1995 and 1996 respectively whereas damage to resistant hybrid ATx2755*Tx2767 was 2 0 and 2 0 at College Station and 4 0 and 4 8 at Corpus Christi during 1995 and 1996, respectively Grain yield of the experimental resistant hybrids ranged from 3991 to 5403 and 2096 to 6231 kg ha ^{1} at College Station, and 3179 to 4284 and 1019 to 3114 at Corpus Christi during 1995 and 1996, respectively Yields of the resistant check ATx2755*Tx2767 were 5186 and 4959 kg ha ^{1} at College Station, and 3689 and 956 at Corpus Christi during 1995 and 1996 respectively Yields of four susceptible hybrids ranged from 1951to 3159 and 726 to 3081 kg ha ^{1} at College Station and 360 to 1542 and 407 to 664 at Corpus Christi during 1995 and 1996 respectively

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 Responses were received from 522 of the 739 (70 6%), 398 (76 2%) of the questionnaires returned were usable Most respondents completed college (38 5%) or had some college education (30 2%) Usable responses were received from growers who farm in a total of 94 counties Usable questionnaires were from 184, 80, and 134 growers in the northern, central and southern regions of Texas, respectively Questionnaire respondents grew an average of 643 7 acres of grain sorghum during each of the past five years Most growers grew sorghum for profit (94 0%) or as a rotation crop (65 1%) and desired better price (96 2%) and yield (89 4%) The most important insect pests to 84 3 and 74 2% of growers were greenbug and worms in the panicle Statewide, 77 4% of growers did their own scouting for sorghum insect pests, and 55% said they used IPM Growers used multiple IPM tactics to manage sorghum insect pests A total of 93 7 and 92 4% of the growers used good seedbed preparation to promote rapid seed germination and crop rotation respectively whereas only 38 6 53 5, and 60 3% applied insecticides infurrow or banded at planting, foliarly, and to seed From 75 to 80% of growers attended chemical company seed company, and Extension Service sponsored meetings to help manage sorghum insect pests From 82 to 94% of growers found bulletins or other written information Extension Service advice, and shortcourses/seminars/meetings helpful in managing sorghum insect pests

Responses to a three-page IPM specialists' questionnaire mailed to 106 private agricultural consultants and 36 Texas Agricultural Extension Service specialists and county agents - pest management will be used to quantify how many of the Texas sorghum growers can be considered IPM users Of the 142 IPM specialists, 85 (59 9%) returned their questionnaires Completed, usable questionnaires were received from 82 (57 7%) More than 70% of the specialists ranked worms in the panicle, sorghum midge, and greenbug very important pests of sorghum Greenbug was ranked very important by twice as many specialists in the northern as in the southern region Sorghum midge was very important to more specialists in the southern than central or northern regions Seventy percent or more specialists ranked economic thresholds, planting date, scouting, natural enemy conservation, applicator calibration, and fertilizer management as very important At least 50% considered resistant varieties, crop rotation, harvest time, and promoting rapid seed germination and seedling growth as very important Scouting and economic thresholds were the IPM tactics considered most important for management of most sorghum insect pests IPM specialists listed scouting, economic thresholds, natural enemy conservation, and resistant varieties as important for management of greenbug Planting date, scouting, and economic thresholds were important for sorghum midge Scouting, economic thresholds natural enemy conservation and selective/biological insecticide use were most important for worms in the panicle

Graduate student research Development of sorghum hybrids with higher and more durable resistance to sorghum midge requires understanding of the cause(s) of resistance Sorghum resistance to sorghum midge is caused by spikelets flowering earlier and glumes closing tightly before ovipositing sorghum midges are in the field Damage to resistant sorghums is to spikelets not yet closed when sorghum midges are ovipositing Higher temperatures resulted in earlier spikelet flowering of most sorghum lines but did not affect hybrids Only 0 2 or fewer sorghum midges per panicle were present between 1 00 and 7 00 a m , when resistant sorghums were flowering By 10 00 a m , when sorghum midges are most abundant 83 0% of spikelets of resistant sorghums had completed flowering and had tightly closed glumes, but glumes of only 56 5% of spikelets of susceptible sorghums were closed Susceptible sorghums were significantly more damaged (55 5%) than resistant sorghums (25 0%) More than three times as many sorghum midges emerged per panicle (75 4) and damage rating was more than double (3 1) for a resistant hybrid changed to flower five hours later than normal (11 00 a m) than for the same hybrid flowering at the normal time (23 8 sorghum midges and 1 4 damage rating) A susceptible sorghum hybrid exposed to the same treatment was as damaged as the nontreated counterpart Glume tightness was estimated at 10 00 a m by attempting insertion of a number 00 insect pin to mimic a sorghum midge ovipositor More glumes of resistant (62 0%) than susceptible sorghums (32 0%) were tightly closed Resistant sorghums had shorter stigmas

(1 08-1 16 mm), longer (1 18-1 20 mm) and wider (1 03-1 05 mm) ovaries, shorter filaments (0 99-1 01 mm), and shorter anthers (1 45-1 47 mm) than susceptible sorghums, (1 27-1 41 mm), (1 13-1 16 mm), (0 99-1 01 mm), (1 25-1 37 mm), and (1 52-1 65 mm), respectively However, no relationship could be determined among sizes of floral parts and resistance to sorghum midge

Four F_3 sorghum populations, segregating for resistance to greenbug biotypes C, E, I, and/or K, were developed at the Texas A&M University Agricultural Research and Extension Center at Lubbock, for the purpose of identifying molecular markers diagnostic of sorghum resistance to greenbug biotypes The populations are

Experimental cross	Population size (F_3 families)	Resistant to biotype(s)	Origin of resistance
Tx2737 × BTx623	489	C	SA7536 1
Tx2752 × BTx623	287	C	KS30
R8508 × Tx2783	283	C E	Capbam
RTx430 × PI550607	195	C E I K	Dzugara Belaya

Resistance to greenbug biotypes C, E, I, and/or K were evaluated for each of these sorghum crosses Approximately 10 seedlings per F_3 family were phenotyped for each biotype Seedlings were visually scored for greenbug damage on a scale of 1-6, with 1 = asymptomatic plant to 6 = dead or dying plant A recently published RFLP map of *Sorghum* (Chittenden et al 1994) was used to identify DNA markers linked to greenbug resistance in these sorghum populations DNA was extracted from each F_3 family, cut with either EcoR1, HindIII, XbaI, DraI, EcoRV, or BstN1 and Southern blotted To ensure complete coverage, RFLP markers were selected to scan the sorghum genome at 10- to 20-cM intervals Markers co-segregating for greenbug resistance have been detected on four linkage groups Thus far, two markers identified are linked to greenbug biotype C resistance, three to biotype E, two to biotype I, and one to biotype K as shown in the following table

Linkage group	Number of alleles	Diagnostic of biotype(s)	Resistant parent
E	2	C	Tx2737
		E	Tx2783
I	1	E	PI550607
G	2	C	Tx2752
		E I	PI550607
J	1	I K	PI550607

Current efforts are to identify other DNA markers diagnostic of resistance to greenbug biotypes C, E, I, and K in these and other sorghum populations Research is underway to determine if these DNA markers segregate for or correspond to greenbug resistance in small grains

Large-scale DNA extraction protocols were modified to produce suitable restriction enzyme digestion of greenbug DNA DNA was extracted from greenbugs from diverse localities to be used in screening of DNA probes developed from a greenbug library Restriction enzymes were screened to determine which enzymes resulted in complete digestion of greenbug DNA The selected restriction enzymes were used to digest the DNA of greenbugs from the different localities Digested DNA was run on agarose gels and transferred to nitrocellulose membranes via the Southern blotting technique Multiple Southern blots have been completed Previously developed probes were radiolabeled via nick translation and hybridized to the screening blots yielding autoradiograms This is an on-going process consisting of stripping the probe and hybridizing a new probe to the membrane After hybridization of approximately 30 to 60 probes, the resulting autoradiograms will be analyzed to determine which probe-enzyme combinations show restriction fragment length polymorphisms (RFLPs) suitable for screening natural populations of greenbug The selected probes will be used to probe field collections of greenbugs RFLP analysis will allow estimation of genetic diversity and characterization of population structure, including estimates of levels of gene flow, sexual reproduction, and effective population size Determination of extent of genetic diversity and characterization of population structure will aid in understanding greenbug biotype formation

Mexican corn rootworm is controlled by crop rotation or soil insecticides Soil insecticides lessen damage by corn rootworms to corn roots but do not reduce corn rootworm abundance Crop rotation has been considered the most effective control In Central Texas, corn is rotated with sorghum, soybeans, cotton, or wheat Recently, the corn-sorghum rotation scheme has failed to reduce abundance of Mexican corn rootworms in corn grown after sorghum Mexican corn rootworm oviposition in sorghum fields did not differ significantly from that in corn Significantly more adults emerged from corn than from other crops Emergence from sorghum was greater, but not significantly so, than from cotton or soybeans Adult Mexican corn rootworm abundance was greatest in flowering corn and sorghum, but remained at constant, low levels in cotton and soybean As corn silks dry, adult Mexican corn rootworms migrated to flowering sorghum A few larvae survived and developed on sorghum roots Of 450 Mexican corn rootworm eggs collected in 1996 and observed during 1997, 80% hatched, 16% died, and less than 1% remain under observation Two-year egg diapause does not appear to occur at significant levels Laboratory studies will be conducted to determine Mexican corn rootworm feeding and oviposition preferences among different growth stages of corn, sorghum, cotton, and soybean Additional laboratory studies will be conducted to assess the ability of larvae to survive on roots of these crops and on common weeds

Networking Activities

Workshops

- * Entomological Society of America, Informal Conference, "Cereal Aphids" Invitational Paper, *Does pyramiding single genes provide horizontal resistance?* 8-12 December 1996, Louisville, KY
- * INTSORMIL Principal Investigators Meeting, "Sorghum and Millet for the 21st Century" Participant 20-22 September 1996, Lubbock, TX
- * International Conference on the Genetic Improvement of Sorghum and Pearl Millet Co-author of two papers *Breeding for resistance to panicle pests of sorghum and pearl millet* and *Breeding for resistance to foliar- and stem-feeding insects of sorghum and pearl millet* 23-27 September 1996, Lubbock TX
- * XX International Congress of Entomology "Global Plant Genetic Resources for Insect Resistant Crops" Invitational Paper, *Genetic diversity of sorghum a source of insect-resistant germplasm* 25-31 August 1996, Firenze (Florence), Italy
- * Sorghum Conference and 20th Biennial Grain Sorghum Research and Utilization Conference Entomology Session Chair 16 19 February 1997, New Orleans, LA

Research Investigator Exchanges

- * Dr Yacouba Doumbia visited the PI in September 1996 Collaborative research on sorghum panicle-feeding bugs in Mali was discussed Special emphasis was placed on increasing sorghum insect research in farmers' fields and on the return of Niamoye Yaro Diarisso on completion of her Ph D degree at Texas A&M University under the direction of the PI
- * The PI continues to serve on the TAMU Advisory Board for the Mali SPARC project and participated in several activities with IER/Malian officials during their visits to Texas A&M University The PI 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 also contributed to revision of the Sorghum Disease Compendium

Germplasm and Research Information Exchange

- * PIs for projects TAM-225 and TAM-223 annually evaluate sorghum germplasm for resistance to insects More recently and during this reporting period, converted exotic sorghums regularly were evaluated for resistance to sorghum midge Also sorghum accessions are regularly evaluated for resistance to greenbug and yellow sugarcane aphid
- * The collaborating PIs in 1995 working with a commercial seed company had two sorghum midge-resistant hybrids produced Seeds of these hybrids were distributed during 1996 to Extension Service and seed company personnel for resistance and production evaluation Results of those research demonstrations and technology transfer efforts were provided in detail in the Project Output sections of this report
- * 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

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Anderson R M and G L Teetes 1996 Evaluation of insecticides for suppression of stink bugs on sorghum 1995 Arthropod Management Tests 21 285

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Diarisso Niamoye Yaro Bonnie B Pendleton and George L Teetes Relationship between sorghum spikelet morphology and resistance to sorghum midge International Conference on Genetic Improvement of Sorghum and Pearl Millet 22 27 September 1996 Lubbock TX University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 644 645

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Teetes George L Gary C Peterson Roger M Anderson Kenneth Schaefer and Jerry W Jones Sorghum midge resistant hybrids for the 21st century International Conference on Genetic Improvement of Sorghum and Pearl Millet 22 27 September 1996 Lubbock TX University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 678

Teetes G L G C Peterson R M Anderson and B B Pendleton 1996 Evaluation of midge resistant sorghum hybrids International Sorghum and Millets Newsletter 37 60

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Journal Articles

Mott Dale A George L Teetes and Michael I Biggerstaff 1996 Magnitude of survival of overwintering sorghum midge Southwest Entomol 21 341 344

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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

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Book Chapter

Teetes George L Gary C Peterson Kanayo F Nwanze and Bonnie B Pendleton 1997 Genetic diversity of sorghum a source of insect resistant germplasm In S L Clement and S S Quisenberry (eds) Global Plant Genetic Resources for Insect Resistant Crops CRC (in preparation)

Proceedings

Teetes, G L G C Peterson and K F Nwanze Genetic diversity of sorghum *Sorghum bicolor* (L) Moench a source of insect resistant germplasm P 702 In XX International Congress of Entomology Proceedings 25 31 August 1996 Firenze Italy

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 Ajayi Breeding for resistance to panicle pests of sorghum and pearl millet International Conference on Genetic Improvement of Sorghum and Pearl Millet 22 27 September 1996 Lubbock TX University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 255 280

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Porter David R John D Burd Kevin A Shufran James A Webster and George L Teetes Greenbug (Homoptera Aphididae) biotypes what are we doing wrong? Southwestern Branch Entomological Society of America 45th Annual Meeting 17 20 February 1997 Oklahoma City OK

Teetes George L Roger M Anderson and Bonnie B Pendleton Evaluation of insecticides against sorghum panicle insect pests Southwestern Branch Entomological Society of America 45th Annual Meeting 17 20 February 1997 Oklahoma City OK

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

During Year 17, two NARS scientists from West Africa began research programs in Niger, working in collaboration with Dr Ousmane Youm at the ICRISAT Sahelian Center One student is a Ph D candidate (S Boire, Mali) and the other is 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 18, the two students conducted their work in Niger during June through November Boire initiated field studies on MHM immature stage mortality, adult MHM biology and fecundity and MHM biology on alternate host plants Kadi Kadi initiated laboratory studies on MHM immature stage development and adult biology using four temperatures and four artificial diets All results are preliminary and are reported in brief below Boire will need to continue his research in INTSORMIL years 19 and 20, and Kadi Kadi should finish his research in Year 19

Graduate student research in the U S was not sponsored in Year 18, and all funds were used to support the education and work of the two NARS scientists

TAM-225B was an invited INTSORMIL representative to two meetings of the Millet Network of West Africa (ROCAFREMI), including the 1997 ROCAFREMI Annual Reunion that convened a conference in Benin on Integrated Plant Production "

Objectives, Production and Utilization Constraints

Objectives

Sorghum and millet collaborative research objectives The collaborative research objectives of TAM-225B are to (1) assess natural enemies for biological control of stalk borers and the millet head miner, (2) implement effective biological controls, and (3) provide graduate level training on processes and strategies for biological controls in sorghum and millet and (4) assess biological control as a component of on farm pest management for sorghum and millet pests in local crop protection practices The listed objectives are pursued in the United States and in the Republic of Niger on millet

Graduate student research A primary objective of TAM-225B is to train national agricultural research system scientists from collaborating countries so that they can conduct needed science for local farming clientele, become productive scientists, and can contribute leadership toward efficient agriculture in countries with developing agriculture TAM-225B is training two scientists from West Africa, and their objectives are to (1) improve methodologies for sampling and manipulating populations of millet head miner (MHM), (2) assess the spatial distribution and mortality of all life stages of MHM, (3) conduct experiments to show age-specific mortality in populations of MHM, (4) identify and assess the role of alternate host plants occupied by MHM, (5) determine the optimal survival of MHM in a laboratory environment, and (6) conduct field cage experiments to assess MHM fecundity Both students are currently in Niger conducting research in collaboration with Dr Ousmane Youm, ICRISAT-Sahelian Center Other graduate students associated with TAM-225B have finished their research and are writing their research results

Constraints

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

Research Approach and Project Output

Millet Head Miner (MHM) Research in Niger 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 millet head miner (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 relatively large guild of natural enemies (reported in previous TAM-225B annual reports and by others), occupies a predictable habitat in an ecosystem with relatively consistent annual presence, and has one generation per year

Before advocating a strategy using biological controls, extant natural enemies must be assessed This is especially important for the low input and fragile Sahelian farming systems Thus, in 1993 we began a research project on MHM survival, especially seeking to understand the contributions of MHM natural enemies to total mortality Specific objectives of our research are to (1) expand aspects of MHM biology, (2) evaluate the impact of MHM enemies, and (3) construct an age-specific life table (k-factor analysis) for MHM

Research Methods

Millet Head Miner

Boire The general purpose of these experiments was to begin assessing the impact of natural enemies on MHM abundance in the region of Sadore, Niger The research was conducted at ICRISAT SC and in farmers' fields at Dogalkeina (7km Northeast of ISC)

Female moths were collected from ICRISAT-SC (ISC) light traps, and these were allocated to three treatments (millet varieties) of five cages Moths were caged one per panicle and allowed to oviposit for 24 hrs, and then moths were removed All panicles were excised and taken to the laboratory Exclusion cages were used to assess the impact of natural enemies, and each cage consisted of 1 5mm diameter wire frame covered with a fine mesh (21 x 21 cells cm-2) All panicles were covered at boot stage A first group of 15 cages (5/millet cultivar) was opened 2 days only and then closed (measured the impact of natural enemies on eggs), a second group of 15 cages was opened from 0-7 days and closed until the appearance of the first mine (measured parasitism of young larvae), and a third group of cages was opened throughout the experiments (measured collective impact of natural enemies attacking all developmental stages) A fourth group remained closed for the entire experiment and served as control

Pupal mortality was assessed by collecting pupae during October through November Sampling was conducted in field plots at ISC and in farmers' millet fields at Dogalkeina A total of 75 holes (1m2) were excavated to a depth of about 40 cm in ISC field plots, and 50 holes were excavated to a depth of about 30 cm in farmers' fields All holes were excavated in 10 cm increments, and all were in sandy soils Excavated soil was sieved using a fine wire mesh (36 cells cm-2) to collect millet head miner pupae (living and dead) and parasitized prepupae (mummies) These pupae were held in the laboratory at 28° C for parasites emergence

Host exposure experiments were conducted during August 20-23 Thirty laboratory reared eggs were stuck on white paper stickers, and these stickers were pinned to panicles in an ISC millet field All the panicles were then caged The stickers were removed after seven days and examined for egg hatch During August through September, sample millet panicles were cut and returned to the laboratory for examination

Samples of alternate host plants also were taken at 20 km intervals on transects Southwest Niamey-Tillabery, Northeast Niamey-Chikal, Southeast Niamey-Kollo/Kirtachi and Eastwest Niamey- Maradi from September 6-13 Panicles of millet, hybrids (Chibra) and a variety of *Pennisetum spp* were cut, labeled and kept in plastic bags to prevent egg larvae and natural enemies escape These panicles were then examined in the laboratory Some infested plants were identified by a millet taxonomist at ORSTOM/Niamey

Kadi Kadi MHM field biology and laboratory life table assessment experiments were conducted to understand the biology of MHM and to assess the impact of parasites and predators on MHM population growth and development The principal objective of the present research was to develop life tables from data collected in the laboratory and field Life table analyses were used to improve understanding of the biology of MHM and as a part of a larger research effort to assess the impact of natural enemies on MHM population growth Specific research objectives were to (1) measure MHM reproduction, development and survivorship at four temperatures and on four larval (2) conduct field cage studies to assess immature stage development and adult fecundity on pearl millet in the field, and (3) to begin developing methods for monitoring MHM predators in the field

Experiments for 1996 focused on comparing MHM development on four diets and four temperatures The four diets were (1) BioServ diet # 9782, (2) a millet-based diet with millet taken at early exertion stage (3) a millet based diet with millet taken at middle flowering stage and (4) a millet-based diet with millet taken at soft dough stage The temperatures used were 24°C, 26°C, 28°C and 30°C Experiments were initiated using eggs collected from adult MHM in a laboratory colony and adults collected from field light traps Adults were held in pairs in oviposition cages containing freshly cut millet panicles as a substrate for oviposition by females Eggs were collected and placed on dry filter paper in small petri dishes to monitor hatching After eggs hatched, young larvae were placed in small plastic cups containing about 30 ml of diet Larvae were transferred into the cups using a small camel hair brush The cups containing larvae were equally distributed among the four rearing chambers, each set to maintain one of the four given temperatures The plastic cups were checked at seven day intervals to change the diets and record the number of surviving and dead larvae When larvae were nearly mature cups were checked daily to record dates of pupation Pupae were sexed and monitored for adult emergence Data were analyzed using the software package SAS (Statistical Analysis System)

Research Findings

Millet Head Miner

Boire The data for diapausing pupae are preliminary, and will be augmented with more analysis and collections in Year 19 A total of 115 pupae (living=112, dead=3) and 94 dead prepupae (mummies) were collected in ISC field plots at the beginning of the dry season (October and November 1996) Most pupae were collected at depths of 10 and 20 cm, and were seldom collected at 30 cm and 40 cm Distribution of prepupae followed a similar trend as pupae In farmers fields at Dogalkeina, 166 pupae (living=134, dead=42) and 77 prepupae were collected from 50 holes and most were collected from depths of 10 20, and 30 cm Pupal mortality was higher in farmers' fields than in the field plots at ISC None of the sampled pupae at ISC or farmer's fields produced parasites

The cage exclusion experiments are continuing in Year 19, and data from Year 18 cannot be analyzed in isolation However, in overview, living larvae were not found in panicles of 40 d open cages examined at the end of September In the 2 days open cages, only 0 66 larvae per panicle were recovered The 7 d open cages showed 52 living young larvae and no parasites, and produced an average of 2 33 mines per panicle

The host exposure experiments are continuing in Year 19, and data from Year 18 cannot be analyzed in isolation Disappearance was the most important factor of egg mortality (60 to 98%) and the control experiment (no access provided to parasites or predators) showed 82% of egg hatch These results suggested that eggs can hatch using the process developed for host exposures, and that the larvae can move to the panicles A total of 217 young larvae were collected during the first three weeks of September, with 192 living (88 48%) and 25 dead (11 52%) For mature larvae, 178 were collected with 7 living (4%) and 171 dead (96%) from October 1-4 Most dead mature larvae were parasitized by *B hebetor* Prepupae were parasitized by the encyrtid *Copidosoma sp* , an egg-prepupal polyembryonic parasite This parasite was collected only from large larvae

The alternate host surveys carried out on MHM produced no MHM eggs However, many MHM larvae were collected on *Pennisetum glaucaum subsp Sieberianum* (Schlecht) and an unidentified related subspecies of *Pennisetum*

Kadi Kadi Laboratory experiments were conducted for comparison of MHM stage development reared in four diets incubated under different laboratory conditions Results are presented in Tables 1 and 2 We recorded fewer MHM adult emergence in the millet based diets because of high larval mortality Variation of mortality between the diets may be attributable to the nutritional quality of respective diets, and to the temperature conditions in respective chambers These

Table 1 Percent real mortality of millet head miner larvae developing at four temperatures and on four diets

Temperature	BioServe	Millet soft dough	Millet medium dough	Millet early Exerted head
24°C	62 5	93 8	62 5	100 0
26°C	50 2	95 8	62 5	91 7
28°C	91 7	95 8	95 8	100 0
30°C	92 7	100 0	96 3	97 3

Table 2 Adult longevity, ovipositional period, and fecundity, and percent egg hatch for millet head miner at 4 temperatures

Temperature	Longevity (days)	Oviposition period (days)	Fecundity	Percent egg hatch
24°C	3 3	2 3	119 3	57 5
26°C	4 3	3 0	120 0	59 4
28°C	4 7	3 7	173 3	46 1
30°C	4 7	3 3	98 0	64 3

data are very preliminary, and will be elaborated on after collecting additional data in Year 19 The irreplaceable mortalities at 26 °C were 42 85%, 38 46%, 23 08%, and 15 38% respectively for the BioServ diet # 9782, the millet-based diet with millet taken at early exertion stage, the millet-based diet with millet taken at middle flowering stage, and the millet-based diet with millet taken at soft dough stage Mean numbers of days for adult MHM longevity and oviposition period were low (2-3 days) at 24°C, and were more nearly what was expected at 26°C, 28°C, and 30°C These results are preliminary, and additional experiments will be conducted in Year 19 to establish the effects of temperature on terminating of diapause in the laboratory

Networking Activities

- In October 1996, Frank Gilstrap was an invited participant and INTSORMIL representative to a ROCAFREMI (West Africa Millet Network) meeting in Dakar, Senegal This meeting established a new organization for ROCAFREMI The workshop began restructuring the network along lines decided in February 1996 Themes discussed at Dakar meeting included network scientist publications, the increased partnering among network projects to improve the scope of research, improving the integration of research among network projects, more focus on IPM and on control of striga, decentralizing the network planning process, more follow up on network decisions, and improved and sustained contact between scientists of different network countries
- In February 1997 Gilstrap was an invited participant and INTSORMIL representative to the Annual Reunion of ROCAFREMI in Cotonu, Benin During this Reunion, Network scientists produced termination reports for Projects 1-3 (millet breeding, pathology and entomology), and implemented a new IPM focus and structure for ROCAFREMI The new structure seeks to promote transferring network research results to farms, and recognizes that this transfer requires closer coordination with extension, non-government organizations and private volunteer organizations

Publications and Presentations

Presentations

1996 Entomological Society of America, Models for Conservation Biological Control in Annual Crops Symposium Dec 1996 Louisville KY

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

Project TAM-228

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Summary

A new bacterial disease of pearl millet first observed in Southern Zimbabwe in 1996 was identified as *Pantoea agglomerans* by D Frederickson at the University of Zimbabwe Aflatoxin of either pre- or post-harvest origin was associated with mixed maturity grain in South Texas sorghum fields that matured in the normal season during the drought of 1996 Pre-harvest aflatoxin was confirmed in some later-planted sorghum fields that also had mixed maturity grain Compared to the normal season fields, the latter matured under a drought stress environment that had higher heat but less severe moisture stress The spread of sorghum ergot (*Claviceps africana*) across the Western Hemisphere was closely monitored especially as it entered Central America, the Caribbean, Mexico, and finally the U S by late March 1997 Incidence severity, primary hosts and potential alternative hosts of *C africana* were noted Impact of ergot on commercial grain sorghum production in South Texas was negligible but there were some harvest and handling problems in a few hybrid seed production fields where late tillering by the female parent allowed high incidence of ergot just prior to harvest Head-directed application of triazole fungicides was effective in preventing most ergot infection on blooming male-sterile sorghums in the field The contact fungicides captan and thiram prevented conidial germination of *C africana* in ergot honeydew on seed surfaces, but triazoles had no apparent effect on this phase of the pathogen

Objectives, Production and Utilization Constraints

Objectives

- Identify unknown virus occurring in the Pandamatenga area (Botswana)
- Evaluate the ecology and economic importance of *Exserohilum turcicum* and *Ramulispora sorghi*, and evaluate specific versus general leaf disease resistance (Zambia, Zimbabwe)
- Identify sources of late season drought tolerance with adequate charcoal rot and other disease resistance (Botswana, Zimbabwe)
- Characterization of *Macrophomina phaseolina* (Botswana, Zambia, Zimbabwe, U S)
- Assist national programs in identification of adapted foliar disease resistant cultivars that have stable disease resistance reactions in strategic multilocational nurseries over several years (Botswana, Zambia, Zimbabwe)
- Develop controls for sorghum ergot (*Claviceps africana*) through chemical control, identification of host plant resistance, and investigation of ergot sclerotial function (Zimbabwe, Brazil)

Research Approach and Project Output

Foliar Diseases (Anthracnose, Leaf Blight, Sooty Stripe)

In 1996-97, four sorghum disease nurseries were planted at two locations in Zambia and three 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, 40 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 1996-97 season in Zimbabwe, there was a low incidence of sooty stripe and moderate incidence and severity of leaf blight at the Henderson Station and only a moderate amount of sooty stripe at the Panmure station Cultivar response to both sooty stripe and leaf blight was consistent with response to both pathogens across both high and low disease pressures of previous years at both locations Cultivars showing the most consistent agronomic desirability and regional adaptation to Zimbabwe have SC326-6 in the genetic background, but especially progeny from the cross of R5646 by SC326-6 Two of those progeny, 86EON361 and 86EON362 from TAM-222, are already being used extensively by M Chisi and B Verma in Zambia and will be utilized in Zimbabwe by breeder N Mangombe In Zambia, sooty stripe incidence and severity were moderate at the Golden Valley station and high at the Mansa station where it displaced anthracnose as the predominant foliar pathogen of sorghum Cultivar response to sooty stripe at Golden Valley and to both sooty stripe and anthracnose at Mansa were consistent with previous year's observations However, the combination of early sooty stripe and late anthracnose development at Mansa did overwhelm some entries with moderate or lower levels of resistance to either or both pathogens The importance of at least moderate resistance to foliar pathogens was evident in about 300 sorghum cultivars from Nebraska that were near the TAM-228 nurseries and being tested in Zambia for the first time These cultivars expressed some agronomic traits desired by the Zambian sorghum improvement program but all entries were either severely damaged or defoliated by sooty stripe at Golden Valley and all were killed by sooty stripe alone, or in combination with anthracnose at Mansa

F_2 progeny of crosses between cultivars with differential response to sooty stripe and leaf blight were grown at the Henderson station in Zimbabwe to determine which ones were segregating for response to leaf blight Four of the ten F_2 progeny appeared to be segregating for resistance to *Exserohilum turcicum* (leaf blight) but not *Ramulispora sorghi* (sooty stripe) The most desirable cross R6956 (susceptible to *R sorghi*, resistant to *E turcicum*) by R8602 (resistant to *R sorghi*, susceptible to *E turcicum*) was unsuccessful but is being produced by TAM-222 for future testing Progeny from these crosses between cultivars with divergent sooty stripe and leaf blight response are being used in development of near-isogenic F_3 populations to assess the impact of leaf blight and sooty stripe on yield

Virus Identification

Virus reactions were recorded in the International Sorghum Virus Nursery (ISVN) and in some other introduced cultivars grown for the first time at the Sebele research station Virus mosaic symptoms and red leaf necrosis were again observed in the released variety Mahube (SDS2583) and its response was particularly severe at the Sebele station

Bacterial Disease of Pearl Millet

A 1996 bacterial leaf spot nursery of pearl millet (E S Monyo, SADC/ICRISAT) being evaluated for *P syringae* by TAM-228 and Dr D Frederickson had a foliar symptom that was distinct from the typical symptoms caused by *P syringae* Dr Frederickson determined that this new foliar disease of pearl millet was caused by *Pantoea agglomerans*

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 In early April 1997 TAM-228 assisted DAR scientists in identifying and selecting cultivars for incorporation into their sorghum improvement program Several cultivars previously demonstrating good agronomic desirability and resistance to sugarcane aphid at the Sebele station in 1996 were tested again in Sebele, along with new cultivars selected on the basis of the 1996 ratings No field evaluations of sugarcane aphid resistance were possible in 1997 but most of the cultivars with good agronomic desirability in 1996 had a similar response in 1997 However, the later than normal planting date and the low level of drought stress indicate that further evaluation under more typical, severe drought stress will be necessary Some of the more consistently outstanding lines alone or as parents in crosses were 87EO366, CE-151, and WSV387 (Kuyuma) and Macia Other cultivars that had sugarcane aphid resistance in 1996 and continued to have good agronomic desirability in 1997 were CE 151, WM#322, FGYQ353, MR112B 92M5 and GR127-92M11

Aflatoxin in Grain Sorghum

Continued drought stress from the previous year and season long drought in the Coastal Bend of South Texas produced three distinct sorghum cropping seasons or harvests in 1996 These seasons (based on harvest dates) were Normal (July), Late (late August-early September), and Fall (late October) For the Normal crop, drought stress and poor field conditions contributed to variability in plant emergence and development so that harvested grain was of mixed maturity Problems of mixed maturity grain were exacerbated in some fields where mid to late-season rain promoted development of stem or axillary tillers Mixed maturity grain was associated with aflatoxin levels above 20 ppb but it was detected only after completion of the Normal harvest so its pre- or postharvest origin could not be determined Samples of aflatoxin-contaminated grain all had immature, shriveled grain but it did not consistently have higher aflatoxin content than other grain fractions Several hybrids and other cultivars left in the field two months beyond the Normal (July) maturity at Corpus Christi had heavy weathering and sprouting damage but no detectable pre-harvest aflatoxin content However, the Late crop (harvested in late August and early September) in this same region had preharvest aflatoxin content generally ranging from 0 to 110 ppb Many of these fields also had mixed maturity grain and samples from one field had aflatoxin levels of 100 ppb in the main heads and 270 ppb in the more immature grain of tillers Drought stress for the Late crop was characterized by higher heat and less severe moisture stress than that of the earlier normal season There was no detectable aflatoxin in the Fall crop (late October) which had only moderate moisture and heat stress during the critical grain-filling and maturation period

Spread of Sorghum Ergot Across the Western Hemisphere and into the U S

Sorghum ergot caused by *Claviceps africana* spread to Honduras by December 1996 Puerto Rico and Mexico by mid-February 1997, and to the Rio Grande Valley (RGV) of the United States by late March 1997 TAM-228 helped monitor the spread of the pathogen to and across these regions and surveyed the primary hosts on which it occurred Occurrence of ergot in Puerto Rico (February 1997) was most severe on male-sterile forage sorghums and A-lines but was generally non-detectable or occurring in trace amounts on most self-fertile sorghums However, some self-fertile sorghums had significant amounts of ergot that was probably related to some fertility factor Johnsongrass had a low incidence of ergot that was detectable only within the sorghum nurseries The presence (and absence) of ergot on male-sterile sorghums of different maturities was consistent with introduction of *C africana* as conidia within a cold front-generated rainstorm that had previously crossed the Dominican Republic where ergot had been earlier reported

In a mid-March survey of the Texas Department of Agriculture (TDA) grow-out nurseries located near Tampico Mexico in southern Tamaulipas state there was a high incidence of ergot in most sorghums planted in mid-October 1996 Most of these sorghums apparently had a cool-temperature induced sterility that made them highly vulnerable to infection by *C africana* Only the later maturing self-fertile sorghums of this planting date had minimal or trace amounts of ergot In another adjacent TDA nursery the sorghum planted in November 1996 apparently escaped most of the cool-temperature-induced sterility because only male-sterile and a few self-fertile sorghums had significant incidence of ergot Sorghum ergot was also observed in the surrounding Tamaulipas region on johnsongrass and grain sorghum either surviving in abandoned fields or growing in roadside ditches Prior to our survey, ergot was reported in other regions of the states of Tamaulipas and San Luis Potosi on both commercial grain sorghum and in hybrid seed production fields

Sorghum ergot was first identified in the U S on March 26 1997, by T Isakeit, who observed it on ratooned or other sorghum surviving in abandoned sorghum fields in the RGV of Texas Ergot was eventually detected in johnsongrass, but usually in association with ergot on nearby grain sorghum, and incidence was usually limited to a few plants or groups of johnsongrass plants The high incidence of ergot on some johnsongrass plants and its absence on adjacent plants of similar maturity indicated that some fertility factor may have contributed to the differential incidence of ergot on this host Ergot began occurring on the current year crop of grain sorghum first in the RGV and then progressively across the state of Texas where it reached the hybrid seed production area in the northwestern region of the state by mid-August In collaboration with several U S scientists and sorghum workers, we successfully utilized male-sterile forages across many areas of the Texas and U S sorghum production region as a trap or indicator crop to detect the presence of ergot These forages are very susceptible to ergot because they have no pollen source and prolonged tillering produces a relatively continuous, proximal source of susceptible ovaries This allows a rapid cycling and buildup of ergot so the disease becomes easily observable in a short period of time

Impact of Ergot in Northern Tamaulipas, Mexico, and the U S through August 1997

Incidence of ergot was non-detectable or minimal in most self-fertile commercial grain sorghum fields maturing under warm conditions from May through August 1997 in northern Tamaulipas, Mexico and South Texas Although some fields in the RGV of Texas had up to 1% of the florets infected, no harvest or other ergot-related problems were noted in those fields Hybrid seed production fields of grain sorghum in northern Tamaulipas (Mexico) and in South Texas did have some incidence of ergot on the male-sterile seed parent The primary problem was not ergot on the main head but on late-season stem or axillary tillers (side branches) of specific female seed parents The tillers emerged prior to harvest, but well after the male pollinator had ceased pollen production, which allowed a high incidence of ergot Some of these hybrid seed production fields in South Texas had a significant problem during harvest either with ergot honeydew hindering harvest through clogging of the combine and creating other grain handling difficulties, or through seed contaminated with the honeydew and ergot sphacelia Most of the ergot in the grain was too immature to contain true sclerotia Some of the harvest problem was resolved by combining at a height which avoided most of the ergot-infected tillers, but especially the recently-infected tillers, with the greatest amount of fresh honeydew The grain from these fields was successfully conditioned to remove almost all ergot sphacelia (nondetectable in conditioned grain) Conidia in the ergot honeydew coating healthy seeds were killed through seed treatment with the contact fungicide captan Some of the ergot-contaminated grain removed by the seed conditioning process is being utilized in feeding trials to determine if there is toxicity to poultry and other animals

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

Only *Sorghum* spp were observed to be naturally infected by *C africana* in surveys made in Puerto Rico, Mexico, and the U S Pearl millet was observed with ergot symptoms in the TDA nurseries near Tampico and in the RGV of Texas but spore morphology indicates that it is a *Claviceps spp* distinct from *C africana* Other ergots have been observed on numerous grasses in close association with sorghum ergot but all appear to be distinct from *C africana* However, these ergot pathogens are being used in cross inoculation studies to confirm their status as non-hosts of *C africana*

Chemical Control of Ergot in the Field

By early June, chemical control and other ergot research plots were established in South Texas 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 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 to 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 but harvested seed are being evaluated for differences in seed weight and viability

Ground applications of Tilt and Bayleton, using a directed-spray application to the top and sides of blooming sorghum heads of a male-sterile sorghum (ATX2752), gave excellent control of sorghum ergot with the triazole fungicides used in the test (Tilt and Bayleton) The fungicides were applied three times at weekly intervals at four different rates (16, 31, 63, and 125 g a i /ha, 467 liters of water/ha) Best control was achieved at the two highest rates of either fungicide and Bayleton provided the best control at the lowest rates An adjacent experiment with the same male-sterile cultivar utilized different concentrations of four fungicides applied until runoff to the top and sides of sorghum heads using a hand application CO2 sprayer Two applications were made at seven day intervals beginning at bloom using the three triazole fungicides Tilt, Bayleton, and Folicur (tebuconazole) at 100, 200, 500 and 1000 ppm and the strobilurin derivative Quadris (azoxystrobin) at 200, 500, 1000, and 2000 ppm Quadris had activity against ergot but gave inconsistent control even at the highest concentration All triazoles gave good control at the highest concentration, but at the lowest concentrations the descending order of efficacy was Bayleton, Tilt and Folicur

Seed Treatments to Control Sorghum Ergot

In early 1997 the sorghum industry was concerned about the safe movement of seed from ergot-affected production areas so they could assure there was no introduction or reintroduction of ergot to other areas An experiment was implemented that involved the collaboration of TAM-228, USDA-ARS in Puerto Rico (J Dahlberg), USDA-ARS Ft

Detrick, MD quarantine facility (G Peterson), and Novartis and Gustafson chemical companies Sorghum seed produced in a non-ergot area was uniformly coated with fresh honeydew obtained from ergot-infected sorghum in Puerto Rico and allowed to dry Aliquots of the honeydew-coated seed were overlaid with different fungicide seed treatments Novartis provided the fungicides difenoconazole (Dividend 3MG) and 4-(2,2-difluoro-1 3-benzodioxol-4-yl) 1H-pyrrole-3-carbonitrile (Maxim 4FS) and Gustafson provided triadimenol (Baytan 30), thiram (42-S Thiram), captan (Captan 400) and a combination fungicide product of triadimenol and thiram (RTU-Baytan-Thiram) The treatment rates (in g a i /100 kg of seed) of each fungicide are shown in Table 1 The treated and nontreated seed (with and without ergot honeydew added) were shipped to the quarantine facility in Ft Detrick, MD for evaluation of fungicide efficacy in preventing conidial germination in the ergot honeydew on the seeds The results showing approximate production of secondary conidia after 24 to 48 hr at 100% R H (seed on water agar) at 21 to 22 C are shown in Table 1 The contact fungicides, captan and thiram, and the RTU baytan-thiram product completely prevented conidial germination of *C africana* on the seed surface Maxim allowed a trace of conidial germination and production of conidia at the lowest treatment rate but allowed only a sparse segmented mycelial growth at the higher treatment rate Neither of the triazole fungicides (Baytan and Dividend) had any apparent effect on conidial germination or production of secondary conidia as they were indistinguishable from the control seed treated only with ergot honeydew Results were similar when the germination tests were conducted on the surface of nonsterile soil

The apparent contrasting activities of triazole fungicides and contact fungicides regarding ergot control in the sorghum ovary, versus mature seed, is probably related to the mode of action of the fungicides and their ability to directly interact with the pathogen at specific sites In the field, triazole fungicides can prevent infection of ovaries because of their systemic translocation within plant tissues Contact fungicides are ineffective in preventing infection in the field due to their lack of systemic activity On the seed surface the contact fungicides have good activity because they are in direct contact with the conidia of the fungal pathogen Triazole fungicides prevent synthesis of sterols by the pathogen, but they apparently do not prevent the conidia from utilizing their own endogenous reserve of sterols which appear to be sufficient to complete the entire sporulation process in less than 24 hr

Networking Activities

Sorghum Ergot Activities

TAM-228 has served as one of the primary resource centers in gathering and disseminating sorghum ergot information for the U S (as well as Mexico and several Latin American countries) as the pathogen spread across the Western Hemisphere since 1995 Information has been gathered by trips, meetings, telephone, and e-mail and disseminated primarily by e-mail, phone, computer, and print media Several phone and other interviews about ergot were given to a variety of media representatives both in and outside the U S A diverse body of ergot information and reprints of the most critical publications were assembled to

Table 1 Efficacy of fungicides in preventing germination and sporulation of macroconidia of *C africana* suspended in ergot honeydew on surfaces of sorghum seed[1]

Fungicide		Rate	Sporulation
Common name	Product name	a i /100 kg	compared to control (%)[2]
Control (honeydew coated seed)			100
captan	Captan 400	55	0
captan	Captan 400	94	0
captan	Captan 400	140	0
thiram	42 S Thiram	109	0
triadimenol/thiram	RTU Baytan thiram	32 93	0
4 (2 2 difluoro 3 carbonitrile	Maxim 4FS	2 5	Trace[3]
4 (2 2 difluoro 3 carbonitrile	Maxim 4FS	5 0	0[3]
difenoconazole	Dividend 3 MG	12	100
difenoconazole	Dividend 3 MG	24	100
triadimenol	Baytan 30	16	100
triadimenol	Baytan 30	31	100
triadimenol	Baytan 30	62	100

[1] Healthy seed was coated with honeydew of *Claviceps africana* from infected sorghum heads and allowed to dry before being treated with a fungicide at the rate indicated in g a i./100 kg of seed Seed coated with honeydew provided the control treatment for comparison with fungicide treated seed Nontreated seed (no honeydew added) provided an additional control treatment to indicate the absence of ergot on the original healthy seed

[2] Relative amounts of sporulation are in comparison to that produced on the control seed coated with ergot honeydew (100%) Seed were incubated at 100% R H (on water agar) for 24 48 hr at 21 22C There were no differences in treatments after 24 hr The sporulation process consists of a macroconidium within the honeydew which germinates to produce a condiophore that bears another single (secondary) aerial conidium at its tip Control seed without ergot honeydew had no visible sporulation

[3] Trace = 50 to 100 conidia per seed Both treatments had some apparent macroconidial germination with production of sparse segmented mycelia

meet the heavy information demand made by scientists, sorghum workers, and the media Throughout 1996 and 1997, many slides of sorghum ergot were scanned into computer images and shared via diskette or computer email with a wide variety of scientists and other individuals interested in the disease The images have been featured on several web sites including TAEX-Plant Pathology-College Station, TAES-Weslaco, University of Nebraska Clay Center Experiment Station, and USDA-Puerto Rico Images have also been utilized by scientists for personal and group education, and information in slide and other presentations, and in a variety of publications

TAM-228 interacted with several scientists at public institutions within the U S to set up trap crops to monitor the spread of ergot across the sorghum growing regions of the U S I also worked with the Texas Department of Agriculture in developing documentation, rates, and other data necessary to initiate a request for a crisis exemption to spray Tilt on seed production fields for control of sorghum ergot Information generated, in part, by this project for control of sorghum ergot on seed is being used by the industry and regulatory agencies as baseline information for control recommendations, guidelines, and registration

At the Global Conference on Ergot of Sorghum held June 1-7, 1997 in Brazil I was appointed chairman of the Global Steering Committee (representing INTSORMIL) Initial steering committee responsibilities were to assemble and finalize Global conference working group recommendations for future research I was also appointed to another steering committee to develop collaborative research on sorghum ergot between the U S and INIFAP of Mexico As part of this collaboration, INIFAP has provided post doctoral scientist, Dr Rodolfo Velasquez-Valle, to conduct ergot research with the TAM-228 project but with special emphasis on chemical control His salary and additional funds are provided by a grant from the USDA-ARS I also served on several subcommittees of an American Seed Trade Association Ad Hoc committee on sorghum ergot, and a USDA/FAS grant for collaborative research on sorghum ergot with EMBRAPA/CNPMS in Brazil was funded for three years

Chronology of Sorghum Ergot-related Activities of TAM-228

September 23, 1996 TAM-228 and TAM-224 were co-coordinators and co-moderators of an Ergot Awareness session held in conjunction with the International Conference on Genetic Improvement of Sorghum and Pearl Millet held in Lubbock, Texas TAM-228 also made a presentation on Chemical Control of Sorghum Ergot

February 19, 1997 Continued Spread of Sorghum Ergot in the Western Hemisphere presented at Grain Sorghum Research and Utilization Conference in New Orleans, LA

February 20-24, 1997 Travel to Puerto Rico to assess incidence and spread of sorghum ergot over the island sorghum nursery areas

February 28, 1997 Chemical control of sorghum ergot presented at GSPA-sponsored ergot discussion session for industry, commodity and regulatory groups, and public scientists at Lubbock, TX

March 15-16, 1997 Biology and spread of sorghum ergot and opportunities for international collaboration presented to INIFAP scientists at Rio Bravo Experiment Station, Rio Bravo, MX Sorghum ergot survey in Texas Department of Agriculture grow outs near Tampico, Mexico and enroute through northern Tamaulipas state

April 7, 1997 Appointed as member of Texas A&M University Sorghum Ergot Extension and Research Task Force

May 9, 1997 Sorghum ergot survey and interaction with area farmers near San Fernando, MX

May-June, 1997 Ex-officio member of all subcommittees of the American Seed Trade Organization Ad Hoc committee on sorghum ergot

May 16, 1997 Sorghum ergot in the United States presented at South Texas Country Elevators Association Conference, South Padre Island, Texas

June 1-7, 1997 Presented a paper, chaired the Country reports session, and chaired the Working Group on Control and Management of Sorghum Ergot, and was appointed chairman of the Global steering committee at the Global Conference on Ergot of Sorghum

June 11, 1997 Chemical control of Ergot in Sorghum Hybrid Seed presented at the U S Conference on Sorghum Ergot in Amarillo, TX

July 2, 1997 Chemical Control of Sorghum Ergot presented 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 presented at International INIFAP-TAMU-USDA/ARS Planning Conference on Sorghum Ergot, Rio Bravo, MX Appointed to INIFAP/TAMU/USDA Steering Committee to develop collaborative sorghum ergot research between U S and Mexico

Other International Travel

TAM-228 PI traveled to Botswana, Zimbabwe, and Zambia during April 11-28, 1997 to evaluate collaborative sorghum disease nurseries and to review current and future research on sorghum and pearl millet diseases with collaborating scientists

Germplasm Exchange

Over 500 lines and cultivars were evaluated for response to various diseases, adaptation, drought response, and sugarcane aphid resistance in the SADC region in 1996-97 (collaborative with TAM-222, B Rooney, TAM-223, and TAM-224)

Research Support

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

Support was provided for travel by D Frederickson to present the paper *Pseudomonas syringae*, cause of severe foliar leaf spots and streaks on pearl millet in Zimbabwe at the 35th Annual Congress of the Southern African Society for Plant Pathology in Badplaas, South Africa, January 19-22, 1997

Support was provided for travel by Esther Mtisi, PPMI, Zimbabwe, to attend the All Africa Crop Science Congress, Pretoria, South Africa, January 13-17, 1997, where she presented a paper entitled, Control of covered kernel smut on sorghum in Zimbabwe

Publications

Journal Articles

Frederickson D E E S Monyo S B King and G N Odvody 1997 A disease of pearl millet in Zimbabwe caused by *Pantoea agglomerans* Plant Disease 81 959

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 In Press

Proceedings

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Odvody G 1997 Aflatoxin in South Texas Grain Sorghum Pre or Postharvest p 101 102 *In* Proceedings of 20th biennial Grain Sorghum Research and Utilization Conference Feb 16 19 1997 New Orleans LA

Odvody G N 1997 Chemical control of Ergot in Sorghum Hybrid Seed Production Fields p 28 30 *In* Proceedings of the U S Conference on Sorghum Ergot June 11 1997 Amarillo TX

Odvody G N 1997 Continued Spread of Sorghum Ergot in the Western Hemisphere p 90 93 *In* Proceedings of 20th biennial Grain Sorghum Research and Utilization Conference Feb 16 19 1997 New Orleans LA

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Odvody G N and T Isakeit 1997 Sorghum Ergot in the United States Public Sector Response *In* Proceedings of the Global Conference on Ergot of Sorghum June 1 7 1997 Sete Lagoas Brazil In Press

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Miscellaneous Publications

Bandyopadhyay R D E Frederickson N W McLaren and G N Odvody 1996 Ergot A Global Threat to Sorghum Production International Sorghum and Millets Newsletter 37 1 32

Bandyopadhyay R D E Frederickson N W McLaren and G N Odvody 1996 Ergot A Global Threat to Sorghum Production Supplemental leaflet (4 p) International Sorghum and Millets Newsletter (ISMN) Sponsored by NGSPA and SICNA

Ergot of Sorghum Disease threat to the Texas Sorghum Industry TAEX publication L 5179 June 1997 Contributing author although not listed

Odvody Gary 1997 Ergot of Sorghum Reported in U S Phytopathology News Vol 31 (5) 75 76

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

One surprising result was that the income controlled by women was reduced with the introduction of new technologies in southern Mali Women are compensated for the increased labor contribution on the communal fields However, women then need to reduce their hours on the private plots and these private plots are often very profitable for them Hence, the income reduction results from the increase in wages not offsetting the value of reduced production on the private plots On the positive side there are institutional changes presently occurring to contest these increased income streams resulting from technological change, especially the shifts from extended to nuclear families and modifications in the payment methods for the gender work groups (see the Results section of this report for more details) In the Malian agricultural systems these gender work groups have become increasingly important in performing seasonal operations, such as weeding,

As the traditional systems of restoring land fertility break down with population pressure, increasing agricultural output will depend upon raising input levels especially inorganic fertilizers and, in semiarid regions, improved water-retention techniques Unfortunately the first effect of devaluation is to raise the prices of imported inputs, discouraging the intensification of agriculture The secondary effect is to raise the price of imported cereals

To the extent that domestic or traditional cereals are substitutes for the imported cereals, the prices of these traditional cereals are expected to rise even faster than those of imported inputs since consumers have to eat There should be a comparative advantage for food production in most developing countries once the distortions of agricultural prices are removed since food products tend to be very bulky with high transportation costs

The price of cereals relative to inorganic fertilizer did increase more than the pre-devaluation level in 1996 Modeling results showed that in the principal sorghum zone, farmers would use inorganic fertilizer on a small area of sorghum This introduction of the fertilization process was expected to set off a dynamic process of internal (within farm) generation of capital to continue this process

The intensification process in cereal production will require region-specific adaptation to different soil types and economic environments With programming, this process of technology adaptation was evaluated in two different zones the heavier soils of the Central Plateau in Burkina Faso with their propensity to crust and the sandy dune soils in Niger where rapid percolation through the soil is the principal problem In the crusting soil, the combination of tied ridges/fertilization with a floor support price for years of good weather, normally resulting in a price collapse increased incomes 31% In the sandy dune soils, higher plant densities longer-season cultivars, and the use of compound inorganic fertilizers increased farm incomes 34% Previous breeding emphasis had been upon earliness, but unless there is a shift to longer season cultivars, the new cultivars will not be in the field long enough to generate a return to fertilization Nigerien breeders are presently responding to this requirement for later material These modeling results indicate the complementarity of technologies and the importance of policy support for technology introduction in the heavier soil region

Objectives, Production and Utilization Constraints

- The objectives of our research are to estimate the potential effects of new technologies, to identify constraints to its diffusion, and recommend complementary policies to accelerate the introduction process In Mali, we have been concentrating on the impacts of new technologies and other factors on the incomes of women Also in southern Mali, we have been evaluating the impacts of devaluation of the CFA (January 1994) on the potential adoption of inorganic fertilizers in the principal sorghum zone In the past year, we have made a comparison of the potential effects of the introduction of inorganic fertilizers on the heavier soils of the Mossi Plateau in Burkina with the sandy dune soils predominating in Niger This includes the effects of complementary technologies and supporting policies

Research Approach and Project Output

Welfare Effects of Technological Change on Women in Southern Mali

In the previous issue of the INTSORMIL report, we showed how women were compensated for increased labor on family plots resulting from the introduction of new technologies The household wage payments functioned as in any labor market with variables, such as technological change, opportunity costs, and bargaining power being important determinants of the wage payments and thereby supporting the bargaining concept of household decision-making The next critical issue is whether these increases in incomes from wage payments were offset by the reductions in the value of the private-plot production as labor was withdrawn there

From the regression results on the determinates of wages to women, Table 1 estimates the impact on income received by one female from the addition of another one-half hectare of cotton Cotton is produced with a fixed package of new cultivars, inorganic fertilizers and pesticides To expand the cotton area by one-half hectare requires the addition of four woman days by each women The average product of the private plots was used to estimate the reduction in the value of output if all labor reduction came out of the private plot Then it was assumed that only one-half and then one-fourth of the labor reduction came from the private plot as women reduced their participation in other activities (see Table 2) In comparing income reduction with income gains from the introduction of technology, women are better off only in half of the sites even when labor reduction in the private plots is only one-fourth of the increase required for the new technology in the family area In all other cases, the income controlled by women is reduced with the introduction of the new technologies This result is consistent with field interviews with both men and women in the region

Table 1 Estimated changes in communal income from technological change in southern Mali

	Private plot producers Δy_c (FCFA/year)	Non private plot producers Δy_c (FCFA/year)
Region	$\Delta L_c = 4$	$\Delta L_c = 4$
Koutiala	792	1084
Sikasso	492	1454
Fana	1048	1612
Bougouni	588	
San		938
Sample Average	728	1144

N=32 [b]N=18 Note that these income changes come from the regression equations explaining wage payments to women Specifically these estimates holds other variables constant while changing the area in the new technology by one half hectare

It was a surprising result that income streams controlled by women were reduced by the introduction of new technologies The household head appears to end up with most of the income gains Hence, the income distribution effect is less a gender issue than a result of the household patterns of production and control As new income streams become available, various family members would be expected to attempt to get larger shares, in a manner similar to the conflict between labor and management in a firm The significance of the bargaining variable in determining the wage payments for communal work supports the concept that these inter-household decisions are made in a manner similar to that of a firm

Institutional changes are presently underway, with the apparent objective of obtaining larger proportions of these income shares for other family members besides the household head In Mali, as in East Africa, there is an increasing fragmentation of the extended family into nuclear families This does not necessarily help women, but it does respond to the concentration of income received by the household head

Of more importance to women are the changes in the traditional gender work groups that perform seasonal agricultural tasks Historically, these associations have kept their earnings to pay for group social functions As they become more important in the region for performing critical seasonal operations, especially weeding, the female members are increasingly demanding to be individually paid their share of proceeds This institutional evolution to more group labor paid in cash should give women more bargaining power So with these two institutional changes, the shares to women and to the adult men that are not household heads are expected to increase

Policy measures to increase the bargaining power of women or to accelerate institutional changes should help to increase the income controlled by women Further research now needs to focus on the evaluation of the impacts that technological change has on the household head's expendi-

Table 2 Estimated income gains and losses for private plot producers in southern Mali due to technological change

	Income gains Δy_c (FCFA/year)	Income losses Δy_p (FCFA/year)		
Region	ΔL_c=4	ΔL_p = 4	ΔL_p = 2	ΔL_p = 1
Koutiala	792	3004	1502	751
Sikasso	492	3160	1580	790
Fana	1048	3648	1824	912
Bougouni	588	6952	3476	1738
Sample average	728	4196	2098	1049

[a] N=34 Δw_c=8 FCFA Income losses refer to the value of reduced production resulting from the time reductions on the private plot by four woman days which was the increased time requirement per woman on the communal plot resulting from the expansion of the area with new technology Then it was assumed that women would reduce their time less and the effects of time reduction of two days and then one were calculated Average rather than marginal products were utilized since we were unable to estimate the production function and we had to assume constant returns to scale

tures in order to determine the net welfare effects of technological change in agriculture on women

Devaluation and Introduction of New Sorghum Technologies in Southern Mali

As new cultivars are being introduced by national institutions supported by various programs in INTSORMIL, it will be critical to improve soil fertility and water availability in the semi-arid regions In southern Mali (Sudanian zone – 600 to 800 mm of rainfall at 90% probability) farmers already widely practice the water-retention device of ridging So the principal problem there is to accelerate the introduction of inorganic fertilizer There are three main constraints to increasing farmers' expenditures on inputs for food crops profitability, risk, and liquidity (Coulibaly, Vitale and Sanders, 1997)

With devaluation the domestic food crops become more profitable with a lag (Figure 1) The lag is caused by the initial effect of devaluation resulting in higher costs for imported inputs The secondary effect depends upon the degree of substitutability between imported and domestic foodstuffs The higher the cross elasticities, the larger the effects on traditional food-crop prices from the increasing prices of imported foodstuffs Frequently there also are time delays for governments to let the prices[1] of imported cereals increase and for substitution to take place in urban areas But with the high transportation costs for bulky food products there should generally be a comparative advantage locally once price distortions are removed

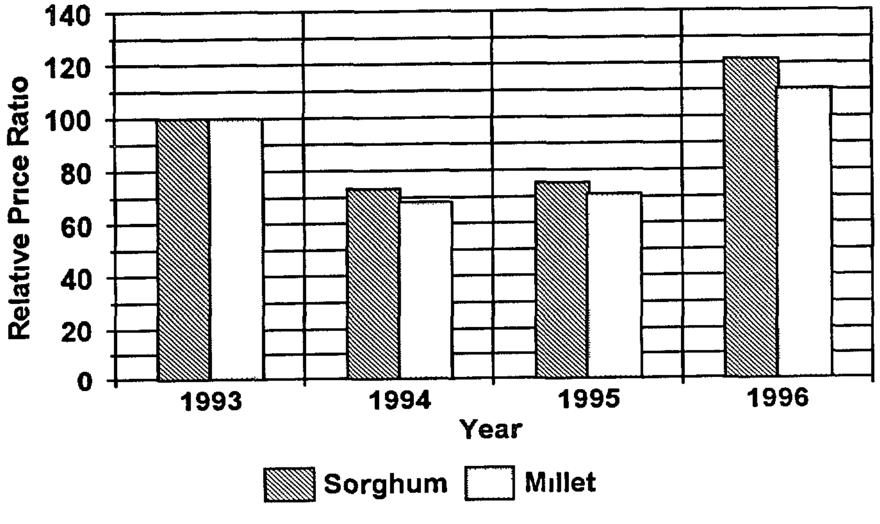

Figure 1 Farmgate cereal prices relative to inorganic fertilizers in southern Mali, 1993-96

Governments in Sub Saharan Africa have traditionally been held responsible for keeping urban food prices low When the prices of imported cereals increased after devaluation policymakers often responded with trade interventions

The main source of production risk of the lack of water at the critical phases of plant development is reduced with the water-retention technique of the ridges More systematic effort needs to be dedicated to the risk of the price collapse of the basic food crops in good rainfall years due to inelastic demand Developing alternative uses of the traditional food crops may be as important as introducing the supply shifters of the new technologies For example, sorghum can be used in bread, beer, and as a feed There also are a number of specialty products, i e , alternative methods of producing sorghum and millet for direct human consumption The economic potential of these alternative uses for traditional food products[2] is an important combined-research activity of food scientists and economists

Substantial attention was paid to the liquidity issue With the dismantling of the credit programs for export crops, such as cotton, in the last decade of structural adjustment, it is unlikely that there will be a return to credit subsidies and even more unlikely that credit programs would be instituted for the food crops Hence, increased liquidity for input purchase will undoubtedly need to be internally financed on the farm until rural financial institutions are developed

Fortunately, there are many sources of cash income for these farms, both from agricultural and livestock activities, and from nonfarm sources including remittances Since farmers always talk about credit programs and constraints, the liquidity factor is probably overrated in the analysis of new technology requirements Resolving the profitability and risk problems and making the farmer aware of this resolution is expected to be sufficient to obtain diffusion In the farm modeling, we study one method of internally generating increased liquidity, i e , cashing in some of the livestock holding

In 1996, two years after devaluation of the CFA, the price of sorghum relative to inorganic fertilizer increased above the pre-devaluation level Then the introduction of fertilized sorghum with new cultivars would occur on 2 9 ha of the average farm, according to risk programming results (Table 3) Available liquidity then constrains further introduction But then the farmer would note the high returns to this activity and in a dynamic context over several years generate internally more capital for continuing the expansion of the intensification process

Alternative Soil-Water Strategies for Different Soil Types

The returns to fertilization will depend upon initial soil fertility and, in semi-arid regions, the availability of water to the plants at critical growth periods In heavier soils, where crusting is a problem, a water-retention device is expected to be a prerequisite to making the use of inorganic fertilizers a viable alternative In sandy soils, percolation through the soil often results in the water passing beyond the roots

Hence, the critical innovation here is to increase the capacity of the soils to slow the movement of water, making it more available to the plant Raising organic matter in the soil is one well-known method of slowing percolation

For two principal soil types in the principal two agroecological regions in the Sahel, farm programming models were used to analyze technology and policy changes to encourage increased inorganic fertilizer use In the Sudanian zone, there were larger effects from tied ridges than from fertilizer In poor rainfall years, the tied ridges substantially reduced the riskiness of using fertilizer alone While it was profitable for 98% of the farms to use both tied ridges and fertilizer in a poor rainfall year, only 76% of the farms using

Table 3 Farm programming results for before and after devaluation in southern Mali[1]

Crop	Technology[2]	Before devaluation		Current prices
		Farm observ	Model results	Model results[6]
Sorghum	Local variety no inorganic fertilizer	1 5	0	0
Millet	Local variety no inorganic fertilizer	8	9 5	9 5
Sorghum	Improved variety 50 kg ha^{1} compound cereal fertilizer[7]	0	0	2 9
Groundnut	Improved variety 50 kg ha^{1} compound cereal fertilizer[7]	2 5	2 1	6
Cowpea	Improved variety 50 kg ha^{1} compound cereal fertilizer[7]	5	0 5	1 4
	Total returns (U S $)[3 4 5]	1865	1826	2056

[1] Results were obtained using a relative risk aversion coefficient of 2 5

[2] The soil preparation technique of ridging is included with all activities

[3] Crop prices used in calculating total returns are producer prices averaged over one year

[4] Total returns include home consumption (valued at producer price) plus market sales minus out of pocket expenses

[5] Total returns are given in 1996 US $ and were calculated using a consumer price index (*International Financial Statistics* June 1996)

[6] This scenario assumed farmers liquidity increased in proportion to livestock prices (130 % increase)

[7] The composition of compound cereal fertilizer is N P K (15 15 15)

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[2] The advantage of the traditional foods on the production side is that farmers already know how to raise them and there have been selection processes for these particular commodities over long time periods Another potential advantage is that little research has been done on the processing or preparation of the traditional cereal or other food products in contrast to the extensive development of techniques for both wheat and rice Food scientists have shown that these techniques can be adapted and transferred between commodities

inorganic fertilizer alone had positive profits in this year (Shapiro and Sanders, 1997) The combination of tied ridges/fertilization resulted in fertilization being used on three-fourths of a hectare and an income increase of 13% (Table 4) Complementing this technological change with the addition of a floor price to avoid a cereal price collapse in good-rainfall years raises the area in fertilizer to 0 9 ha and the income increase to 31% This is a reasonable income increase for the combined-technology/policy changes Once farmers begin to use fertilizer, they are expected to generate their own capital to expand the area fertilized

In the sandy soil of the lower rainfall Sahelo-Sudanian region of Niger, the short-cycle cultivars provide drought escape and increase expected incomes 30% Field evidence of increasing diffusion of these cultivars validates the model However, this strategy is not sustainable since it will mine the soil of the basic nutrients, especially nitrogen and phosphorus The availability of phosphorus (simple superphosphate) alone would further raise incomes and result in 2 1 ha of fertilized millet (Table 5) To introduce both nitrogen and phosphorus a longer-season improved cultivar is necessary to take advantage of the longer time in the field Nigerien breeders in INRAN (the national research institute) have begun selecting for longer-season cultivars This introduction of both nitrogen and phosphorus is a more sustainable solution than phosphorus alone In the Dosso region of Niger, where fertilizer trials have been undertaken over six years, inorganic fertilizer consumption has been increasing rapidly Farmer awareness of the high returns to fertilizer is expected to be an important factor in the initial diffusion process A fertilizer subsidy accelerates diffusion and increases farm incomes The smuggling of the highly subsidized fertilizer from Nigeria into Niger and the observed higher fertilizer use in the Maradi region of Niger also validates the model results

Moving farther north into the lower rainfall regions of the Sahelo-Sudanian region, neither feasible technical change nor policy change brought inorganic fertilizers into model solutions Here development of agroforestry systems with improved grazing is probably more appropriate than further extension of marginal and unsustainable crop production Without fertilization, soils will be depleted, hence, the inability to bring inorganic fertilizer into the model solution seems to be a good indicator for researchers to look for alternatives besides crops in planning for these regions

The key new input in both regions is inorganic fertilizer With the varying soil and economic conditions, the accompanying technologies and supporting policies are often different But the importance of increasing fertilizer use for profitable, sustainable crop production is clear Modeling seems to be a useful planning tool for defining the limits of future crop production

Table 4 Effects of a water-retention device and a support price policy on adoption of fertilizer on a representative farm in the Sudanian zone in Burkina Faso

Policy or program	Fertilizer use (ha)	Rainfed crop income (US$)	% Change crop income
1 Current practices	N/A	558	—
2 Tied ridges	N/A	624	12
3 Fertilizer	0 73	587	5
4 Tied ridges/fertilizer	0 73	632	13
5 Support price	0 93	733	31

N/A not available
Exchange rate 273 FCFA/US$ (IMF 1990)
Source Adapted from Sanders et al 1996

Table 5 Effects of various technologies and a subsidy on adoption of fertilizer on a representative farm in the Sahelo-Sudanian zone in Niger

Policy or program	Fertilizer use (ha)	Rainfed crop income (US$)	% Change crop income
1 Current practices	N/A	486	—
2 Improved short cycle cultivars	0	631	30
3 Phosphorus only	2 1	685	41
4 Long cycle cultivars[a]	1 5	651	34
5 Input subsidy (10%)	1 2	657	35

[a] Combined with both N and P fertilizers
Exchange rate 273 FCFA/US$ (IMF 1990)
Source Adapted from Sanders et al 1996

Networking Activities

Conferences and Workshops

* John Sanders gave two papers in a workshop held during November in Lome, Togo, by the International Fertilizer Development Center on soil fertility and input and output markets in West Africa In March, the University of Hohenheim in Germany and ICRISAT held a regional conference on soil fertility in Niamey, Niger Sanders presented a paper at this conference In June in Washington, DC, Sanders presented a paper at the International Food Policy Research Institute (IFPRI) at an invited seminar He reported on research on technology development in West Africa and then also gave a presentation of the results from the fieldwork on the impact of technologies on women to a small group from USAID Nina Lilja presented results from her Ph D fieldwork on factors determining the income of women at the American Agricultural Economics Association meetings in San Antonio, Texas, in July 1996 , and at the European Agricultural Economics Association meetings in Edinburgh, Scotland, in September 1996

Research Exchange

* On a three-week trip to Ethiopia to complete various technical papers with Barry Shapiro, Sanders spent two days working with the national sorghum program of Ethiopia He visited farms, gave a seminar on undertaking impact studies, and planned collaborative activities with their economists, especially Yeshi Chiche Also Sanders spent two weeks in Senegal working in ISRA and collaborating with economists there on the measurement of impact A series of studies on impact measurement have now been undertaken in collaboration with ISRA Sanders also attended the INSAH 20th anniversary celebration, representing the Inter-CRSP Jeff Vitale spent two months in the summer of 1996 working with Demba Kebe, and other Malian economists, on modeling of technological change He also gave a workshop for IER economists on this topic

Research Information

* We have been making copies available to African scientists of "The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa" To date copies have been sent to 98 professionals in the continent

Publications and Presentations

Journal Articles

Lilja Nina John H Sanders Catherine A Durham Hugo De Groote and Issiaka Dembélé 1996 Factors influencing the payments to women in Malian agriculture American Journal of Agricultural Economics 78(5) 1340 1345

Nichola Tennassie and John H Sanders 1996 The determinants of adoption when inputs are rationed A Probit analysis in the Sudan Science Technology and Development 14(3) 130 142

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

Books, Book Chapters

Lee John G Douglas D Southgate and John H Sanders 1997 Methods of economic assessment of on site and off site costs of soil degradation In Rattan Lal W H Blum and C Valentin (eds) Methods of Assessment of Soil Degradation CRC Press Boca Raton FL

Dissertation

Lilja Nina K 1996 Technological change in agriculture and the welfare of women in southern Mali Ph D diss Purdue University Dept of Agricultural Economics West Lafayette IN

Presentations

Lilja Nina John H Sanders Catherine A Durham Hugo De Groote and Issiaka Dembélé Factors influencing the payments to women in Malian agriculture paper presented at annual meeting of American Association of Agricultural Economists (AAEA) San Antonio TX July 1996

Lilja, N J H Sanders and C A Durham Household decision making and intra household wage determination in Mali contributed paper 8th Congress of European Association of Agricultural Economists (EAAE) Edinburgh Scotland Sept 1996

Sanders John H Availability and adoption of improved technologies in the semiarid and subhumid zones of West Africa, IFDC (International Fertilizer Development Center) Soil Fertility Workshop Lomé Togo Nov 1996

Sanders John H and Jeffrey D Vitale Structural adjustment and technological change in cereal production in West Africa IFDC Soil Fertility Workshop Lome Togo Nov 1996

Sanders John H and Jeffrey D Vitale Institutional and economic aspects of fertilizer use in West Africa Experiences and perspectives regional workshop on soil fertility management Niamey Niger Mar 1997

Sanders John H Developing technology for agriculture in Sub Saharan Africa Evolution of ideas some critical questions and future research invited seminar International Food Policy Research Institute (IFPRI) Washington DC June 5 1997

Sanders John H The Impacts of new technologies and other factors on the incomes of women in agriculture in the Sahel USAID/Africa Washington DC June 6 1997

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

Project UNL-213

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University of Nebraska

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Summary

Research has shown that pearl millet produces equal yield to grain sorghum under stressful conditions in Nebraska, and is less affected by planting date and row spacing In Western Nebraska, early planting in narrow rows increased yield of both crops, with a greater yield increase found for grain sorghum In Eastern Nebraska, planting date had little influence on grain yield of both crops, but narrow rows led to increased yields Pearl millet growth analysis found that dry matter accumulation and nutrient uptake were not greatly influenced by hybrid or nitrogen rate, but varied greatly across years due to climatic differences The hybrids 59022 × 89-0083 and 1011A × 0896R produced the highest grain yields, and nitrogen application increased grain yield 0 5 Mg ha^{1}

Research in Niger found small genotype and large production practice differences on pearl millet grain yield production, dry matter accumulation and nutrient uptake In the high yield year of 1995, pearl millet translocated dry matter out of stems and leaves to the head during grain fill, but in 1996, stem and leaf dry matter either remained constant or increased Research results support recently published recommendations the ≥20 000 hills/ha, ≥40 kg ha^{1} nitrogen, and ≥18 kg ha^{1}phosphorus is required to optimize pearl millet grain yield, even in dry years

Research in Mali indicated that pearl millet/cowpea rotation resulted in the highest grain yield, stover nitrogen concentration, and agronomic use efficiency of nitrogen Crop residue treatments had no effect on grain yield, but residues left on the surface had greater soil phosphorus and potassium levels than with residue removal or incorporation after five years Cropping increased soil pH and carbon, but decreased potassium and cation exchange capacity INTSORMIL has supported IER scientists who have worked in cooperation with the PVO World Neighbors and the Malien Extension Service (PNVA) the past five years to extend technology developed by IER World Neighbors workers report wide adoption of early season grain sorghum and pearl millet cultivars, improved intercropping practices, and improved manure management through animal corraling and composting with crop residues

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

- Publish manuscript documenting pearl millet-cowpea crop rotation as a yield enhancer, and continuous, rotational and intercropping systems studied as depleters of soil nutrients in Mali
- Conduct long-term studies to determine the influence of crop residue removal, incorporation, and leaving on the surface on grain and stover yield of pearl millet, and the long-term effects on soil nutrient levels
- Continue studies in Niger and Nebraska to determine dry matter production and partitioning, and nutrient uptake of pearl millet cultivars with different growth habits
- Report the lack of differential cultivar response to level of production input (i e manure, fertilizer, plant population) in studies conducted in 1995 and 1996
- Determine the influence of planting date and row spacing on grain yield ot dwarf pearl millet hybrids in eastern and western Nebraska
- 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 the 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, dwaft 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 are being analyzed to determine differences in nutrient concentration, dry matter and nutrient uptake and partitioning, and crop growth and nutrient uptake rates An ongoing study to determine recommended planting date and row spacing for dwarf pearl millet hybrids was continued for the second year on sandy soil sites near Ogallala and Mead, NE, and on a silty clay loam site at Mead, NE Narrow row spacings of 38 or 50 cm were compared to 76 cm for two planting dates The dwarf pearl millet hybrids 68A × 89-0083 and 68A × 086R responses were compared to the grain sorghum hybrid check DK28

Research Results

Western Nebraska has lower rainfall and shorter growing season than Eastern Nebraska In Western Nebraska, pearl millet yielded less than grain sorghum at early planting dates, but more at late planting dates (Table 1) Early planting increased pearl millet yield 10 to 15% and grain sorghum by 72% Narrow row spacing produced higher yields for both crops, but the increase for grain sorghum of 26% was much greater than for pearl millet with 6 to 10% increase In Eastern Nebraska, planting date had a small effect on grain yield of both crops across very different years environmentally and soil types Narrowing rows increased yield of both crops, but less than in Western Nebraska Pearl millet had larger increases in grain yield due to narrowing rows in the drier, more stressfull 1995 growing season, while grain sorghum had similar responses in both years Pearl millet produced similar yield to grain sorghum in stressful production situations, but in better production situations, grain sorghum always produced higher grain yields Pearl

Table 1 Row spacing and planting date influence on pearl millet and grain sorghum grain yield in Nebraska in 1995 and 1996

		Western Nebraska			Eastern Nebraska			
		Sandy soil			Sandy soil	Silty clay loam soil		
Treatment	Crop/Hybrid	1995	1996	Mean	1996	1995	1996	Mean
Row spacing					Mg ha^{1}			
Wide	PM 68A × 89 0083	1 6	1 9	1 75	3 1	1 6	4 3	3 0
(76 cm)	PM 68A × 086R	1 8	2 1	1 95	3 6	1 8	3 7	3 0
	GS DK28	1 2	2 7	1 95	4 0	2 3	4 2	3 5
Narrow	PM 68A × 89 0083	1 4	2 3	1 85	3 2	2 2	4 0	3 1
(38 or 50 cm)	PM 68A × 086R	1 9	2 4	2 15	3 3	1 8	4 1	3 1
	GS DK28	1 7	3 2	2 45	3 4	3 4	5 3	4 0
	L S D (0 05)	0 16	0 21		0 30	0 34	0 40	
Planting date								
Early	PM 68A × 89 0083	1 7	2 2	1 95	2 9	2 0	4 5	3 1
(June 3 18)	PM 68A × 086R	2 0	2 4	2 20	3 4	1 7	4 4	3 2
	GS DK28	1 9	3 6	2 75	3 2	2 8	6 4	4 1
Late								
(June 18 July 3)	PM 68A × 89 0083	1 4	2 0	1 70	3 4	1 7	4 8	3 3
	PM 68A × 086R	1 7	2 3	2 00	4 0	1 6	4 4	3 3
	GS DK28	0 9	2 3	1 60	4 2	2 8	4 3	3 8
	L S D (0 05)	0 16	0 21		0 30	0 34	0 40	

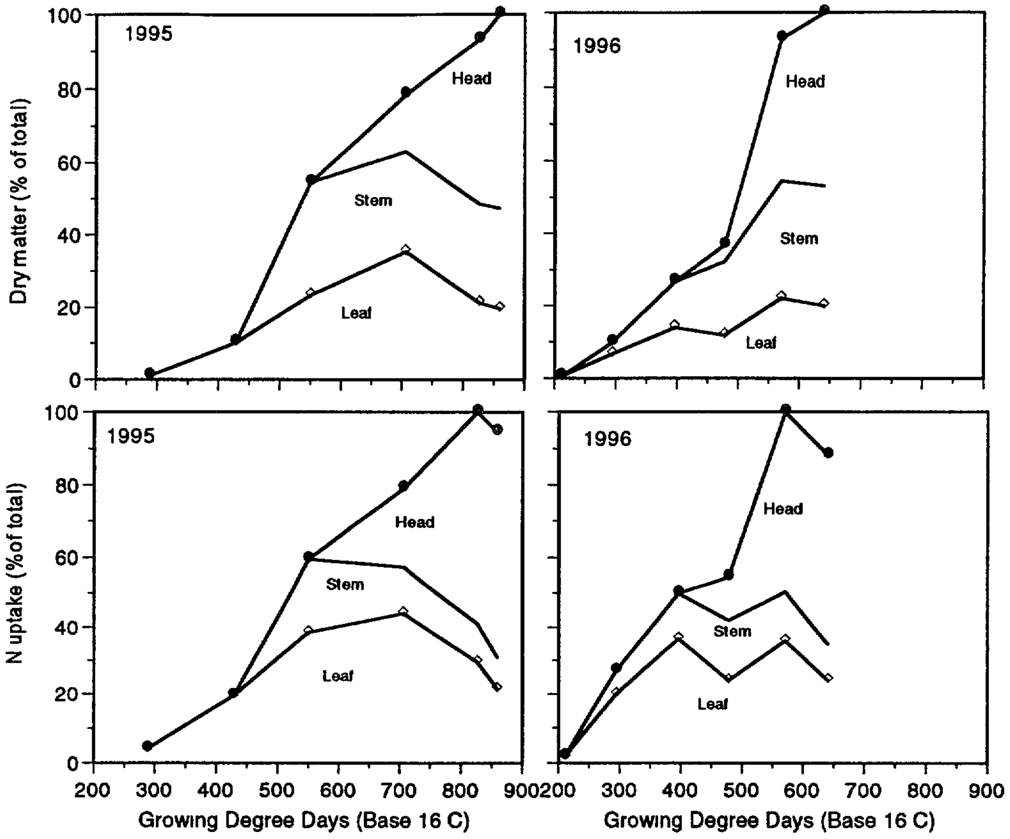

Figure 1 Relative pearl millet, dry matter and nitrogen accumulation and partitioning by plant part in 1995 and 1996 at Mead, NE

millet grain yields were less effected by planting date and row spacing than was the grain sorghum hybrid DK28

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 3 0 Mg ha^{1} higher in 1996 than in 1995, and yield differences were closely associated with the number of heads produced The 1361M x 6RM hybrid produced the lowest grain yield in both years, and the application of 78 kg ha^{1} nitrogen increased grain yield by 0 5 Mg ha^{1} and the number of heads/m^{2} by 3 in both years In 1995, growth analysis found dry matter production ranging from 225 g m^{2} for the hybrid 590A x 89-003 to 325 g m^{2} for the hybrid 1011A x 086RM The crop growth rate reached a maximum of 0 5 to 0 7 g m^{2}/growing degree day (GDD - Base 16 C) approximately 650 GDD's after planting In contrast in 1996, growth increased linearly throughout the growing season to 1000 to 1500 g m^{2} at physiological maturity with the highest crop growth rates of 3 5 to 5 0 g m^{2}/GDD occuring near physiological maturity In both years, relative dry matter accumulation and nitrogen uptake occurred slowly during the early part of the growing season, increasing as stem and head growth took place (Fig 1) Greater translocation of dry matter and nitrogen from the stem and leaves to the head occured in 1995 than in 1996, likely due to the greater evapotranspirational stress present Few differences in nutrient concentration were found therefore, nutrient uptake differences were closely associated with dry matter accumulation Pearl millet growth and nutrient uptake were influenced to a small degree by hybrid and nitrogen, but varied greatly across years in response to different climatic conditions

International

Niger

Research Methods

A two-year experiement to determine the dry matter accumulation and nutrient uptake of the pearl millet cultivars Hemi Kirey (local), Zatib (improved tall), and 3/4 HK (Hemi Kirey -improved short) grown under *Low Yield Conditions* with no fertilizer application and plant population of 10,000 hills/ha, and high yield conditions of five Mg ha^{1} manure, 23 kg ha^{1} nitrogen, 18 kgha^{1} phosphorus, and plant population of 20,000 hills per ha was completed Plots

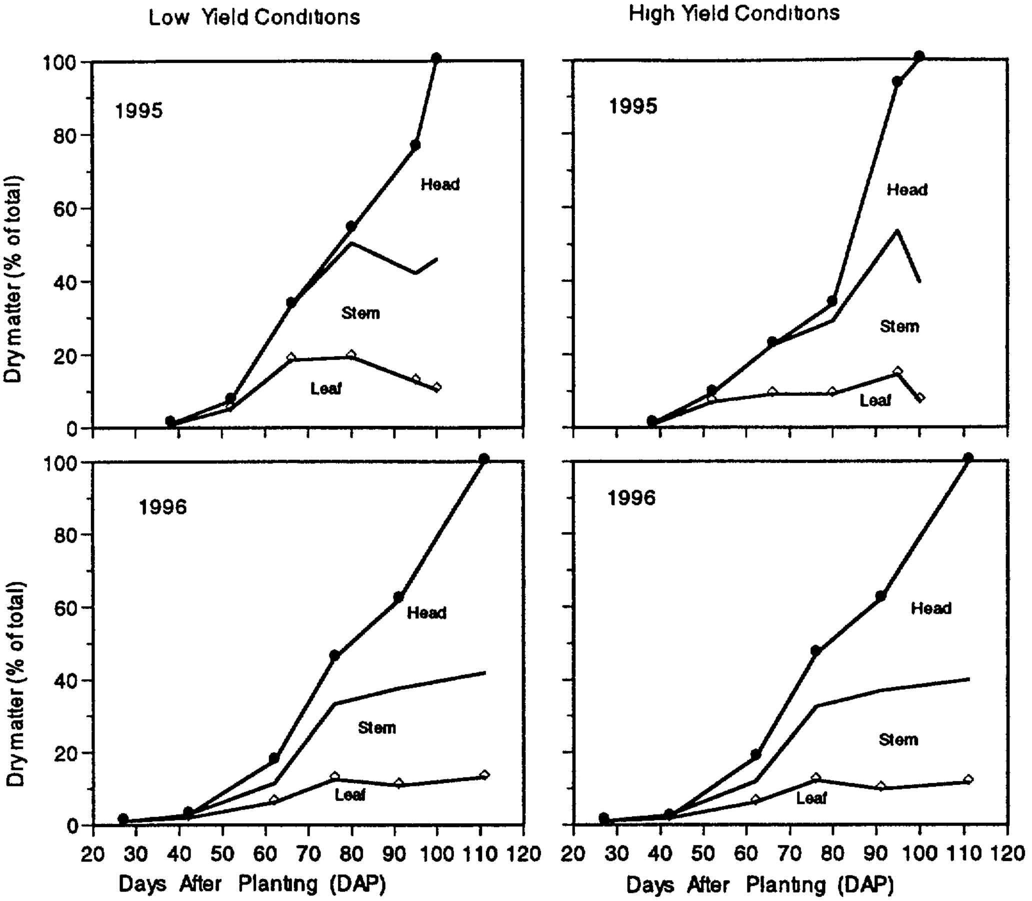

Figure 2 Relative pearl millet, dry matter accumulation and partitioning by plant parts under low and high yield conditions at Kollo, Niger in 1995 and 1996

were sampled bi-weekly, plant parts separated dried and weighed, and nutrient levels determined Data are being analyzed to determine differences in nutrient concentration, dry matter and nutrient uptake and partitioning, and crop growth and nutrient uptake rates

Research Results

Average grain yield was 0 6 Mg ha ^{1} greater and average dry matter production was 90 g m^{2} greater in 1995 than in 1996 due to rainfall differences Few differences were found among pearl millet cultivars except that the short variety 3/4 HK produced 50 to 125 g m^{2} less dry matter than the other cultivars and Heini Kirey produced the greater grain yield than other cultivars in 1995 Yield conditions had a large impact on dry matter production in both years, with high yield conditions increasing dry matter production from 135 to 473 g m^{2} in 1995 and from 92 to 335 g m^{2} in 1996 In the high yield year of 1995, dry matter was translocated out of the stem and leaves to the head 80 to 95 days after planting, while under low yield conditions of 1996 the stem and leaf dry matter either remained constant or actually increased from 75 to 105 days after planting Crop growth rates increased throughout the growing season with rates being greatest near physiological maturity These results are consistent with those recently published (Payne, W A 1997) Managing yield and water use of pearl millet in the Sahel Agron J 481 - 490) suggesting that ≥20,000 hills/ha, ≥ 40 kg ha ^{1} nitrogen, and ≥18 kg ha ^{1} phosphorus is required to optimize pearl millet grain yield, even in dry years Pearl millet cultivar differences, in spite of the large difference in genetic background, had much smaller impacts on grain yield and dry matter than did the production level inputs (Fig 2)

Mali

Research Methods

Long-term cropping system and residue management studies were continued at Cinzana and Koporo More intensive plant sampling/nitrogen analysis were done to determine the nitrogen use and agronomic use efficiencies of continuous, rotational and intercropping systems Soil analysis was conducted to determine the effect of five years of residue removal, incorporation and leaving on the surface on soil nutrient levels

Research Result

Rotation with cowpea increased pearl millet grain and stover yield by approximately 30% over continuous pearl millet (Table 2) Other cropping systems had similar grain yields, but stover yields were greater for sole cropped pearl millet following pearl millet/cowpea intercrop > continuous pearl millet > intercropped pearl millet/cowpea Grain nitrogen concentrations were similar but stover nitrogen concentrations were greatest for pearl millet rotated with cowpea, intermediate for intercropped pearl millet with cowpea, and lowest for continuous pearl millet These differences are large and indicate an important difference in livestock feeding value based on protein content Grain nitrogen use efficiencies were similar for all cropping systems, but total biomass nitrogen use efficiency was greatest for continuous pearl millet This is logical given the fact that the total amount of nitrogen in this cropping system should be lower, since cowpea was never present to contribute biologically fixed nitrogen However, agronomic efficiency of nitrogen use (i e fertilizer use efficiency) was the greatest for pearl millet rotated with cowpea, intermediate for continuous pearl millet and pearl millet rotated with a pearl millet/cowpea intercrop, and lowest for pearl millet intercropped with cowpea These data indicate that crop rotation combined with low amounts of fertilizer nitrogen application results in the highest grain yields combined with efficient use of fertilizer nitrogen

Crop residue management treatments had no influence on pearl millet grain or stover yields from 1991-95 (Table 3) Regardless of residue treatment, cropping over the period increased soil pH, carbon and phosphorus concentration, and decreased potassium and cation exchange capacity Phosphorus increase was due to basal fertilizer application in 1990 (after sampling) and 1993 Crop residue treatments had little influence on soil pH, carbon and cation exchange capacity after five years However, leaving crop residues on the soil surface resulted in higher soil phosphorus levels than for the other residue treatments, and incorporating and leaving residues on the soil surface had greater potassium concentration than residue removal Although yield differences did not occur for this non-degraded site with moderate

Table 2 Nitrogen use and agronomic efficiency of pearl millet cropping systems in 1995

	Yield		Nitrogen concentration		Nitrogen use efficiency		Agronomic efficiency	
	Grain	Stover	Grain	Stover	Grain	Biomass	Grain	Biomass
	Mg/ha		%		G dry matter/g N		G N/g N fertilizer	
Cowpea Millet rotation	2 1	6 0	1 50	0 75	27	103	105	406
Intercrop Millet rotation	1 6	5 1	1 62	0 64	28	116	82	335
Continuous Millet	1 6	4 6	1 56	0 58	32	122	81	310
Continuous Intercrop	1 4	3 7	1 55	0 68	30	109	70	254
Millet Intercrop rotation	1 3	3 4	1 55	0 70	29	107	65	237

Table 3 Crop residue management influence on soil properies after five years

	1991 95 Average yield		pH		Carbon		Phosphorus		Potassium		Exchange capacity	
Treatment	Grain	Stover	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995
Residue (R)	Mg/ha				%		ppm		cmol/kg			
Removed	1 5	3 4	4 9	5 3	0 16	0 37	8	24	0 30	0 13	2 8	1 2
Incorporated	1 6	3 6	4 7	5 5	0 21	0 41	10	26	0 28	0 18	2 5	1 0
Surface	1 5	3 5	4 7	5 5	0 20	0 36	11	35	0 31	0 19	2 8	1 1
Mean	1 5	3 5	4 8	5 4	0 19	0 38	10	28	0 30	0 17	2 7	1 1
Year (Y)			**		**		**		**		**	
Residue (R)			NS		NS		**		*		NS	
Y x R			NS		NS		**		NS		NS	
C V (%)			5		35		22		50		31	

soil phosphorus levels, leaving crop residues on the soil surface appears to be a more sustainable system based on soil phosphorus and potassium levels

Technology Transfer in Mali

Technology Transfer Methods

During the past decade the PVO World Neighbors has been working with 20+ communities in the Segou region Initially, contact with IER scientists and extension agents (PNVA) consisted of seed distribution In 1990, a more formal interaction developed between IER scientists, PNVA agents, and communities with World Neighbor involvement Initial activities were on crop production practices and manure management In 1992, IER scientists and PNVA agents started on-farm testing and research with these communities which continues to date Obviously there were many players involved in these activities, but INTSORMIL played an important role in the research which led to the technologies, and IER scientists collaborating with INTSORMIL Project UNL-213 (along with Karim Traore, former pearl millet breeder) were instrumental in helping move these technologies on-farm World Neighbor workers indicate that during the past five years the following IER developed technologies have been tested on farm

* six grain sorghum varieties
* five pearl millet varieties
* four cover crops
* improved intercropping system practices
* improved fallow systems (species grown during the fallow period)
* improved manure management (composting, corraling animals)

Technology Transfer Results

World Neighbor employees indicate wide spread adoption of early season improved grain sorghum (CSM 219) and pearl millet (IBV 8001, Composite Souna Sagnon, and Benkadinyo) cultivars, improved manure management (corraling animals at night, composting with crop residues), and use of improved intercropping systems In addition, animal traction is widely used, at least partially due to IER training efforts Crop residue management has shifted from using it for livestock feed and burning the excess to leaving approximately 1/3 of crop residue in the field (helps protect the soil, but not so much as to hinder animal traction) and removing the rest for use as either livestock feed or composting with animal manure Some fertilizer use on cereals occur since it is available from cotton production in the area These interactions have identified needs of these communities for development of improved long season cultivars of grain sorghum and pearl millet with desirable food quality, bird damage to early season cultivars, lack of water for composting during the dry season, and transportation needs for composted manure with crop residues The research/technology tranfer activities in this region merit a more formal impact assessment in the future

Networking Activities

Workshops

* American Society of Agronomy Meetings, 3 - 8 Nov 1996, Indianapolis, IN
* Soil Fertility Management in West African Land Use Systems Regional Workshop Sponsored by the University of Hohenheim and ICRISAT Sahalien Center, 4 - 8 March 1997, Niamey, Niger
* ROCAFREMI (West and Central Africa Pearl Millet Research Network) P4 Agronomy Meeting, 10 - 14 March 1997, Bamako, Mali

Research Investigator Exchange

Visited Nigerien and Malien research collaborators during 4 - 14 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 P4 Agronomy group on “research management” and “myths of soil fertility in West Africa” during their meeting 10 - 14 March 1997 in Bamako, Mali
- Funds passed through to Mali to assist with collaborative research efforts
- Plant samples from Niger (96 samples for multi-elements) were analyzed in Nebraska
- Camera was purchased to assist in documenting research efforts/impact in Mali

Publications and Presentations

Abstracts

Mason S C T D Galusha, R W Klein and A Limon Ortega 1996 Pearl millet row spacing and planting date in the Great Plains Agon Absts p 130

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 85 IN Abstracts Soil Fertility Management in West African Land Use Systems University of Hohenheim and ICRISAT Sahalien Center Niamey Niger

Maman N S C Mason and S Sirifi 1997 Genotype and fertilizer influence on pearl millet growth and nutrient uptake in Niger Agron Absts (In Press)

Maman N S C Mason and T D Galusha 1997 Genotype and N influence on pearl millet growth and nutrient uptake Agron Absts (In Press)

Coulibaly A O Niangado M Diagouraga, and S Coulibaly 1997 F_1 cross cultivars an alternative to improve the yield potential of pearl millet in central and Soudanian zone of Mali International Symposium on Phytogentic Resources 24 28 Feb Bamako Mali

Journal Articles

Bagayoko M S C Mason S Traore and K M Eskridge 1997 Pearl millet/cowpea cropping system yields and soil nutrient levels African Crop Sci J 5(1) 99 (Erratum)

Limon Ortega, A S C Mason and A R Martin 1997 Production practices improve grain sorghum and pearl millet competitiveness Agron J 89 (In Press)

Mason S C J M Lasa J Lasschuit, N E D Croz Mason and A Garcia 1996 Combining ability effects for sorghum emergence potential in crusted soils coleoptile diameter and length and kernel weight Maydica 41 295 299

Miscellaneous Publications

Coulibaly A S Traore M Bagayoko and O Coulibaly 1996 Production of organic manue by composting and animal corraling Monthly Workshop of Technology Review IER/PVNA 4 5 Nov 1996 Cinzana, Mali

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-214
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Dr Alhousseini Bretaudeau, Professor, IER, B P 06, Katibougou, Mali
Mr Seyni Sirifi, Agronomy Division, INRAN, B P 60, Kollo, Niger
Dr R K Pandey, Agriculture Advisor, World Bank, Niamey, Niger

Summary

Studies on N fertilization management in Niger for sorghum indicated that yields were reduced in 1996 compared to 1995 Fertilizer N rates from 0 to 200 kg ha^{-1} were not significantly different at either of two locations tested Numerically, however, the 50 to 100 kg ha^{-1} rate was superior for increasing grain yield Grain yields at the lower rainfall location, Tillakaina, were double that of the greater rainfall location, Bengou, due to lack of adequate plant stand at the Bengou location Numerically, higher planting densities were more productive in the moist region, Bengou, and lower densities looked more productive in the drier area of Tillakaina

Three new studies were initiated in Niger for the coming year 1) a study on soil preparation for sorghum planting, 2) a study on sorghum-peanut intercropping, and 3) a study on N use efficiency on sorghum in cooperation with a World Bank project

On-farm studies were initiated in Mali at three locations using five varieties and three soil nutrient levels The preliminary results indicated that yield levels were less than one t ha^{-1} and did not improve dramatically by fertilizer addition Most likely the primary limiting factors this season were soil moisture, poor stands, and perhaps disease Newer varieties responded to nutrient additions better than the local control variety

Controlled studies in nitrogen uptake and use indicated that the greatest N use efficiency occurred if the nutrient supply was 100% in the NO_3^- form rather than a mixture of NO_3^- and NH_4^+ ions The African genotypes, Malisor 84-7 and S34, had greater N use efficiency than the U S line CK60

A greenhouse study on root uptake kinetics of N showed that TX631, a U S line, has a greater capacity to absorb NO_3^- at enhanced NO_3^- levels than African genotypes However, when the NO_3^- supply is deficient, African types are superior It appears that African genotypes are better suited to extract nutrients in N deficient soils than U S genotypes, in part due to their greater capacity for extracting NO_3^- at levels below their U S counterparts The African genotypes also have larger, more highly branched, root systems

Objectives, Production and Utilization Constraints

Objectives

- Identify sorghum and pearl millet genotypes which are superior in nutrient use efficiency (primarily nitrogen)
- Determine the physiological and morphological mechanisms which allow genotypes to be nutrient use efficient

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

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

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

Constraints

Soil nutrient deficiency stresses

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

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

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

Research Approach and Project Output

International Research

Studies on Row Spacing and N Fertilization of Sorghum in Niger - Seyni Sirifi

The second year of a two year study was conducted at Bengou (600 mm rain zone) and Tillakaina (300 to 400 mm rain zone) During the 1996 cropping season the rainy season was very short at both locations Yields were generally reduced from that in 1995

Five genotypes were used in both experiments in order to find out their performance to different densities and N rates The five genotypes consisted of three improved (SRN-39, IRAT 204, and SEPON 82), one hybrid (NAD-1), and one sorghum land race variety In both experiments, a 5 x 5 factorial in a randomized complete block design with four replications was used

In the N fertilization experiments, the levels of nitrogen applied were 0, 50 100 150 and 200 kg ha ^{1} of urea in split application (at the first and second weeding period) Before planting phosphorus in the form of simple super phosphate (100 kg hakg ha ^{1}) was also applied uniformly in each plot Seeding in this experiment was done on July 25, 1996 at Bengou and on July 29, 1996 at Tillakaina These planting periods were principally too late in the moist zone where seeding of sorghum usually occurs in early June The main problem occurring in both locations was drought and the short period of the rainy season (from the end of July to the end of September), which caused death of several sorghum plants at different growing stages, mainly between heading and filling stages at Tillakaina station

The spacing trial was similar to that of the N fertilization trial in terms of experimental design varieties and cropping conditions (rainfall pattern, planting time, weeding thinning pests and disease problems) The only difference between these two experiments was the N level which was 100 kg ha ^{1} of urea uniformly applied in each plot in split application in the row spacing trials

For N fertilization trials, no interaction was found between N rates and genotypes for the three variables measured This might be caused by the large variations among and between treatments due to rainfall patterns drought and other reasons Coefficients of variations (CV) were very high in trials of the two agro-ecological zones They were 69 91, 89 50, and 50 74% for panicle grain, and biomass yields respectively, at Bengou At Tillakaina, the CV were 40 42, 46 28 and 29 85% for the same variables respectively At Bengou, genotype NAD-1 followed by the land race variety, produced more panicle, grain and biomass yield than the other genotypes in the study (Table 1) Panicle, grain and biomass yields of NAD-1 were 1300, 770 and 3516 kg ha ^{1}, respectively Yields were very low compared to those obtained in 1995 The 1995 panicle and grain yields were about four times greater than those of 1996 for most of the genotypes For example 4380 kg ha ^{1} panicle yield and 2331 kg ha ^{1} grain yield was produced by NAD-1 in 1995, against 1300 kg ha ^{1} and 769 kg ha ^{1} respectively in 1996 N rates did not significantly affect yield of the three variables, although in absolute means 100 kg ha ^{1} urea rate resulted in greater panicle grain and biomass yields

At Tillakaina, panicle, grain, and biomass yields were also low but pretty close to those obtained in 1995 The local variety did not perform well compared to the improved ones Genotypes NAD 1 and SEPON 82 were the most productive among the genotypes tested in 1995 and 1996 N rates did not influence panicle, grain, and biomass yields either at Bengou or Tillakaina, but in terms of absolute values, the 50 kg ha ^{1} urea rate tended to increase panicles, grain, and biomass yields

For the row spacing trials interaction was not observed between row spacing and genotypes Row spacing did not significantly affect panicle grain and biomass at Bengou and Tillakaina Genotypes differed in panicle grain and biomass yields in the Bengou trials whereas they differed only in grain yields at Tillakaina As in the fertilization trials, genotypes NAD1 and the land race variety were more productive at Bengou while NAD1 and SEPON 82 performed better at Tillakaina

The main characteristics of the 1996 cropping season were late planting and drought throughout the season These environmental conditions affected production of sorghum

Table 1 Means of panicle, grain and stover biomass production averaged over five fertility rates at two locations in Niger

	Bengou			Tillakaina		
Varieties	Panicle kg ha^{1}	Grain kg ha^{-1}	Stover kg ha^{1}	Panicle kg ha^{-1}	Grain kg ha^{1}	Stover kg ha^{-1}
SRN39	483	209	1910	2044	1397	2955
NAD1	1300	770	3516	2705	1800	3609
IRAT 204	487	236	1687	2361	1641	3349
SEPON 82	435	227	2368	2464	1682	3413
LOCALE	809	374	3031	1856	1366	2750
LSD	318	209	837	586	463	608

and other crops in all agro-ecological zones of Niger Production of all rainfed crops was less compared to the previous year Although a reduction in yield was observed in the two experiments in both location sites, it is important to indicate that trends in genotype performance looked the same in 1995 and 1996 Some of these trends are as follows

* No interaction was found between genotypes and N rates, and between genotypes and row spacing

* N rates did not affect panicles, grains, and biomass yields, but in absolute mean values, 100 kg ha ^{1} urea in the moist zone (Bengou), and 50 kg ha ^{1} urea in the dry zone (Tillakaina) gave more yields in panicles, grains and biomass

* High planting densities (0 80m x 0 20m, and 0 80m x 0 40m) seemed to be more productive in the moist region (Bengou), whereas low planting densities (0 80m x 0 80m, and 0 80m x 0 60m) looked more productive in the dry area (Tillakaina) in absolute mean values

Research Activities Initiated in 1996 in Niger

Besides the experiments on sorghum conducted through the INRAN/INTSORMIL project, the following research activities were also undertaken in collaboration with some researchers of other institutions such as ICRISAT, World Bank, and Peanut CRSP The report on most of these studies will be descriptive due to a non availability of data or a non analysis and interpretation of available data

Study on Soil Preparation

This study compared seven soil preparation methods in combination with three fertilizer levels in order to determine the appropriate soil preparation and fertilization before planting for sorghum Treatments included no till, plowed, ridges, other methods for soil preparation factors, and use of manure, and chemical fertilizers for fertilization aspects The experiment started in 1994 and results obtained so far showed that tied ridging with 5 t ha ^{1} of manure and 50 kg ha ^{1} of urea gave best yield in grain and biomass This soil preparation method and fertilization is going to be tested on-farm from this year (1997) and in the INRAN/INTSORMIL project in the next five years

Study on Sorghum-Peanut Intercropping - Peanut CRSP/ICRISAT

This study was initiated in collaboration with Dr Bill Payne, Crop Physiologist at ICRISAT, and Dr Issaka Mahamane, Coordinator of Niger INTERCRSP project Trials were conducted at Kollo and at an INTERCRSP research site at Tara, near Bengou station The main objective of the study was to find an appropriate sorghum and peanut intercropping strategy Sorghum genotype NAD-1 and three peanut varieties (55 437, TX 32-1, and WB 9) were used in this experiment Sorghum was planted at 0 80m x 0 80m row spacing, while three different densities were used for peanuts in a randomized complete block design with four replications Results of the trial gave good indication of the feasibility and usefulness of this type of intercropping, which is not very common in our cropping system The trial conducted at Kollo failed due to drought and diseases on peanut plants This experiment is an exploratory study on sorghum and peanut intercropping and will be continued especially at Tara

Study on N Use Efficiency on Sorghum - R K Pandey, World Bank

This research activity consisted of the use of five nitrogen levels (0, 45, 90, 135, and 180 kg N/ha) on a hybrid (NAD-1) and an improved (SRN-39) sorghum genotype Trials were conducted at Kollo and Lossa stations Row spacing of sorghum was 0 80m x 0 20m, 50 kg P205/ha and 100 kg KCL/ha were applied before planting Data collected from that experiment are available but are not yet analyzed The experiment is going to be conducted for at least two more years to compare genotypes for N response and N use efficiency

On-Farm Trials in Mali - Abdoul Toure

On-farm studies were initiated in 1996 in, or close to, three locations in Mali Treatments consisted of 1) zero nutrient additions, 2) zero N and 46 kg ha ^{1} P, and 3) 40 kg ha ^{1} N and 46 kg ha ^{1} P Five varieties were used at each location and included a local variety, three radiation mutated varieties, MikSOR 86-76-11, MikSOR 86-24-20, MikSOR 86-30-42, and the parent CSM 388 from which they were devised The mutated lines were developed at the University of Katibougou by Dr Alhousseini Bretaudeau Each farm is considered to be a replication

Results indicated that grain yields in these farmers' fields was about 770 kg ha ^{1} on the average Only a slight increase occurred with use of P fertilizer (783 kg ha ^{1}), but with both N and P fertilizer added, yields averaged 896 kg ha ^{1} It appeared that CSM 388 and the derived mutants responded better to applied nutrients than the local sorghum variety When averaged over all varieties, there was no significant increase in yield due to fertilizer Given the low yields, it appeared other factors such as moisture supply, disease, or poor stands were dominant in determining yield Careful attention will need to be paid to proper soil preparation (stands) and moisture conservation (residues) in these trials during the following years of this study

Domestic Research and Research Related to Student Training

Studies on Genotypic Differences in NO3 and NH$_4^+$ Uptake and Its Effects on Dry Matter Production and N Use Efficiency - Abdoulaye Traore

Nitrate is the major N source for grain sorghum The NO$_3$ taken up needs to be reduced into NH$_4^+$ in order to be metabolized Literature cites genotype differences in both NO$_3$ and NH$_4^+$ uptake The objective of this study was to investiage the genotypic differences among four grain sorghum genotypes in N uptake under either NO$_3$ or NH$_4^+$ form and its influence on nitrate reductase activity (NRA), total N content, dry matter production and N use efficiency (NUE)

Four grain sorghum genotypes, Malisor 84-7, S34, CK60, and M 35-1 were grown in a greenhouse in three different nutrient solutions The solutions were the same in their total N content but differed in the NO$_3$ /NH$_4^+$ ratio

Solution 1 100% NO$_3$ /0% NH$_4^+$

Solution 2 75% NO$_3$ /25% NH$_4^+$

Solution 3 50% NO$_3$ /50% NH$_4^+$

The treatment combinations were replicated four times in a randomized complete block design ANOVA and single degree contrast methods were used to analyze the data Two plants were grown in each pot of nine liters Roots of the two plants were separated with a plexiglass plate, however the solution could freely circulate between the two compartments as a bubbling system was aerating the root media Specific electrodes were used to determine NO$_3$ and NH$_4^+$ uptake through regular sampling One plant was harvested at the 10 leaf stage, and the remaining one was allowed to grow to the flowering stage before harvesting

At the 10 leaf stage, there were no significant differences among genotypes for NO$_3$ or NH$_4^+$ uptake, however, NO$_3$ and NH$_4^+$ were different among nutrient solution treatments The greater the concentration of the solution in NO$_3$ or NH$_4^+$, the greater the uptake of that particular molecule (Table 2) The geographical origin of a variety did not make any difference in their uptake However, the total N content (%) was different among genotypes with CK60 having greater tissue concentration than Malisor and M35-1 (Table 2) Genotype S34 had the least Nitrate reductase activity, total leaf area and shoot biomass were not significantly different among genotypes or nutrient solutions (Table 2) In contrast, root biomass was significantly different among genotypes and nutrient solutions with M 35-1 having greater root biomass than S34 followed by Malisor 84-7 which was greater than CK60 NUE$_1$ was statistically different among genotypes and nutrient solutions (Table 3) S34 and M 35-1 were similar and had greater efficiency than Malisor 84-7, which in turn was superior to CK60 Among nutrient solutions, solution 1 with 100% NO$_3$ and 0% NH$_4^+$ induced greater NUE than solution 2, which was greater than solution 3 This result contradicts the hypothesis that greater NH$_4^+$ uptake would be more efficient due to the fact that there is no reduction needed

In summary, this experiment indicated that at the 10 leaf stage, increasing NH$_4^+$ ratio in the nutrient solution did not induce any significant changes on plant growth and biomass production Local genotypes, Malisor 84- 7, S34 and M35-1 selected in low N conditions are more N use efficient than CK60 Solution 1 with 100% NO$_3$ induced the greatest NUE$_1$ and this value decreased with increasing NH$_4^+$ in the solution

Nitrate Uptake Kinetics and N Utilization of Sorghum - Cassim Masi

Nutrient absorption is one of the principal functions of plant roots, and kinetics of nutrient absorption affects nutrient supply and plant growth The uptake kinetics of nitrate (NO$_3$) into roots of 42-d-old sorghum genotypes differing in root branching and N utilization were examined over the concentration range of 0 2 to 1 2 mM NO$_3$ in the greenhouse using the nutrient solution depletion technique The genotypes consisted of one U S genotype, and three African genotypes The objectives of this study were 1) to determine the NO$_3$ uptake kinetic parameters and root uptake coefficient (α) of the four sorghum genotypes from different ecological zones under greenhouse conditions and 2) to determine if the genotypic net uptake of NO$_3$ (I_n) conforms to saturable Michaelis-Menten type kinetics over a range of NO$_3$ concentrations within a 12 h-period A set of three replicates for each genotype comprising of absorption curves was fitted to a rectangular hyperbola representing the Michaelis-Menten equation of the form $I_n = I_{max} ([NO_3] - C_{min}) / K_m + ([NO_3] - C_{min})$

No significant differences were observed among the sorghum genotypes in mean root radius (R_0) and shoot dry matter (Table 4) However, root fresh weight (RF*wt*), root length (*L*), and root surface area (RSA) varied significantly

Table 2 Nitrate reductase activity, N uptake, and NUE_1 in four grain sorghum genotypes

	NRA (μmol NO_2 cm ^{2} h ^{1})	NO_3 uptake (mg NO_3)	NH_4^+uptake (mg NH_4)	Total plant N %
Genotypes				
Malisor 84 7	0171 a	1361 14 a	439 74 a	2 29 b
S34	0182 a	1339 70 a	405 01 a	2 17 bc
CK60	0224 a	1122 37 a	364 69 a	2 92 a
M35 1	0183 a	1559 71 a	435 47 a	2 23 b
Nutrients Solutions				
Solution 1	0187 a	1606 13 a	0 00 c	2 08 c
Solution 2	0193 a	1524 86 b	573 05 b	2 31 b
Solution 3	0190 a	906 19 c	661 00 a	2 82 a

Table 3 Biomass yield and NUE_1 of four sorghum genotypes grown at different NO_3 /NH_4^+ ratios in nutrient solution

	Leaf area (cm ^{2})	Shoot biomass (g)	Root biomass (g)	NUE_2 (g/g)
Genotypes				
Malisor 84 7	1956 a	25 6 a	9 3 b	45 8 b
S34	2210 a	25 8 a	11 0 ab	47 7 a
CK60	1341 a	19 1 a	7 1 c	36 0 c
M35 1	2419 a	28 6 a	13 1 a	47 3 a
Nutrient Solutions				
Solution 1	2150 a	27 8 a	11 9 a	51 2 a
Solution 2	2079 a	26 8 a	11 7 a	43 9 b
Solution 3	1717 a	18 9 a	6 8 b	37 4 c

among the sorghum genotypes Mean values for RF*wt* ranged from 103 9 to 126 5 g plant ^{1}, *L* ranged from 185 to 269 m plant ^{1} and RSA ranged from 0 49 to 0 74 m^2 plant ^{1} Although IR204 had significantly greater RF*wt*, *L* and RSA than TX631 and M90378R, these root characteristics did not account for an increase in either shoot N concentration or uptake kinetics in the [NO_3] used The genotype TX631 had greater shoot N concentration of 2 07% than WSV387 despite being ranked last in RF*wt* and *L* No significant linear correlation was observed either between RF*wt* and *L* and shoot N concentration when these genotypes were grown in hydroponics In contrast, a strong linear correlation between shoot N concentration and biomass N use efficiency (NUE_1, r = -0 99, p>0 01) was observed TX631 which ranked first in shoot N concentration had a much smaller NUE_1 value compared to the African genotype WSV387 The relationship between shoot N concentration and NUE_1 found in this study is consistent with the results from the field among ten sorghum genotypes when tested in depleted N soils

The greater value for I_{max} determined for TX631 suggests that this genotype has a greater capacity to absorb NO_3 compared to the other genotypes at enhanced NO_3 levels (Table 5) Plants need to have as high I_{max} value, and as low K_m and C_{min} values as possible to acquire a greater capacity for uptake efficiency In this regard, estimated values of C_{min} ranged from 0 01 to 0 14 mM None of the four genotypes evaluated in this study had the greatest I_{max} and lowest values of both K_m and C_{min} Similarly, none of the genotypes met the conditions of the first two of these characteristics, namely ranking the first with greatest I_{max} and the least K_m The roots of TX631 were not inhibited from absorbing NO_3 under increased levels of [NO_3] This may be due to the roots exerting a greater affinity for the NO_3 ions at the prevailing conditions, possibly at the plasmalemma level It has been reported that greater specific uptake rates (uptake per unit mass of root) can compensate for small root size

The results of these studies indicated that the exotic genotypes exhibited a greater root affinity coupled with a smaller C_{min} value which suggests that these genotypes are likely to be more efficient at absorbing NO_3 at limited nutrient supply than TX631 The U S genotype, on the other hand, had a high I_{max}, K_m and C_{min} which made it more adapted to conditions of adequate fertilizer application that is characteristic of U S agricultural systems Therefore, in this study, the parameters I_{max}, K_m and C_{min}, and α were useful in evaluating the NO_3 uptake characteristics of these genotypes based on their ecological environments Although the Michaelis-Menten parameters, I_{max}, and K_m or C_{min} were not significantly correlated with either uptake status of the genotypes or root morphology, at least I_{max} was positively correlated with the root uptake coefficient r = 0 95*) The implication of this finding is that I_{max} and α may play a significant role at exerting a favorable NO_3 uptake capacity for some sorghum genotypes

Table 4 **Comparison of root and shoot characteristics root fresh weight (*RFwt*), mean root radius ($\overline{R}_o$), root length (*L*), root surface area (RSA), shoot dry matter (DM), shoot N content (%), and biomass N use efficiency (NUE_1) among genotypes averaged over NO_3 concentrations**

Genotype	Root fresh weight (*RFwt*)	Root radius (*R_o*)	Root lenght (*L*)	Root surface area (RSA)	Shoot dry matter (DM)	Shoot N status N conc	Shoot N status NUE_1
	g plant^{-1}	µm	m plant^{-1}	m^2 plant^{-1}	g DM plant^{-1}	%	g DM g N^{-1}
TX631	98 3	416	188	0 49	30 9	2 07	52 5
IR204	126 5	435	269	0 74	37 6	1 96	54 2
WSV387	123 9	443	205	0 57	37 4	1 74	60 4
M90378R	103 9	421	185	0 49	36 2	1 98	53 5
$LDS_{(0\ 05)}$	18 3	NS	74	0 19	NS	0 25	6 1

Table 5 **Parameter summary for the 3-parameter Michaelis-Menten model fitted to the nitrate uptake by roots of four sorghum genotypes grown hydroponically in the greenhouse**

Genotype	Uptake parameter[1]	Kinetics estimate	Standard error	Approx student t values[2]	Correlation matrix of paratmeters I_{max}	Correlation matrix of paratmeters K_m
Tx 631	I_{max}	6 39	0 49	13 0	1 00	
	K_m	0 33	0 10	3 8	0 95	1 00
	C_{min}	0 14	0 02	7 0	0 95	0 84
IR204	I_{max}	4 22	0 54	7 8	1 00	
	K_m	0 27	0 16	1 7	0 94	1 00
	C_{min}	0 12	0 04	3 0	0 69	0 85
WSV387	I_{max}	3 03	0 47	6 5	1 00	
	K_m	0 29	0 25	1 2	0 96	1 00
	C_{min}	0 04	0 08	0 5	0 85	0 96
M90378R	I_{max}	2 78	0 29	9 5	1 00	
	K_m	0 16	0 13	1 2	0 93	1 00
	C_{min}	0 11	0 05	2 2	0 70	0 93

[1] Kinetics parameters I_{max} (µmol g^{-1} RFwt h^{-1}) K_m (mM) and C_{min} (mM) were estimated using the nonlinear regression analysis to fit the modified Michaelis Menten equation $I = I_{max}([NO_3^-] - C_{min})/(K_m + ([NO_3^-] - C_{min}))$ values are for 12 h uptake of nitrate in roots of 42 d old sorghum genotypes grown hydroponically in the greenhouse

[2] Calculated as the ratio of parameter estimate and standard error

The results of these studies also suggest that the U S genotype responded favorably to increased NO_3 levels primarily by increasing the capacity of NO_3 uptake rather than effecting the root affinity (K_m) or C_{min} An enhanced capacity of uptake, complimented by a reduced root affinity and greater C_{min}, represent adaptation characteristics in tune with the nutrient rich habitat Conversely, the African genotypes adjusted their uptake kinetics by reducing K_m and C_{min} values and this strategy represents an adaptation to dwindling nutrient levels

Networking Activities

Project UNL-214 has developed several collaborative research projects outside of the NARS The first of these in Niger is with Dr R K Pandey of the World Bank who is interested in N use efficiency improvement in sorghum We have initiated experiments this year (1997) and anticipate cooperation for at least three years We are proposing that World Bank funds be used to support day to day operations and equivalent INTSORMIL funds be used for equipment purchases

The second activity is also in Niger and is with the peanut CRSP Seyni Sirifi has initiated cooperative research activities (see this report) which will be ongoing

A third activity is with Dr Alhoussein Bretaudeau with the University of Katibougou in Mali Dr Bretaudeau is interested in the nitrogen responsiveness and use efficiency of several sorghums he has developed through radioactivity mutation These sorghums are receiving wide attention by local farmers for their reported increase in drought tolerance

The UNL-214 principal investigator participated in the West and Central African Sorghum Research Network (ROCARS) and is one of the two INTSORMIL representatives Dr Maranville made a presentation for INTSORMIL at their annual meeting at Bamako Mali in March, 1996

Publications

Madhavan S J W Maranville and J P Markwell 1996 Relationship between carbon isotope discrimination and nitrogen stress in sorghum Agron Abstr P 101

Traore A A W Toure and J W Maranville 1996 Nitrogen management for sorghum in semiarid ecosystems Agron Abstr P 130

Masi C S M 1997 Studies of root systems and nitrogen uptake in diverse sorghum genotypes Ph D diss University of Nebraska 192 P

Germplasm Enhancement and Conservation

Breeding Sorghum for Increased Nutritional Value

Project PRF-203

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Ouendeba Botorou, Millet Coordinator, ROCAFREMI, Niamey Niger
Robert Schaffert, Sorghum Breeder EMBRAPA Brazil

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 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 to use 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 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 can be appreciated

Production and marketing of seed in the private sector is not new in Niger Rice seed used in the country is produced by a co-op 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

Experience producing hybrid sorghum in Niger is as follows 750 kg for the 1996 season, 1400 kg in 1997, and 8000 kg for planting in 1998 The demand for seed far exceeds the supply The production of hybrid seed for 1996 and 1997 was done by INRAN, however, in 1997, producing seed for this 1998 season, eight private farmers produced seed successfully (ranging from 870 to 1700 kg ha ^{1}, good to very good for first time seed production) stimulating interest among others to produce seed in the 1998 season, where it is anticipated that some 50 - 60 hectares will be produced primarily by private individuals with on-station production focusing on foundation seed While these quantities of seed are very small, it is an encouraging start The strategy to initiate the seed production activity has purposely been step by step First, to gain control of seed stocks and to begin to find interested seed producers New producers were and are encouraged to sow no more than 1/2 to 1 hectare as there is a needed learning experience It is important that new producers succeed, but if they fail, they do not have a large investment Feeling that a reasonable base now exists, a thrust is being made to identify producers for 1998 The thrust has been to first effectively produce and market seed and then begin aspects of certification and a seed law

The hybrid is a product of research, and INRAN is in a transitional phase initially producing hybrid seed but with an understanding that they phase out of this activity as private individuals increasingly take up production Dr Lee House has been working with INRAN on seed production until I Kapran completes his Ph D Issoufou Kapran is the INRAN Sorghum Breeder and will complete his Ph D degree in February 1998, and will return to continue production of NAD-1 and other new sorghum hybrids under development for production in Niger

Brown Midrib (bmr) Sorghum-Sudangrass

Forage utilization and digestibility by ruminant animals is limited by the lignin percentage in the plant Genetic control of the lignification process offers the most direct method of reducing lignin content and of increasing fiber and energy digestibility Recent studies in our laboratory have shown the brown midrib gene mutation reduces lignin content in the sorghum plant tissue The result of this is significantly increased utilization and digestibility of cellulose and hemi-cellulose in sorghum plant tissue This results in improved performance of ruminant animals when fed forage of brown midrib forage cultivars

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 U S 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

The first commercially available brown midrib sorghum-sudan hybrid cultivar has now been produced by Production Plus Seed Company in Plainview, Texas Initial response of livestock producers has been excellent and about 1 million pounds of seed was sold in 1997 Foundation seed stocks are available for production of 7-8 million pounds of seed for 1999 These brown midrib cultivars will substantially improve the efficiency of ruminant animal production in the United States as a result of their superior digestibility

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 collaboration with 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 West 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 with 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% over the best parent under dry-land conditions, but only 22% 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, G 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 sub-Saharan 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 hybrids ranked higher 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

Objective 1 - *Sorghum hybrids in Niger - A case history of hybrid development in the Sahel* Sorghum is the second most important food crop in the West African country of Niger The crop is grown as rainfed in regions of the country that receive approximately 400-800 mm of annual precipitation Annual acreage of sorghum in Niger increased from less than 500,000 hectares in 1961 to two million hectares in 1996 In contrast, national average yields declined from 0 6 t ha^{1} in 1961 to 0 2 t ha^{1} in 1996 (FAO/SMIAR, 1997) Cultivation into marginal lands with declining fertility and the unwise use of poor-yielding local cultivars contributed to this limited productivity Research on sorghum improvement in Niger started in the 1950s with the French research institute for tropical agriculture (IRAT) Emphasis was on the breeding of open-pollinated varieties up to the establishment of INRAN, the national institute for agricultural research in Niger In the 1980s, sorghum breeders at INRAN in collaboration with the international sorghum and millet program (INTSORMIL), added a hybrid testing component to the selection of improved cultivars It was felt that the use of heterosis is in line with INRAN's mandate of contributing to national food self-sufficiency Experience elsewhere shows that hybrids have the potential of modernizing the agricultural sector of a country Our collaborative effort aimed at evaluating the superiority of hybrid sorghum cultivars under the marginal growing conditions prevalent in much of Niger

Materials and Methods

Experimental hybrids were synthesized from adapted germplasm provided by the Purdue Sorghum Research Program and tested at several INRAN field research stations Selected hybrids gradually move from observation nurseries of preliminary trials to advanced yield trails at several locations for two to three years The experimental design included at least one open-pollinated local variety as a check Elite hybrids resulting from these national tests were also evaluated in the West African Sorghum Hybrid Adaptation Trial (WASHAT) Data collected include estimates of maturity, plant height plant stand grain yield and grain quality, and reactions to biotic and abiotic stresses An elite hybrid, TX623A × MR732, later named NAD-1, emerged as the most promising based on the summary of the cumulative data collected over the years Its superior performance has been on demonstration in farmers' fields in several locations Since 1989 experimental seed production of NAD-1 has been underway to evaluate the feasibility of commercial hybrid seed production

Results and Discussion

Agronomic Evaluation

A summary of the annual analyses of data reported by INRAN sorghum breeders is presented in Table 1 Experimental hybrid yields averaged approximately 2 tons/ha Best hybrids yielded up to 6 5 t ha^{1} whereas best variety checks never exceeded 3 8 t ha^{1} These results confirm the findings of two graduate thesis projects conducted at Purdue University and initiated the thrust on sorghum hybrid research in Niger Issoufou Kapran reported heterosis values of 45% under irrigation and 66% in rainfed conditions of Niger In the same tests, hybrids also out yielded local checks

Table 1 Yields of sorghum hybrids at research stations in Niger, 1984-92

Year	Number of hybrids tested	Grain yield t ha^{-1} Trial mean	Best hybrid	Local variety
1984	22	2 3	5 6	
1985	17		4 0	
1986	149	2 5	2 7	1 1
1987	147	2 6	5 5	3 2
1988	81	1 9	4 9	2 7
1989	67	2 8	6 5	3 8
1990	49	2 4	5 0	3 0
1991	78	1 8	2 0	1 0
1992	88	1 9	4 6	

by 61% with irrigation and 49% under rainfed conditions Tom Tyler found that hybrids with parents grouped as exotic, intermediate, or local, were higher yielding than their respective parents by an average of 127%, 83%, and 66% Through the results of these early thesis projects and subsequent national tests conducted through INRAN and INTSORMIL collaboration, the agronomic value of heterosis for Niger's agriculture has largely been demonstrated

NAD-1, a medium-maturing, white-seeded hybrid with good tolerance of mid-season drought (common in Niger), was the most attractive cultivar to breeders and farmers alike In national trials, its yield average was 3 1 t ha ^{1} between 1986 and 1992 Also in the 1989 WASHAT trial, it ranked third of 20 entries for grain yield at nine locations across West and Central Africa Estimates of NAD-1 yield potential under farmer management were obtained starting in 1993 (Table 2) Averages vary between 1 7 t ha ^{1} and 3 3 t ha ^{1} Despite severe drought conditions, the hybrid was superior to Mota Maradi (MM), an early-maturing and widely adapted local variety Also, from on-farm trials of the regional sorghum network, the yield of NAD-1 was 80% higher than the average of farmer checks The strong interest expressed by farmers in this hybrid over the years is thus easily understandable

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, **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 co-ops, and individuals that potentially could turn into commercial seed producers

Table 2 Yield of elite sorghum hybrid, NAD-1, under farmer conditions in Niger, 1993-96

Year/Activity	Local variety t ha ^{1}	NAD 1	% over local
1993 Demonstrations		2 4	
1994 Demonstrations		3 3	
1995 NAD 1 vs MM trial	1 0	1 6	60
1996 NAD 1 vs MM trial	0 7	1 7	143
Regional network trial	1 0	1 8	80

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 being used today by INRAN, INTSORMIL, and the Sahelian Center of ICRISAT, to educate policy makers and private producers on the need for, and 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 act vities 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

Objective 2 *Develop rapid screening techniques for breeders to assess the new high digestibility trait recently discovered by Dr Hamaker in germplasm from our program* Grain sorghum has been documented to have low protein digestibility relative to other cereal grains, whether cooked for human consumption in semi-arid tropical regions or for feeding livestock Low protein digestibility of sorghum is most pronounced in cooked foods, and is somewhat lower as a feed grain In collaboration with Bruce Hamaker, sorghum germplasm has now been identified that has substantially higher uncooked and cooked flour in vitro protein digestibility than normal cultivars Sorghum lines were found within a high-lysine population derived from the mutant P721Q that have about 10 to 15% higher uncooked and 25% higher cooked protein digestibilities using a pepsin assay Highly digestible sorghum grain showed little reduction in digestibility after cooking, compared to the large reduction that is typical of normal sorghum cultivars Using the three-enzyme pH-stat method, it was shown that the highly digestible lines had the same degree of peptide bond hydrolysis in approximately 5 min as was found in 60 min in the normal cultivar, P721N (Figure 1) Differences in protein digestibility were related to enzyme susceptibility of the major storage prolamin, α-kafirin, that comprises about 50 to 60% of the total sorghum grain protein Using the ELISA technique to track the pepsin digestion of α-kafirin, the highly digestible lines had about 90 to 95% α-kafirin digested in 60 min compared to 45 to 60% for two normal cultivars γ-Kafirin, a minor structural prolamin found mainly at the periphery of protein bodies, was also somewhat more digestible in the highly digestible sorghums More digestible protein from sorghum grain, that additionally is high in lysine content, could be of important benefit to populations who lack adequate protein in their diets, and may, pending further studies, prove to increase the value of sorghum as a feed grain

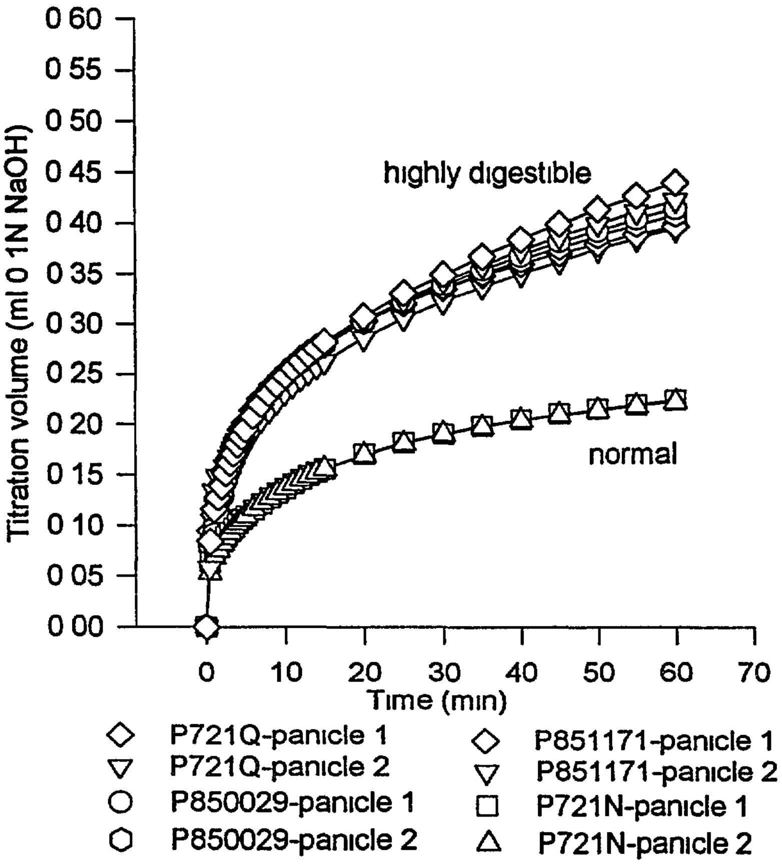

Figure 1 **Titration curves by the pH-stat method over 60 minutes comparing two uncooked panicles of one normal (P721N) and three highly digestible (P721Q, P850029, P851171) sorghum lines (Figure courtesy of Charlotte Weaver and Bruce Hamaker)**

Objective 3 *Identification of molecular markers linked to high protein digestibility and or high lysine in high lysine sorghum lines* Sorghum is one of the four major cereal crops grown in the world for use either as human food in most developing countries, or as animal feed in the developing world Compared to other cereal crops, sorghum is low in protein (especially in such amino acids as lysine) In 1973 however, Axtell and Singh identified some high lysine sorghum germplasm in the world collection Axtell and Mohan also developed a high lysine sorghum mutant P721 opaque (Q) at Purdue University using diethyl sulfate When grown in the field, however, P721Q was found to be poor both in agronomic traits and kernel textural (floury endosperm) qualities Many crosses and selections involving the high lysine mutants were made, and presently, several high lysine inbred lines with good agronomic characteristics are available at Purdue University Some of the lines were recently found by Hamaker to have high protein digestibility The objectives of this research are (1) to determine whether high lysine, high protein digestibility, and hard kernel texture can be inherited together, (2) to determine whether the three traits are correlated, and (3) to identify molecular markers linked to the three traits either separately or as a unit

Two F_{10} populations comprising 103 P851171 (a high lysine mutant) × SRN39 (a normal type) and 29 P850115 (a high lysine mutant) × MR732 (a normal type), together with their parents, were grown at a winter nursery in Mexico in November 1996 Mexico was the environment of choice because of its warm and dry tropical weather during seed setting This is particularly good for kernel texture screening The experimental design was a randomized complete block design with three replications Field data on agronomic traits were taken in the middle of April 1997

In May 1997, three selfed heads from each plot were harvested and bulked together leaving some remnant seed All harvested seed was shipped to Purdue for laboratory analysis At the present, data have been taken on kernel density, kernel hardiness, and lysine content Kernel density and hardiness were determined using a pycnometer and TADD machine, respectively Recently, materials were sent to the University of Missouri-Columbia Experiment Station Chemical Laboratories for lysine content determination using the AOAC standard ion exchange chromatography procedure Currently, we are in the process of determining protein content using the micro-Kjeldahl method We plan to start protein digestibility assays using the pH-stat method Molecular markers work is scheduled to begin some time in January 1998

Objective 4 *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 a low lignin brown midrib gene 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 1 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

Objective 5 *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

Networking Activities

Workshops

- *In-Progress* - The West African Hybrid Sorghum and Millet Workshop will be held September 27 - October 2, 1998 A steering committee will meet in January 1998 to develop the program and identify potential speakers and attendees 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 are available in Niger for sale during 1998 and for demonstration plots associated with the workshop in Niger The seed production effort in 1997 involved a major effort by Dr Lee House, with McKnight Foundation and World Bank support, under the auspices of the Purdue INTSORMIL project (PRF-203A and PRF-209) Dr House made four extended trips to Niger in 1997 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 1997 was a training program conducted at the ICRISAT Sahelian Center in the Spring of 1997 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 1998 A practical training manual on hybrid seed production in Niger was prepared in English and French

Research Investigator Exchanges

* A number of sorghum scientists from the U S and throughout the world were involved in exchanges during 1997 Many of these scientists participated in the INTSORMIL/ICRISAT International Conference on the Genetic Improvement of Sorghum and Pearl Millet during the Fall 1996 Our most recent exchange occurred with the new Director General of ICRISAT, Dr Shawki Barghouti, to discuss West African sorghum research Dr M V Rao who was, according to Dr Norman Borlaug, the most influential wheat breeder during the Green Revolution Days in India, spent a week with our faculty and graduate students on the sorghum project in 1997

Germplasm and Research Information Exchange

* Numerous request 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 funds for Dr Adam Ababoucar to attend training in France and installation of the equipment with French technicians in Niamey, Niger A diesel pump for irrigation was provided by PRF-203 to provide supplemental irrigation for hybrid seed production in Maradi in 1997

Publications and Presentations

The most important presentation made was an invited paper on heterosis in sorghum and millet at the CIMMYT Heterosis Conference in Mexico City 1997

A very useful practical training manual on hybrid seed production was published in French and English for use in training activities in Niamey Niger Spring 1997

Axtell J D I Kapran Y Ibrahim G Ejeta, L House B Maunder 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)

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

Project PRF-207

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Dr Mitchell Tuinstra, Department of Agronomy, Kansas State University
Dr Darrell Rosenow, Texas A&M Univ Agricultural Experiement Station, Route 3 Box 219, Lubbock, TX
Mr David Andrews, Department of Agronomy, University of Nebraska, Lincoln, NE
Dr Kay Porter, Pioneer HiBred International, Plainview, TX

Summary

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limited production, knowledge of germplasm and appropriate physical environment for evaluation and testing Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses Research and germplasm development activities in PRF-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 18 we reported on the results of two major studies that were recently completed and published The first study involved a genetic analysis of post-flowering drought tolerance in sorghum using a mapping population developed for this purpose We generated a linkage map from 170 molecular markers (RFLP and RAPD) and associated the marker data with phenotypic characterization of post-flowering drought tolerance conducted under controlled irrigation regimes We identified 13 genomic regions associated with post-flowering drought tolerance Genomic segments accounting for 12% of grain yield per se, 36% of yield stability, 51% of duration of grain fill, and 62% the variability in rate of grain development were identified

The second study dealt with identification of major physical and chemical kernel characteristics associated with grain mold resistance in diverse landraces of sorghum We found that a more meaningful characterization of grain mold resistance is made possible as a result of developing a quantitative selection index that integrated both physical and chemical properties of resistant genotypes The use of such an index may facilitate the development of highly resistant and agronomically acceptable parental lines and hybrids in an array of sorghum genetic background

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 Consevation and Diversity

- To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation
- To develop and enhance sorghum germplasm with increased levels of resistance to drought, *Striga*, diseases, and improved quality characteristics
- To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U S and LDC scientists and institutions
- To assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity or for discerning genetic diversity of sorghum and millet germplasm pools

Training Networking and Institutional Development

- To provide graduate and non-graduate education of U S and LDC scientists in the area of plant breeding and genetics
- To develop liaison and facilitate effective collaboration between LDC and U S sorghum and millet scientists
- To encourage and facilitate positive institutional changes in research, extension and seed programs of collaborating countries involved in sorghum and millet research and development

Program Approaches

The research efforts of PRF-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, IN 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 TX 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, AZ Over the years, assistance in field evaluation of nurseries has also been provided by industry colleagues, particularly at Pioneer HiBred 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 close interaction with research scientists and program leaders of NARS and associated programs Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali and some in Southern Africa through SADC/ICRISAT

Project Output

Research Findings

Genetics of Post-Flowering Drought Tolerance and Components of Grain Development in Sorghum

Sorghum is one of the most drought tolerant crops, yet it possesses substantial genetic variability for drought tolerance in its gene pool Mechanisms for maintaining plant growth and development in arid environments are complex and not well understood Expression of drought tolerance in sorghum genotypes tend to depend on the stage of plant development Susceptibility to drought can occur during the early vegetative seedling stage during the period of panicle development prior to flowering and during the post-flowering stage of grain development This developmental interaction complicates overall characterization of drought tolerance unless attention is given to the developmentally specific reactions to drought by sorghum genotypes The purpose of this study was to characterize the expression and inheritance of traits associated with post-flowering drought tolerance and grain development in a set of recombinant inbred (RI) sorghum lines The objectives of this study were (1) to characterize the RI mapping population for the expression of post-flowering drought tolerance and components of grain development, (2) to identify QTL associated with these traits, and (3) to determine if loci associated with the rate and duration of grain development are associated with post-flowering drought tolerance

The experimental material consisted of 98 recombinant inbred sorghum lines developed from a cross between inbred lines TX7078 (pre-flowering drought tolerant, post-flowering drought susceptible) and B35 (pre-flowering drought susceptible and post—flowering drought tolerant) using the Single-Seed Descent method of plant breeding Field studies to evaluate the RI lines for differences in agronomic performance were conducted under post-flowering drought and fully-irrigated conditions at two locations, Nayarit, Mexico, and Yuma, Arizona A third study evaluating differences in rate and duration of grain development was conducted at the Purdue University Agronomic Research Center near West Lafayette, IN Post-flowering drought tolerance was estimated using grain yield under stress, yield stability, seed weight stability, and visual score for staygreen (as a measure of resistance to premature senescence) The rate and duration of grain development for each RI line were determined from measurements of the number of days to anthesis, number of days to physiological maturity, and seed weight at physiological maturity The genetic analysis of the RI lines were done using 150 RAPD and 20 RFLP markers where the 170 markers identified in this population were ordered into a linkage map as described in our 1996 INTSORMIL annual report

Significant differences in grain yield, seed weight, and staygreen were observed among genotype in each testing environment These differences indicate segregation in the mapping population for genetic factors contributing to these traits Differences among RI lines for both duration and rate of grain development were also significant

Thirteen genomic regions were associated with post-flowering drought tolerance in our mapping population (Table 1) Regions of linkage group F and I were associated with grain yield in the post-flowering drought trial Together these loci account for about 12% of the variability in grain yield under post-flowering drought These QTL were also associated with the staygreen trait Four QTL were detected on linkage groups B, C, and E for yield stability under post-flowering drought These four QTL account for 36% of the variability in yield stability Seven QTL on linkage groups A, E, G, and N were associated with duration of grain development and account for 51% of the phenotypic variability in duration of grain fill in the mapping population QTL identified for rate of grain development accounted for 62% the variability in rate of grain development Some of the QTL for rate of grain filling were also associated with higher seed weight

Previous studies have demonstrated that differences in yield stability are unrelated or may be negatively related with differences in yield potential A comparison of QTL for yield, yield stability, and seed weight stability under drought in this study confirmed the presence of little genetic relationship between these different measures of tolerance Markers associated with yield, yield stability, and seed

Table 1 Effects of QTL identified using combined and individual year analysis of the recombinant inbred population The significance of associations (P>F)[a] between markers and traits are shown

Marker		Treatment[b]	Combined Trait	Analysis	1992	1995
A	t375/45	D	Seed weight stability	0 0045	0 1882	0 0013
B	tF16/68	D	Staygreen	0 0041	0 0003	0 2063
	UMC22	D	Yield stability	0 0015	0 3041	0 0084
	TL19/62	D	Staygreen	0 0014	0 0260	0 0083
	E1/300	I	Seed weight	0 0064	0 0981	0 0028
	BC15/95	D	Yield stability	0 0001	0 0564	0 0001
C	tH9/82	D	Yield stability	0 0045	0 4613	0 0516
	B229/47	I	Seed weight	0 0020	0 0048	0 0056
D	UMC85	I	Seed weight	0 0049	0 0319	0 0081
E	tD19/170	I	Seed weight	0 0009	0 1214	0 0001
		D	Yield stability	0 0002	0 3012	0 0001
	B206/89	D	Yield stability	0 0001	0 6953	0 0001
		D	Seed weight stability	0 0085	0 0335	0 0480
	UMC109	I	Yield	0 0088	0 2363	0 0107
		I	Seed weight	0 0005	0 1148	0 0001
F	tM5/75	D	Staygreen	0 0001	0 0025	0 0001
		D	Yield	0 0096	0 3982	0 0078
		I	Yield	0 0004	0 0151	0 0009
	UMC84	I	Seed weight	0 0001	0 0001	0 0015

[a] Probability of obtaining a higher F value by chance
[b] D=post flowering drought I=fully irrigated

weight were variable across testing environments These results reaffirm the importance of multi-environment testing when evaluating drought tolerance and other traits subject to environmental interaction Markers associated with stay-green and seed weight were more stable and consistent across environments Marker-assisted selection for these loci should be productive for enhancing the expression of these traits across environments

Grain Mold Identifying Kernel Properties Associated with Resistance to Grain Mold in Sorghum

Grain mold is a serious disease of sorghum in environments where physiological maturation of the sorghum kernel coincides with seasonal humidity and warm temperatures Damaged kernels tend to have reduced test weight, viability, and nutritional quality as well as kernel appearance and associated market value Use of resistant cultivars is the only feasible way to minimize damage from grain mold Selection efforts are hampered by limited knowledge of traits associated with genetic resistance to grain mold

Identifying chemical and physical kernel properties associated with resistance of sorghum to grain mold would facilitate screening germplasm for resistance before subsequent inclusion of specific genotypes in a breeding program An array of phenolic compounds (condensed tannins, phenolic acids, flavan-4-ols) have been implicated in grain mold resistance in sorghum Physical kernel properties, including a high proportion of corneous to floury endosperm, thick surface wax of the grain, and kernel density have also been associated with enhanced resistance to grain mold However, these findings were based on a limited number of genotypes The objectives of this study were to (1) evaluate a large working collection of diverse tropical landraces of sorghum for grain mold resistance, (2) characterize a diverse sorghum germplasm collection for kernel traits associated with grain mold resistance, and (3) assess the cumulative contribution of physical and chemical kernel properties in sorghum on overall resistance to molding

The contribution of physical and chemical kernel attributes to mold resistance in accessions, with different kernel color, are shown in Table 2 In general, white sorghum accessions without a pigmented testa were characterized by mostly corneous endosperm texture, relatively low levels of apigenindins and luteolinidin, and negligible amounts of flavan-4-ols and tannin On average, differences between resistant and susceptible white sorghum accessions were not significant for each trait, except for days to flowering However, late flowering was not always related to resistance to molding in white sorghums The accessions used in this study exhibited a broad range of panicle types, however, relative panicle compactness seemed to have little impact on expression of resistance or susceptibility to grain mold damage Physical kernel attributes may become more important factors in resistance to grain mold after physiolgical maturity Sorghum kernels with more corneous endosperm were more resistant to grain mold than those with floury endosperm

Sorghum genotypes with high level of grain mold resistance originaing from diverse geographical areas and belonging to different botanical races were identified We found that resistance to grain mold in these sorghums was strongly associated with high concentration of phenolic compounds (apigeninidin, flavan-4-ols, and tannin), kernel hardness, and pericarp color Each of these kernel properties contributed to grain mold resistance differently in white, red, and brown pericarp sorghum accessions In general, white sorghum accessions without a pigmented testa were characterized by mostly corneous endosperm texture, relatively low levels of apigeninidin and luteolinidin, and negligible amounts of flavan-4-ols and tannin Sorghum accessions with red pericarp, but without pigmented testa, had mostly corneous endosperm texture, relatively high levels of apigeninidin, luteolinidin, and flavan-4-ols and a negligible amount of tannins Grain mold resistance in red sorghums was strongly associated with high concentration of flavan-4-ols, although in some red sorghums an inverse relationship between concentration of flavan-4-ols, and resistance was also observed Brown sorghum accessions contained high levels of flavan-4-ols and tannin, and moder-

Table 2 Kernel physical and chemical properties of mold resistant and susceptible white, red, and brown sorghum accessions from the working collection

	White without Testa		White with Testa		Red		Brown	
Properties	Resistant	Susceptible	Resistant	Susceptible	Resistant	Susceptible	Resistant	Susceptible
Number of accessions	38	36	24	10	21	22	75	5
Days to flowering	83 79 aa	79 36 b	84 67 a	84 70 a	80 81 a	77 18 b	86 24 a	83 00 a
Panicle shape	5 40 a	5 14 a	6 58 a	7 00 a	5 52 a	5 50 a	5 99 a	6 60 a
Kernel weight (g)	2 75 a	2 63 a	2 87 a	2 55 b	2 55 a	2 63 a	2 87 a	2 26 b
Endosperm texture	2 17 a	2 39 a	3 00 a	3 20 a	2 57 a	2 86 a	3 36 a	3 20 a
Apigeninidin (A475/g)	0 50 a	0 57 a	0 67 a	0 75 a	0 90 a	0 80 a	0 72 a	0 81 a
Luteolinidin (A495/g)	0 49 a	0 58 a	0 68 a	0 77 a	0 93 a	0 83 a	0 67 a	0 82 a
Flavan 4 ols (A550/g)	0 01 a	0 01 a	0 06 a	0 05 a	0 72 a	0 48 b	0 40 a	0 07 b
Tannin (A550/g)	0 00 a	0 00 a	0 32 a	0 30 a	0 04 a	0 01 b	0 47 a	0 33 b

[a] Means within a row in each pair of columns follwed by the same letter were not significantly different from each other at the P 0 05 level based on a paired t test

ate levels of apigeninimidin and luteolindin Grain mold resistance in brown sorghum accessions was generally associated with increased levels of both flavan-4-ols and tannins, again with some exceptions

We computed principal component analysis to develop a numerical index that integrated the more important kernel attributes, and this index effectively differentated resistant and susceptible sorghum genotypes The first three principal components together accounted for >70% of the total variation of all traits in the two sets of accessions The first principal component alone explained about 40% of the total variation of all traits in our collection The correlation between composite scores for PC1 and visual grain mold scores were significant and negative

We concluded that both physical and chemical kernel properties confer resistance to grain mold in different kernel color categories of sorghum The results of our study suggested that overall resistance to grain mold may not be explained by any one character, particularly in white sorghums without pigmented testa The use of a selection index in screening for grain mold resistance may facilitate the development of highly resistant and agronomically acceptable parental lines and hybrids in an array of genetic background

Networking Activities

Workshop and Program Reviews

Served as a member of the organizing committee of both INTSORMIL Principal Investigators Conference and the International Conference on Genetic Improvement of Sorghum and Pearl Millet held at Lubbock, TX, September 1996 Presented joint papers with several colleagues at these meetings

Presented a joint paper (with L G Butler) at Sixth International Parasitic Weed Symposium, Cordoba, Spain, April 1996

Served as Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research, June 1997

Participated in African Dissertation Internship Awards Selection, Rockefeller Foundation, November 1996, and April 1997

Attended American Society of Agronomy National Meetings, Indianapolis, IN, November 1996

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

Dr Paula Bramel-Cox, Director, Genetic Resources Unit, International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), February 1996, and June 1997

Dr Jill Lenne, Principal Plant Pathologist, ICRISAT, July 1996

Dr Aberra Debelo, Sorghum Breeder and Program Leader, Ethiopia Sorghum Improvement Project, September 1996

Dr Abdelgabar Babiker, Sudan National Coordinator for Sorghum and Millets, September 1996

Dr Abdel Moneim Bashir El Ahmadi, Director National Seed Industry, Sudan, September 1996

Publications

Refereed Papers

Tuinstra, M R E Grote P B Goldsbrough and G Ejeta 1996 Identification of quantitative trait loci associated with pre flowering drought tolerance in sorghum Crop Sci 36 1337 1344

Vogler R K G Ejeta and L Butler 1996 Inheritance of low production of *Striga* germination stimulants in sorghum Crop Sci 36 1185 1191

Ouendeba, B W W Hanna G Ejeta W E Nyquist and J B Santini 1996 Forage yield and digestibility of African pearl millet landraces in a diallel with a missing cross Crop Sci 36 1517 1520

Menkir A G Ejeta L G Butler A Melake Berhan and H M Warren 1996 Fungal invasion of kernels and grain mold damage assessment in diverse sorghum germplasm Plant Dis 80 1399 1402

Melake Berhan A L G Butler G Ejeta and A Menkir 1996 Grain mold resistance and polyphenol accumulation in sorghum J Agr Food Chem 44 2428 2434

Vogler R K G Ejeta and L G Butler 1996 Integrating biotechnological approaches for the control of *Striga* Afric Crop Sci Journ 3 217 222

Menkir A G Ejeta, L Butler and A Melake Berhan 1996 Physical and chemical kernel properties associated with resistance to grain mold in sorghum Cereal Chem 73 613 617

Menkir A P B Goldsbrough and G Ejeta 1996 RAPD based assessment of genetic diversity in cultivated races of sorghum Crop Sci (In press)

Conference Proceedings

Ejeta G and L G Butler 1996 Biotechnological approaches for understanding mechanisms of resistance to *Striga* P 568 573 In M T Moreno et al (ed) Advances in Parasitic Plant Research Sixth International Parasitic Weed Symposium Cordoba Spain April 16 18 1996

Babiker A G T N E Ahmed G Ejeta L G Butler A Mohammed M T El Mana S M El Tayeb and B E Abdel Rhamman 1996 Chemical Control of *Striga* hermonthica in sorghum P 769 776 In M T Moreno et al (ed) Advances in Parasitic Plant Research Sixth International Parasitic Weed Symposium Cordoba, Spain April 16 18 1996

Andrews D J G Ejeta, M Gilbert P Goswamy A Kumar A B Maunder K Porter K N Rai J F Rajewski V S Belum Reddy W Stegmeier and B S Talukdar 1997 Breeding Hybrid Parents In Proc of The International Conference on Genetic Improvement of Sorghum and Pearl Millet Lubbock TX 23 27 September 1996 University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 173 187

Abstracts

Ibrahim Y Melake Berhan L G Butler J Bennetzen and G Ejeta 1996 Identification of QTL for field resistance to *Striga* in sorghum Agron Abs p 163

Tuinstra, M R G Ejeta and P B Goldsbrough 1996 Genetic and phenotypic analysis of near isogenic lines differing at loci associated with drought tolerance Agron Abs p 166

Books Edited

Ejeta, G S Z Mukuru and N Ibrahim 1996 Sorghum and Millets Research in East and Central Africa Proc Workshop organized to re establish a sorghum and millets network in the region

Invited Research Lectures

Ejeta G 1996 Interdisciplinary Collaboration in Plant Breeding Presented at the Summer Institute for African Agricultural Research June 9 14 University of Wisconsin Madison WI

Ejeta G 1996 Sorghum Research in Africa Presented to the International Agriculture Club October 30 1996 Purdue University West Lafayette IN

Ejeta G 1996 New Initiative in Regional Sorghum Research in the Horn of Africa Presented at the INTSORMIL Principal Investigators Conference September 22 1996 Lubbock TX

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

Project TAM-222

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Dr Aboubacar Toure, Sorghum Breeder, IER, B P 438, Sotuba, Bamako, Mali (Post-Doc Fellow at Texas A&M/Texas Tech University, January, 1996 thru May, 1998)
Dr Francisco Gomez, Sorghum Breeder and Head, Sorghum Investigations, EAP, P O Box 93, Zamarano, Honduras
Dr Osman El Obeid Ibrahim, Sorghum Breeder, ARC, Wad Medani, Sudan
Dr L E Clark, Sorghum Breeder, TAM-222 (Cooperating Investigator), Texas A&M University Research and Extension Center, Vernon, TX 76384 (Retired February, 1997 - Now Professor Emeritus)
Dr R A Frederiksen, Plant Pathologist, TAM-224, Department of Plant Pathology, Texas A&M University, College Station, TX 77843
Dr G C Peterson, Sorghum Breeder, TAM-223, Texas A&M University Research and Extension Center, Lubbock, TX 79401-9757
Dr W L Rooney, Sorghum Breeder, Department of Soil & Crop Sciences, Texas A&M University, College Station, TX 77843
Dr L W Rooney, Cereal Chemist, TAM-226, Department of Soil & Crop Sciences, Texas A&M University, College Station, TX 77843
Dr R D Waniska, Cereal Chemist, TAM-226, Department of Soil & Crop Sciences, Texas A&M University, College Station, TX 77843
Dr G N Odvody, Plant Pathologist, TAM-228, Texas A&M University Agricultural Research and Extension Center, Corpus Christi, TX 78406
Dr G L Teetes, Entomologist, TAM-225, Department of Entomology, Texas A&M University, College Station, TX 77843
Dr Gebisa Ejeta, Sorghum Breeder, PRF-207, Department of Agronomy, Purdue University, West Lafayette, IN 47907
Dr H T Nguyen, Molecular Biologist, Department of Plant and Soil Science, Texas Tech University, Lubbock, TX 79409-2122

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 excellent germplasm for use in the U S and host countries New cultivars were introduced into the U S and evaluated for useful traits Forty fully converted exotic lines and 50 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released

Performance of stay green vs non-stay green hybrids under severe post-flowering moisture stress showed that the stay green trait dramatically reduced lodging from 72 6% to 0% The stay green hybrids also produced an average of 1500 lb/acre more than the non-stay green hybrids under the stress conditions 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 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

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
- Identify and assist in developing new germplasm with resistance to grain mold, drought, headbug, anthracnose, and *Striga*

Honduras

- Enhance germplasm base with sources of resistance to grain mold, foliar diseases and drought, 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 semiarid environment and high temperatures and is ideal for large scale field screening and breeding for improved resistance to drought Sorghums with identified high levels of specific types of drought resistance in Texas 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 broad band extends from eastern Burkina Faso across all of Mali, except the extreme north, into Senegal and Guinea, and the northern areas of countries bordering on the south This quality problem is primarily due to the head bug/grain mold complex Guinea sorghums have quite good resistance to this complex, but their yield is not high and they do not respond well to improved production practices Also, they are extremely difficult to handle in a breeding program, and efforts to improve them in yield have generally failed Their unique grain quality adaptation essentially disappears in crosses to non-guinea types Head bugs are the major constraint to the use of improved high yielding nonguineense type sorghums in much of West Africa Head bug damage is often compounded by grain mold resulting in a soft and discolored endosperm, rendering it unfit for decortication and traditional food products The early maturity of introduced types compounds the grain deterioration problem Therefore, head bug resistance, grain mold/weathering resistance, and proper maturity are essential In southern Mali, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season In the drier northern areas of Mali and in Niger where drought stress is severe, earlier, less photosensitive material can be used, and drought tolerant Durra and Feterita sorghums generally perform well

Mali and Niger are both drought prone areas with both pre- and post-flowering drought tolerance important Foliage diseases such as anthracnose and sooty stripe are important is the central and southern parts of Mali In Sudan, 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 Genetic sources of resistance are used whenever possible in crosses involving disease and drought resistance to develop breeding progeny for selection in host countries

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 for new diverse germplasm sources with resistance to pests, diseases, and environmental stress New collections can provide new sources of desirable traits Many developing countries are an important source of diverse germplasm in sorghum and millet The collection, preservation and utilization of genetic diversity in sorghum is tremendously important to long-term, sustainable sorghum improvement programs Use of genetic diversity is critical to produce sufficient food for increasing populations in the future

Research Approach and Project Output

Research Methods

Introductions from various countries with drought or disease resistance, or specific desirable grain or plant traits, are crossed in Texas to appropriate elite U S lines or elite breeding materials Seed of the early generations are sent to host countries for selection of appropriate traits and adaptation Technical assistance is provided, as time and travel permits, in the selection and evaluation and use of such breeding material in the host country

New disease resistant breeding material is generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance Advance generations of breeding lines also are selected each year Initial screening is 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 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 Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs

Research Findings

Forty fully converted exotic lines and 50 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released in late 1996 (Table of lines on page 86, 1996 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 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 all 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

Severe post-flowering moisture stress developed in the Drought Hybrid Test at Corpus Christi in 1996 This provided the opportunity to compare grain yield of stay green and non stay green hybrids under severe post-flowering stress, and to compare their yield under non-stressed conditions (Table 1) Sorghum hybrids possessing the stay green trait performed significantly better than non-stay green hy-

Table 1 Performance of selected stay green and non-stay green (top six hybrids) sorghum hybrids under severe post-flowering soil moisture stress, Corpus Christi, Texas, 1996 and grain yield under non-stress conditions at Corpus Christi, 1997

Hybrid designation	LPD[1] rating	Lodging[2] %	Grain weight gm/100	Grain[3] weight gm/100 Lubbock	Reduction[4] in grain weight gm/100	Percentage reduction in grain weight	Grain yield kg ha^{1}	Grain yield kg ha^{1} Non stress CC 1997
A403*8BE2668	2 4	0	2 06	2 29	23	10 0	5070	5980
A402*Tx2862	2 0	0	1 78	2 68	90	33 6	4470	5910
A402**BE2668	3 2	0	1 88	2 41	53	22 0	4185	5850
A35*89CC443	2 0	0	2 48	2 51	03	1 2	4160	6830
A35*Tx2908/R8503	2 8	0	2 16	3 18	1 02	32 1	3410	6760
A35*Tx430	3 0	0	2 01	3 12	1 11	35 6	3070	5780
A807*Tx2783	4 8	85	1 36	2 22	86	38 8	2440	6180
A407*88V1080	4 6	75	1 76	2 29	53	23 1	2320	5490
A807*Tx2908	4 9	90	1 56	2 34	78	33 3	2310	6630
ATx2752*Tx430	4 6	58	1 75	3 22	1 47	45 6	2310	5730
A402*Tx2908[a]	4 2	55	1 49	2 43	94	38 7	2060	5760
A402*Tx2908 (by Blank)	2 5	0	2 17	2 43	26	10 7	4500	
Stay Green (6) (Means)	2 57	0 0	2 06	2 70	0 64	22 4	4060	6185
Non Stay Green (5) (Means)	4 62	72 6	1 58	2 50	0 92	35 9	2289	6025

For direct comparison with entry[a] immediately above to show the effect of a blank border row on performance as a result of different moisture stress

[1] Visual leaf and plant death rating where 1=green 5=dead

[2] Basal stalk lodging typical of premature moisture stress induced lodging

[3] Grain weight of grain from non stressed trial at Lubbock for non stressed comparison

[4] Reduction in grain weight per 100 kernels Corpus Christi vs Lubbock

brids under severe post-flowering stress in 1996 at Corpus Christi Stay green hybrids maintained green leaves (2 57 LPP rating), whereas the plants in non-stay green hybrids were nearly all dead (4 6 LPD rating) The beneficial effect of stay green on lodging was dramatic, 0% versus 72 6% lodging The grain yield advantage of the stay green hybrids was dramatic and averaged over 1700 kg ha ^{1} Reduction in grain weight of threshed grain in stay green hybrids was significantly less than in non-stay green hybrids However, this did not explain the large differences in grain yield Even if combining is successful in picking up all lodged plants, and with no germination, grain mold, or other pest loss on lodged plants, it appears that many grain produced under severe post-flowering stress are too small to be successfully threshed and saved in normal harvesting 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 QTL's were identified for stay green along with two others Two hundred new 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 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 and disease wise in Southern Africa and are given in Table 2 Some involving TAM428 and CE151 also showed excellent resistance to the sugarcane aphid

The guinea-type, white-seeded, tan-plant breeding progeny named "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 on-farm trials in Mali It was also included in the ROCARS (Sorghum Regional Network) regional trials It's headbug resistance is slightly inferior to the local guinea cultivars, but appears to have an acceptable level under on-farm conditions In one on-farm trial with World Vision near Bla the improved local, Seguetana Cin

Table 2 Breeding progenies with excellent adaptation/disease resistance/sugarcane aphid resistance in Southern Africa

(CE151*BDM499)	(Macia*Dorado)
(Sureño*CE151)	(Macia*Sureño)
(SRN39*90E0328)	(ICSV1089BF*Macia)
(Sureño*SRN39)	(Macia*TAM428)
(SRN39*87E0366)	(TAM428*SV1)
(87E0366*WSV387)	(86E0361*Macia)
(87E0366*TAM428)	(B1*Segaolane)

zana, was rated a 3 for headbug damage (1 = none to 10 = completely destroyed), N'tenimissa rated 4, while the *Striga* tolerant cultivar P9403 rated a 7, indicating a significant headbug presence 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 increased at six locations, 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, and will be tested extensively in 1997-98 season 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 headbug tolerance

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

Inheritance of resistance of leaves to insecticide burn was determined to be inherited as a single recessive gene Sorghum lines react similarly to a broad range of insecticides used on sorghum and cotton including some of the new harvest aid (defoliants) chemicals used on cotton

Thirty fully converted exotic sorghum from the cooperative TAES-TAMU/USDA-ARS Sorghum Conversion Program were selected for release during winter 1997-98 They include new diverse sorghums from primarily India, Ethiopia, and Nigeria (Table 3)

Networking Activities

Workshops and Conferences

* Served as Chair of Organizing Committee for the International Conference on Genetic Improvement of Sorghum and Pearl Millet, September 22-27, 1996, Holiday Inn Plaza, Lubbock, TX The Conference was sponsored by INTSORMIL and ICRISAT and supported by The Rockefeller Foundation, Overseas Development Administrations (ODA) UK , Texas Seed Trade Association, The National Grain Sorghum Producers Association, Texas A&M University, and Texas Tech University It was attended by 250 sorghum and millet scientists from 45 countries The Conference covered the current "state of the art" of breeding and genetics improvement in sorghum and pearl millet, along with an in-depth look at the current and future application of biotechnology and other new techniques to enhance crop improvement The conference provided a forum for public and private sorghum and pearl millet researchers and molecular geneticists from around the world to interact and receive updates on current and future crop improvement technologies There were 43 major invited papers presented, as well as 60 poster papers The group also toured research plots at the Texas A&M Research Center, and private seed companies research plots, and seed production and seed processing operations
* Participated in, presented paper, and chaired a session at the International Conference on Genetic Improvement of Sorghum and Pearl Millet, Sponsored by INTSORMIL and ICRISAT, Sept 22-27, 1996, Lubbock, TX
* Participated in, chaired a session, and presented poster papers at 20th Biennial Grain Sorghum Research and Utilization Conference Feb 16-19, New Orleans, LA

Research Investigator Exchanges

* Met and had discussions on sorghum research with numerous public and private scientists from around the world during the International Conference on Genetic Improvement of Sorghum and Pearl Millet in Lubbock, TX, Sept 22-27, 1996
* Coordinated the assembly and planting of the Mali Sorghum Collection of indigenous cultivars in 1997 in Mali, in cooperation with IER, INTSORMIL, ORSTOM, CIRAD, and USDA-ARS Seed was procured from ICRISAT (India), ORSTOM (France), U S , CIRAD (France) and IER, and planting plans made This involved extensive communication and collaboration with scientists from ICRISAT, ORSTOM, CIRAD, USDA-ARS, and IER
* Traveled to Mali Nov 7-23, 1996 to evaluate the INTSORMIL/IER collaborative research program, plan future collaborative research with the IER National Program, and make plans and arrangements for the Mali Sorghum Collection grow out in 1997 in Mali
* Traveled to Honduras and Nicaragua Dec 2-7, 1996 to evaluate and plan INTSORMIL/SRN/EAP collaborative sorghum research in Honduras, and discuss potential future collaborative research in Nicaragua
* Participated in the INTSORMIL PI Conference, September 20-22, 1996 at Lubbock, TX immediately proceeding the International Conference on Genetic Improvement of Sorghum and Pearl Millet
* Traveled to Mali, May 26-June 1, 1997 to arrange the seed assembled for the Mali Sorghum Collection grow

Table 3 Thirty converted lines for releases and information on original exotic cultivars

Desig [1]	SC No [2]	PI or other No [3]	Local name No or description[4]	Origin[5]		Classification[6]		Reason for conversion[7]	Fert Rx[8]
				City/Province	Country	R	WG		
IS 1041C	191	246716 PJ7R		India	India	D DB	41 50 D Sub	Div/Elite/JCS	R
IS 1108C	847	291214 SA1781	Viramgam		India	D	41 D	Mod Nur (M2)	R
IS 1132C	201	248328 N 1	Cherukupatcha Jonwa	Nandyal	India	D	41 D	Div/Elite/JCS	R
IS 1220C	610	NSL51074 AS5227	Tsinan		China	B	8 Ner Kaol	Mod Nur (M)	PR
IS 1461C	848	NSL54668 AS356	Ennai Kittan Cholam	T N /Pindigul	India	D	41 D	Mod Nur (M2)	B
IS 3025C	235	267614 No 313	Chabe Ady	Wollega	Ethiopia	GB	17 Doc Rox	Elite/LRH	PR
IS 3123C	947	NSL55957 No19633		Thru Georgia USA	India	16	61 S verticillifforum	Mod Nur (M)	
IS 3817C	301	NSL51030	Bank Oumano Ziamri Fing	Bamako	Mali	G	4 Guineense	Mod Nur (M1)	PR
IS 4748C	833	NSL55428	Desi	Rajkot Gujacat	India	D	41 D	Mod Nur (M)	BR
IS 4789C	834	NSL54803	Amreli	Amreli Gujacat	India	D	41 D	Mod Nur (M)	B
IS 5030C	621	NSL51265	Anji	M R /Wardha	India	B	12 Dochna	Mod Nur (M)	R
IS 5193C	445	NSL54894	Kinda Jonna Burganpad	A P./Khammam	India	D	41 D	Mod Nur (M)	R
IS 5332C	247		Jonha Ankola	Cuttah Orissa	India	G	1 Roxburghii	Mod Nur (M)	R
IS 5677C	581	NSL55032	Gund Jola	KAR/Belgaum	India	D	41 D	Mod Nur (M2)	R
IS 6436C	498	NSL55743	Jowar Shenoli 4 2	M R /N Satara	India	D	46 (1) Nandyal	Mod Nur (A)	R
IS 6457C	485	NSL55714	Karad Local Gati	M R /Karad	India	D	46 (1) Nandyal	Mod Nur (M2)	R
IS 6725C	550	NSL50495	76 AB Farako Ba		W Volta	G	3 Conspicuum	Mod Nur (F)	B
IS 7182C	391	NSL54120	Dawa U A R Busari		Egypt	C	34 C Kaura	Mod Nur (M2)	R
IS 7431C	287	NSL50605 BE38	Dawa	Keffi	Nigeria	G	3 Conspicuum	Mod Nur (M)	R
IS 7437C	371	NSL54144 KA5	Kaura Zago	Ingawa	Nigeria	C	34 C Kaura	Mod Nur (M2)	R
IS 7461C	373	NSL54218 KA32	Kaura	Tambu	Nigeria	C	34 C Kaura	Mod Nur (M2)	R
IS 7570C	297	NSL50634 PL35		Womba	Nigeria	G	3 Conspicuum	Mod Nur (S)	R
IS 7755C	386	NSL54167 ZA40	Kaura Dantsen Kuira	Rigachilwa	Nigeria	C	34 C Kaura	Mod Nur (M2)	R
IS 12542C	22	148083,MN695	No 71	Warabalu Adesh	Ethiopia	D	41 D	Div/Elite/IES	R
IS 12545C	25	148086 MN697	No 73	Caracari Berilie	Ethiopia	D	41 D	Div/Elite/IES	B
IS 12547C	27	148088,MN687	No 63	Kembolcha Bekedjie	Ethiopia	D DB	41 50 D Sub	Div/Elite/IES	B
IS 12625C	134	276785 SA2303	Unnamed R1 20	Dire Dawa	Ethiopia	DB	45 50 D Doc Sub	Div/Elite/JCS	R
IS 12636C	145	276800 SA2318	Unnamed R1 J179	Dire Dawa	Ethiopia	B	12 Dochna	Div/Elite/JCS	B
IS 12671C	180	276852 SA2370	Zengada	Dire Dawa	Ethiopia	D	41 D	Div/Elite/JCS	R
SC 1271C	1271	ET 35			Ethiopia	C	39(1) Zerazera	Elite Zerazera	

[1] Desig = Designation of converted lines was obtained by adding C to the IS number used in the World Sorghum Collection Those without an IS number were given a C following the SC number

[2] SC No = The serial number given to the exotic variety when entered into the Sorghum Conversion Program and used during conversion The non recurrent parent was Btx406 a 4 dwarf Martin B line

[3] PI number (National Plant Germplasm System) is the designation given to the converted accession followed by in some cases a local designation number given to the original exotic parent

[4] The local name number code or description of the exotic variety

[5] Country of origin of each exotic line insofar as records indicate

[6] Classification of exotic line R = Race is based on Harlan & DeWet (2) where B = Bicolor G = Guinea C = Caudatum K = Kafir and D = Durra WG = Working Group number and name where Sub = Subglabrescens Ner = Nervosum Kaol = Kaoliang Doc = Dochna and Rox = Roxburghii and they are based on a Modified Snowden s Classification by Murty and Govil (3)

[7] General reason for conversion Modified Nursery = Modified Nursery selected by Rachie *et al* from World Sorghum Collection 1963 – 64 MI = representative of each classification group as described by Murty and Govil (3) M = lines representing major variation in each group M1 = line representing each of the working group classifications M2 = other variations of possible breeding value A & S = breeding value to Indian program F = lines for forage testing and hybridisation I E Stokes and J C Stephens former USDA ARS sorghum researchers at Meridian MS and Chillicothe TX respectively Div/Elite/IES or JCS = Elite diversity as chosen by I E Stokes or J C Stephens Elite/LRH = Elite germplasm as chosen by L R House at ICRISAT India former sorghum researcher SADC/ICRISAT Zimbabwe Africa

[8] Fert Rx = Fertility reaction as determined from crosses between a milo kafir cytoplasmic genetic male sterile (A1) and the exotic line R = restorer (prograny all male fertile) B = maintainer (progeny all male sterile) PB or RP = partial restorer

out, and made a planting plan for the collection Discussed ICRISAT and ROCARS participation with the grow out and Germplasm Workshop to be held in conjunction with the collection harvested in November, 1997

* Participated in INTSORMIL Technical Committee (TC) meetings, July 15-17, 1996 and May 19-21, 1997 at Lincoln, NE

* Participated in Sorghum Crop Germplasm Committee (SGC) as Ad Hoc member, Sept 27, 1996, Lubbock TX

* Traveled to Miami, FL in late May, 1996 to meet with Sue Hall, ICRISAT, Jeff Dahlberg, USDA and SICNA, and Jim Osborne, NC+ and SICNA Board, to develop plans for SICNA and ICRISAT to co-sponsor the International Sorghum and Millets Newsletter

* Participated in the InterCRSP Workshop to develop plans for InterCRSP research in West Africa, St Louis, MO, July 1-3, 1996

* Participated in Sorghum Biotech Partnership meeting (Cargill, NK, NC+, Crosbyton), May 1, 1996, TAES Center, Lubbock, TX

* Coordinated a 6-week training program in sorghum breeding and served as host for Mr Socar Sidibe, Malian sorghum breeding technician at Lubbock, August-September, 1996

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

* Organized the travel of Mr Sidi Bekaye Coulibaly, Mali National Sorghum Coordinator and INTSORMIL Country Coordinator, Sept 7-12, Lincoln, NE, and Sept 12-Oct 17, Lubbock, TX including training in sorghum breeding and computer use in breeding program management

* 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 headbug resistance in Mali in Dr Henry Nguyen's lab at Texas Tech University, Lubbock, TX

* Participated in Sorghum Ergot Workshop, and Sorghum Research Planning Meetings, June 11-12, 1997, Amarillo, TX

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 D S Murty Sorghum Breeder, ICRISAT, Bamako, Mali

* Dr Sam Z Mukuru, Sorghum Breeder, ICRISAT, Nairobi, Kenya

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

* Dr L E Claflin, Pathologist, KSU-208, 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

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 in Mali in 1997, to evaluate classify, describe, and increase seed The increased seed will be made available to all parties, and put into long term storage at ICRISAT, NSSL and ORSTROM A small Working Collection would be selected for maintenance and active use in Mali It is 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 is ORSTROM in France There are approximately 1,800 accessions with some duplicates from ICRISAT and ORSTOM, making a total of about 2 700 plots in the Collection grow out

* Forty-three new exotic sorghums were selected for entry into the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program in 1996-97 These included several cold tolerant lines 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 Seven hundred and eighty-three photoperiod insensitive sorghums from the Sudan Collection were evaluated for response to drought (Lubbock and Chillicothe)

* Forty fully converted exotic lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program released in late 1996 were distributed and seed placed in permanent storage at the NSSL at Ft Collins, Colorado Fifty partially converted bulks from the Conversion Program also were distributed Another 30 fully

converted lines and 50 partially converted bulks were selected for release submission in early 1998

Seed Production and Distribution

* Twenty-four sets (17 private, 7 public) of the 40 converted lines released in late 1996 from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were distributed, along with 11 sets (9 private) of the released 50 partially converted bulks The male sterile version (A-lines) of five new female parental lines containing drought resistance and lodging resistance were distributed to 6 additional companies during the year (13 previously distributed) via a pre-release distribution agreement 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 collaborators These contained sources of desirable traits such as resistance to downy mildew, anthracnose, leaf blight, rust, and charcoal rot, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance Seed was increased and many sets of standard replicated trials containing elite germplasm and source lines were packaged and distributed in the U S and internationally These include the ADIN (All Disease and Insect Nursery), IDIN (International Disease and Insect Nursery), GWT (Grain Weathering Test), DLT (Drought Line Test), DHT (Drought Hybrid Test), and the UHSN (Uniform Head Smut Nursery) Countries to which large numbers of germplasm items were distributed include Mali, Zimbabwe, Botswana, Zambia, Ethiopia, Guatemala, 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 methodology, as well as information on sources of new useful germplasm and sources of desirable traits was provided to Mr Sidi Bekaye Coulibaly and Bocar Sidibe (Mali), Bruce Winter and Bob Henzell (Australia), and Paresh Verma (India) Pollinating bags, coin envelopes, and breeding supplies were provided to the Mali breeding program

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

Project TAM-223

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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*) and yellow sugarcane aphid (*Sipha flava*) Breeding and selection activities are done using conventional methodology A collaborative molecular biology research project is mapping insect resistance traits of economic importance Current molecular biology emphasis is to map and characterize the genes for resistance to greenbug biotypes

Extensive research to develop lines resistant to sorghum midge which 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), has identified three A/B-line pairs which will be of use as sorghum midge resistant hybrid 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 the susceptible hybrids in late plantings Release of the lines as A/BTx639 A/BTx640 and A/BTx641 has been approved Seven sets of the lines were distributed under a pre-release memorandum to private seed companies (six U S and one Guatemalan) for evaluation in 1997 The lines will be available for general distribution in August/September 1997 These are the first sorghum midge resistant A/B-line pairs with the traits needed for acceptable commercial resistant hybrids Private companies will evaluate the lines as seed parents, using proprietary lines as the pollen parent, 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 biotechnology to increase understanding of the genetics of plant resistance traits
- Identify and define sorghum genotypes with varying levels or tolerance to drought and chemical stress of Sahelian soils

Constraints

Sorghum production and yield stability is constrained by many biotic and abiotic stresses Insects pose a risk in all areas of sorghum production with damage depending on the insect and local environment To reduce stress impact, research is needed to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems Genetic resistance to multiple stresses in a single genotype will further reduce environmental risk and contribute to improved productivity This is especially important as production ecosystems experience induced change due to cultivars and/or technology, the natural balance between cultivars and biotic stresses also being changed and insect damage becoming increasingly severe

To meet the demands of increased food production in an economically profitable, environmentally sustainable production system genetic resistance may be utilized at no additional cost to the producer This requires a multidisciplinary research program to integrate resistant hybrids into the management system Cultivars resistant to insects will readily integrate with other required inputs as part on 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, head bugs 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 being the result 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 Africa for resistance to head bugs and identification of sorghum genotypes resistant/tolerant to soil toxicity For the U S , sorghum midge, biotype E and/or I greenbug, and yellow sugarcane 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

Germplasm is evaluated for resistance to insects of economic importance in the collaborative breeding/entomology program in field nurseries or greenhouse facilities, depending on the insect mode of infestation Sources of germplasm for evaluation are elite accessions from other programs (including ICRISAT), introductions, and partially or fully converted exotic genotypes from the sorghum conversion program

New sources of resistance are crossed to elite material in the breeding program, and to other germplasm lines with superior trait(s) Studies to determine the genetics of resistance and the resistance mechanism are conducted when possible Advanced elite materials are evaluated at diverse locations for stability of resistance, adaptation and reaction to additional stress factors Based on data analysis and phenotypic evaluation, crosses are made among elite lines to produce additional germplasm for subsequent evaluation Improved adaptation, additional stress resistance (disease resistance and/or drought tolerance), and other favorable traits are incorporated into insect resistant germplasm whenever possible

Elite lines and hybrids are provided to LDC cooperators for evaluation in indigenous environments The germplasm is evaluated under the local production system (fertilizer, tillage, plant population, etc) and agronomic and yield data collected

For insects important in LDCs but not in the U S an array of germplasm is provided to the LDC cooperator The germplasm is evaluated for resistance to the specific insect by the cooperator Based upon experimental results crosses are made to produce relevant populations for inheritance and entomological studies These populations are provided to the cooperator for further evaluation Molecular biology is currently used to study head bug resistance in Mali and the U S Ratings for resistance are collected in replicated field trials in at least two locations in Mali 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 valuated 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 During recent years significant progress to improve the agronomic eliteness 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 Exotic introductions partially converted lines from the Sudan Collection, and converted lines were 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 high sorghum midge density generally perform well under moderate/low midge density However, lines that perform well under moderate/low midge density may not perform well under high midge density

Seventy-seven lines were evaluated for resistance to sorghum midge and agronomic desirability in the Midge Line Test (Table 1) Included in the test were four susceptible and nine resistant checks and 64 experimental breeding lines All resistant checks and experimental lines were significantly less damaged than the susceptible checks The most resistant check, Tx2880, was not significantly less damaged than several resistant entries Two of the new lines selected for release, MB110-B92-3 (Tx640) and MB110-B93-6 (Tx641), were not significantly more damaged than Tx2880, Tx2882, or Tx2782 While MB104 B91 6 (Tx639) was significantly more damaged than the resistant checks it sustained significantly less damage than the standard B-line check Tx2755 This was the fourth year that Tx639, Tx640 and Tx641 had excellent seed set under high and moderate sorghum midge population density Most experimental entries were not significantly more damaged than Tx2880 Tx2882, or Tx2782 Experimental entries with a high level of resistance over locations and acceptable agronomic traits were selected for additional evaluation Two ICRISAT introductions, PM12713 and ICSV745 were evaluated for resistance PM12713 flowered too late to evaluate for resistance ICSV745 had significantly more damage that most resistant checks and experimental entries

The primary resistance source used in the program is TAM2566 originally SC175 9 a partially converted Zerazera (IS12666) from Ethiopia Major research emphasis for several years has been to use other resistance sources to 1) diversify the genetic base of the program for resistance and 2) attempt to improve the level of resistance Many lines were evaluated in the Midge Line Test that derive from two or three different resistance sources Additional resistance sources used 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 be made to broaden the genetic base of the program and select for other useful traits like tan plant improved foliar traits, and larger kernel size Most of these lines have excellent resistance and agronomic traits Several were selected to test in hybrids

Hybrid combining ability of lines for yield potential and sorghum midge resistance is studied to evaluate experimental 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 These lines possess the characteristics required of hybrid seed parents Improvement is now needed in R lines to provide additional heterosis and superior agronomic traits

Grain yield midge damage rating and 100 kernel weight for entries in the Midge Hybrid Test are shown in Table 2 Grain yield is for three locations early planting (Corpus Christi) and late plantings (Corpus Christi and College Station midge nurseries) Midge damage rating is for the two midge nurseries as sorghum midge were not present during anthesis of the early planting Kernel weight is based on two samples from harvested grain in the Corpus Christi midge nursery The standard resistant hybrid check is ATx2755*Tx2767 and the standard susceptible check is ATx2752*RTx430 For late plantings where sorghum midge are present most experimental hybrids produced significantly more grain than the susceptible checks Addition-

Table 1 Mean midge damage rating and agronomic desirability of entries in the Midge Line Test at Corpus Christi and College Station, TX, 1996

	Midge Damage Rating[1]		Desirability[2]	
Pedigree	CC[3]	CS	CC	CS
Tx378	9 0	6 3	3 4	3 3
Tx623	8 7	5 7	2 4	2 4
Tx430	8 7	6 7	2 6	2 6
Tx2767	7 3	4 5	3 0	2 5
TAM2566	6 7	3 0	3 4	3 2
(Tx2882*89CC132) CM49 CM1 CM1	6 7	2 3	2 5	2 0
(MR112 90M5*87E0366) CM4 CM3 CM1	6 7	1 0	2 2	2 2
Tx3042	6 3	6 3	2 8	3 2
Tx2755	6 3	3 0	2 9	2 5
Tx2801	6 3	4 0	2 7	2 3
(MR112 90M5*87E0366) CM4 CM2 CM1	6 3	2 0	2 3	2 2
ICSV745	6 0	3 7	2 1	2 2
95ML83/((IS12573C*PHYR) 15 5 1 1 2 1 1*Tx2766) CM2	6 0	2 0	3 2	2 7
(Tx2782*MB108B/P G) CM6 CM1 CM1	6 0	3 0	2 3	2 2
94ML34/95ML68/(MB110 21 L1 BM2 CC1*Tx623) CM8 CM1	5 7	3 3	2 5	2 5
(Tx2882*89CC132) CM53 CM3 SM2	5 7	1 7	2 3	2 5
(MR112 90M5*87E0366) CM12 SM2 SM2	5 7	2 0	2 4	2 1
(Tx2882*89CC132) CM53 CM3 SM1	5 3	2 0	2 4	2 3
(Tx2872*Tx2782) SM2 CM3 SM1 SM2	5 0	3 0	2 5	2 4
Tx2883	4 7	1 3	2 7	2 6
94M2/94ML32/95ML31/(Tx2877*86PL2119 20) BM22 LMBK	4 7	1 7	2 4	2 2
MB104 B91 6	4 3	2 3	2 6	2 7
94ML31/95ML61/(Tx2782*Tx2876) BM13 CM2 SMBK ML1	4 3	2 0	3 0	2 1
94ML69/95ML64/(PM12713*Tx2766) CM2 CM1 CMBK ML5	4 3	3 7	2 5	2 5
(Tx2882*86EO374) CM8 SM1 CM3	4 3	2 3	2 4	2 5
95ML53/(Tx2782*Tx2878) BM40 CM2 CM1 CM2	2 7	2 0	2 7	2 5
95ML86/(Tx2880*SC170 6 17) SM15 CM1 CM1 CM2	2 7	1 7	2 7	2 6
MR112B 92M4	2 3	3 0	2 9	2 9
94M3/94ML33/95ML32/(Tx2877*860L2119 20) BM22 LMBK	2 3	2 0	2 5	2 4
95ML66/(PM11344*Tx2767) BM7 LMBK CM1=CMBK CM2	2 3	1 7	2 6	2 3
95ML76/(MR118 3 R2 CC2 CS1 CS1 SM1*Tx2872) SM2 LMB	2 3	2 0	3 1	2 6
95ML/(Tx2880*SC170 6 17) SM10 CM2 SM1 SM2	2 3	1 0	2 5	2 4
(Tx2782*MB108B/PG) CM10 SM1 CM2	2 3	2 3	2 3	2 3
(Tx2882*87E0366) CM13 SM1 SM1	2 3	2 0	2 5	2 1
(((SC572 14*SC62 14) C12 BM1 BM1 BM1 LMBK*Tx2767)	2 3	2 0	2 9	2 5
Tx2882	2 0	2 0	2 6	2 3
Tx2782	2 0	1 3	3 1	3 0
IS6919C/SC846 14E/ZZ	2 0	2 3	3 1	3 4
95ML67/(PM1134*Tx2782) CS24 LMBK CM2 CM2 CM1	2 0	1 3	3 0	2 9
95ML74/((SC62 14*Tx2782) B12 CC1 CC1*Tx2878) SM18	2 0	2 3	2 3	2 1
95ML77/(86EO362*MR103 3/Tx2880) SM8 CM1 CM1 CM2	2 0	2 3	2 7	2 5
95ML84/(Tx430*Tx2872) BM3 CM2 SM1	2 0	1 0	2 4	2 4
94ML69/95ML64/(PM12713*Tx2766) CM2 CM1 CMBK ML1	2 0	2 0	2 4	2 3
(Tx2782*MB108B/P G) CM1 CM1 CM2	2 0	1 0	2 8	2 4
(Tx2882*87EO366) CM13 SM1 SM3	2 0	1 7	2 4	2 3
(((SC572 14*SC62 14) C12 BM1 BM1 BM1 LMBK*Tx2767)	2 0	3 0	2 8	2 3
Tx2880	1 7	1 7	2 8	2 5
94ML43/95ML51/(((Tx2767*SC693 14) B6 L1 BM1 BM1)*T	1 7	1 7	2 5	2 7
(Tx2782*Tx2878) BM47 CM2 SM2 CM1	1 7	3 7	2 8	2 6
(Tx2767*((SC572 14*SC62 14) B5 L1 BM1 CM1)) SM5 SM	1 7	2 0	2 6	2 3
(Tx2882*87EO366) SM7 SM2 CM2	4 0	2 3	2 5	2 5
(MR112 90M5*87EO366) CM7 CM1 CM1	4 0	2 0	2 3	2 7
MB108B/PG	3 7	2 3	1 9	2 1
Tx430*Tx2878) SM3 SM1 SM3	3 7	4 3	2 4	2 5
Tx2782*MB108B/P G) SM2 SM3 SM1	3 7	2 0	2 7	2 4
94ML56/95ML55/(Tx2872*Tx2880) SM10 SM2 SM1	3 5	2 7	2 8	2 2

Table 1 - Continued

	Midge Damage Rating[1]		Desirability[2]	
Pedigree	CC[3]	CS	CC	CS
B86815 1 3 CCBK	3 3	2 7	2 6	2 6
MB110 B92 3	3 3	3 0	2 8	2 3
MB110 B93 6	3 3	2 0	2 2	2 3
95ML57/(Tx2880*Tx2882) BM1 CM1 CM1 SM2	3 3	2 7	2 3	2 7
95ML60/(MR114 90M11*Tx2880) SM5 LMBK SM2 CM2	3 3	2 0	2 6	2 6
(MB108/P G *MB110-49 B2 CC2 CC1 LMBK) SM4 CM2 SMBK	3 3	2 0	2 3	2 5
(Tx2782*Tx2878) SM4 CM1 CM1	3 3	3 7	2 9	2 5
(Tx2872*Tx2880) SM6 SM2 SM2	3 3	1 0	2 4	2 3
(((SC572 14*SC62 14) C12 BM1 BM1 BM1 LMBK*Tx2767)	3 3	2 7	2 5	2 2
(94M1/94ML31/95ML30/MR126 BM5 BM2 LMBK CM2 LMBK LMB	3 0	1 7	3 0	3 0
(94ML61/95ML58/(Tx2887*Tx2890) SM2 LMBK SM1 CM1	3 0	2 0	2 6	2 3
94ML66/95ML62/(MR114 90M11*6EO361/(R5646*SC326 6))	3 0	3 0	2 3	2 5
95ML88/(MR118 3 R2 CC2 CS1 CS1 SM1*Tx2882) SM15 SM	3 0	2 7	2 7	2 7
94ML68/95ML63/((SC228 14*Tx2767) 2 B2 BM2 LM2*Tx28	3 0	1 3	2 7	2 3
(MB108B/P G *MB110 49 B2 CC2 CC1 LMBK) BM10 CM1 CM	3 0	2 0	2 4	2 4
(Tx2782*Tx2878) SM4 CM1 SM1	3 0	2 0	2 6	2 5
(Tx2882*87EO366) CM7 SM1 CM1	3 0	2 3	2 4	2 4
MR114 90M11	2 7	2 3	2 5	2 5
95ML73/((SC62 14*Tx2782) B12 CC1 CC1*Tx2878) SM17	2 7	1 7	2 7	2 5
94ML57/95ML56/(Tx2880*Tx2882) BM1 LMBK SM1 SM1	1 3	1 0	2 3	2 5
94ML68/95ML63/((SC228 14*Tx2767) 2 B2 BM2 LM2*Tx28		1 3	0 0	2 4
LSD 05	1 6	1 5	0 3	0 3

[1] Rated on a scale of 1=0 10% 2=11 20% 9=91 100% 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, midge damage rating, and 100 kernel weight of selected entries in the Midge Hybrid Test at Corpus Christi (early and late planting) and College Station, TX, 1996

	Grain Yield[1]			Midge Damage Rating[2]		100 Kernel Weight
	CC[3]	CS	CA	CC	CS	g
A94 13(MB110 11)*Tx2882	3258	3729	4174	1 7		1 80
A94 5(MB109 1)*Tx2882	3159	4188	4512	1 7	2 0	1 90
A94 3(MB104 11)*Tx2882	3140	5029	4667	1 3	1 3	2 03
A94 11(MB110 1)*Tx2882	3122	5177	5878	2 0	1 0	1 94
A91 6(MB104)*Tx2882	3114	4176	3852	1 3	1 7	1 83
A94 17(MB110 11)*Tx2882	2915	5193	4165	2 3	1 3	2 17
A94 16(MB110 11)*Tx2880	2889	4570	4536	1 7	2 3	1 98
A93 5(MB110)*Tx2882	2874	4598	4240	1 7	2 0	2 26
A94 10(MB110 1)*Tx2880	2866	4670	4093	1 3	1 0	1 99
A94 16(MB110 011)*Tx2882	2822	4192	4369	1 3	2 0	2 44
A94 13(MB110 11)*Tx2767	2643	4779	4414	1 7	2 3	2 09
A94 4(MB104 11)*Tx2882	2552	4022	4393	1 7	1 7	2 01
A94 9(MB110 1)*Tx2880	2429	4966	4453	2 0	1 0	1 88
ATx2755*90M11	2389	4902	4065	2 3	1 7	2 10
A94 15(MB110 11)*Tx2882	2371	5155	4012	2 7	1 7	2 13
A94 4(MB104 11)*Tx2880	2361	4985	4100	1 3	2 0	2 04
A91 6(MB104)*Tx2880	2350	5354	4204	1 7	1 3	2 29
A92 3(MB110)*Tx2880	2337	6225	4196	2 0	1 3	1 97
A94 15(MB110 11)*Tx2880	2244	4770	4686	2 0	2 0	2 15
A92 6(MB110)*Tx2767	2231	5909	4613	2 0	1 3	2 09
A94 17(MB110 11)*Tx2767	2215	5070	4078	2 3	1 3	2 06
A94 16(MB110 11)*Tx2767	2184	4940	4258	2 3	1 0	2 11
ATx2755*Tx2880	2151	5703	5094	2 0	2 0	2 03
A94 17(MB110 11)*Tx2880	2099	3457	4707	2 3	1 7	2 00

Table 2 Continued

	Grain Yield[1]			Midge Damage Rating[2]		100 Kernel Weight
	CC[3]	CS	CA	CC	CS	g
A94 9(MB110 1)*Tx2882	2094	3359	3741	2 3	1 7	1 85
A94 10(MB110 1)*Tx2767	2075	6657	5199	2 7	1 3	2 06
A94 3(MB104 11)*Tx2880	2063	5541	4738	2 0	2 0	2 15
A93 5(MB110)*Tx2767	1999	5193	4462	2 3	1 3	2 26
A92 3(MB110)*Tx2882	1972	4730	5161	1 7	1 0	1 93
A94 9(MB110 1)*Tx2767	1942	5694	4858	3 0	1 0	1 94
A94 15(MB110 11)*Tx2767	1920	5899	3737	2 3	1 7	2 15
ATx2801*90M11	1844	2465	4466	3 0	1 7	1 99
A94 8(MB110 1)*Tx2767	1676	4327	4031	2 7	1 3	2 04
ATx2755*Tx2882	1599	3735	4894	3 0	1 7	2 10
ATx2755*Tx2782	1579	3629	3840	2 7	2 0	1 65
ATx2755*94M2	1549	4173	5063	6 0	1 7	2 09
A92 3(MB110)*Tx2767	1495	6113	4977	2 7	1 0	2 06
A91 6(MB104)*Tx2767	1342	6402	4715	2 7	2 0	1 99
A94 10(MB110 1)*Tx2882	1288	1318	4259	4 0	4 0	2 15
A94 4(MB104 11)*Tx2767	1263	5538	3459	3 7	1 3	2 07
A94 3(MB104 11)*Tx2767	1153	4847	4593	3 3	2 0	2 14
ATx2801*94M2	1051	4613	4895	4 7	2 0	2 19
A93 6(MB110)*Tx2882	1019	2094	3599	6 0	3 7	1 81
ATx2801*94M3	974	3557	5189	4 7	2 0	2 05
ATx2801*Tx2882	972	4984	4406	4 7	1 7	1 98
ATx2755*Tx2767	957	4955	4212	4 7	2 0	2 14
ATx2755*94M3	942	4311	5459	5 7	2 0	2 19
ATx2801*Tx2782	877	4008	4251	3 7	1 7	1 82
ATx2755*Tx430	819	3510	4573	7 7	2 0	2 39
ATx2752*Tx2864	663	2388	5193	9 0	4 7	2 11
ATx3042*Tx2737	617	726	4033	8 3	8 0	3 02
A94 6(MB110 1)*Tx2882	599	2754	3100	6 7	2 3	2 04
ATx399*Tx430	444	3081	4598	8 7	5 3	2 64
ATx2801*Tx2767	434	4203	4196	8 3	2 3	2 13
ATx2752*Tx430	407	1854	5478	9 0	7 7	2 57
A1*Tx2864	257	3012	5062	8 3	2 7	2 35
ATx2801*Tx430	214	3491	4445	9 0	4 3	2 43
A35*Tx2864	78	1714	4839	9 0	5 3	2 29
A1*Tx2783	35	1229	4861	9 0	8 0	2 15
LSD 05	629	1083	1359	1 2	2 4	0 24

[1] Grain yield in kg h ^{1}

[2] Rated on a scale of 1=0 10% 2=11 20% 9=91 100% of kernels that failed to develop

[3] CC=Corpus Christi Midge Nursery CS=College Station CA=Corpus Christi early planning

ally several experimental hybrids produced significantly more grain than the resistant checks Differences between hybrids were greater at Corpus Christi under high pest density While the differences were not as large under moderate density (at College Station), the experimental hybrids still expressed better yield potential and resistance than previously available resistant hybrids or susceptible checks Differences at College Station under moderate pest density represent grain yield potential under conditions more likely to be encountered in producers fields

Kernel size of resistant versus susceptible hybrids was studied in the Corpus Christi midge nursery test Susceptible hybrids usually produce grain larger than resistant hybrids In many comparisons susceptible hybrids produce significantly larger kernels However, several resistant hybrids produced kernels similar in size to susceptible hybrids To improve potential use of sorghum midge resistant hybrids the kernel size should be increased

To evaluate grain yield potential in a normal planting, the Midge Hybrid Test was also planted at the normal time The test flowered without sorghum midge damaging the entries As a group the susceptible checks produced more grain than the resistant checks or experimental resistant entries However, there were experimental resistant hybrids that produced grain yield similar to susceptible hybrids Hybrids with the A-line designation of ‘A94-’ are in preliminary evaluation Several experimental A-lines produced excellent hybrids that were among the top entries at all locations

To evaluate grain yield in producers fields studies were conducted in conjunction with several private seed companies using the hybrids ATx640*Tx2880 and ATx640*Tx2882 Hybrids were planted by companies in conjunction with their normal testing program In earlier planting dates susceptible hybrids generally produced 10 to 15% more grain than the resistant hybrids As the planting date became progressively later the grain yield difference disappeared At the latest planting dates resistant hybrids produced more grain that susceptible hybrids

Thirteen lines from the Sudan collection were planted for observation in 1996 The lines did not appear to resist damage caused by sorghum midge A test of partially converted (F_2 generation) selections of lines phenotypically similar to AF28 that were identified in the Sudan collection was planted at Corpus Christi and College Station Selections were made in several lines that appeared to contain a low level of resistance to sorghum midge The selections will receive additional evaluation in 1997 Forty converted lines were also evaluated for resistance to sorghum midge None of the lines appeared to be resistant to damage caused by sorghum midge

Selection continued in the development of new germplasm resistant to biotype E or I greenbug New R-lines resistant to biotype E continued to produce high yielding hybrids Two of the lines are in a tan plant, white pericarp genetic background with excellent foliar disease resistance The lines could be useful in developing food type sorghums with improved biotic stress resistance Several lines with tan plant and red pericarp were selected for advanced evaluation including use as hybrid parents The lines also possess wide adaptation and excellent foliar traits, including resistance to several diseases Selections to develop biotype I resistant lines were made in many populations Screening against biotype E and I greenbugs identified several genotypes which contain resistance to both biotypes Selections are directed at developing lines resistant to both biotypes since resistance is controlled by different genes Numerous crosses were made to introgress the resistance gene(s) into an array of elite germplasm

Molecular biology research to identify markers resistant to biotype C, E, and I greenbug continued Markers have been identified for resistance to each of the biotypes Genetic inheritance is also being studied For biotype C resistance derived from SA7536-1 two loci for resistance have been mapped One loci for resistance derived from Capbam to biotype E has been mapped Resistance derived from PI550607 is more complicated with two loci for biotype E, two loci for biotype I, and one loci for biotype K mapped Research is assisting in understanding the nature of the resistance Discussions have been initiated with small grains scientists to study greenbug resistance across species, to study greenbug within an ecosystem, and to study biotype evolution Potential areas of collaboration have been identified Grant proposals with both sorghum and small grains scientists have been submitted The greenbug provides unique opportunities for cross species, multidisciplinary, multi-state research Discussion will continue in the future

A 46 entry paired plot screening nursery for soil toxicity was grown on the Cinzana Experiment Station at a previously selected site The research was a continuation of activity previously conducted jointly with the Soil Management CRSP Bagoba was used as the resistant check and Malisor 84-5 was used as the susceptible check A new site was used for the research in 1996 and the nursery was evaluated in November 1996 This new site did not have as high a level of soil toxicity as the previous site Plant stands were obtained in most plots One durra type sorghum from Chad, OH/84-3/5, appeared to have some level of tolerance to soil toxicity For 1997, 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 will be planted in the soil toxicity site on the Cinzana station and in a farmers field adjacent to the Cinzana station

Head bug damage was rated at the Cinzana Station in three populations developed to study the application of molecular biology to identify resistance and develop improved genotypes The populations -Tx436*BTx635, Malisor 84-7*S34, and BTx635*S34 - were developed specifically for this study These populations were developed in Texas and Puerto Rico and sent to Mali to evaluate for reaction to head bugs Dr A Toure, IER sorghum breeder is conducting this research for his Rockefeller Foundation post-doctoral fellowship Based on observation of plots at Cinzana and the ratings obtained, it was concluded that the best population to use for additional research was Malisor 84-7*S34 Progeny from this resistant parent *susceptible parent population expressed good head bug resistance/susceptibility The study will be continued and expanded in 1997 to include progeny developed by the ICRISAT West African sorghum program

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

Networking Activities

Workshops

* Participated in the XX International Congress of Entomology, August 25-31, 1996, Florence, Italy

- * Co-author of manuscript titled "Genetic Diversity of Sorghum, *Sorghum bicolor* (L) Moench, a Source of Insect Resistant Germplasm"
- * Chair of Planning Committee for the INTSORMIL Principal Investigators Conference, Sep 20-22, 1997, Lubbock, TX
- * Member of Planning Committee for the Genetic Improvement of Sorghum and Pearl Millet International Conference, Sept 23-27, 1997, Lubbock, TX Senior author of manuscript on "Breeding for Resistance to Foliar- and Stem-Feeding Insects of Sorghum and Pearl Millet" Co-author of manuscript on "Breeding for Resistance to Panicle Pests of Sorghum and Pearl Millet" Organized and participated in two field tours held in conjunction with the Conference
- * Participated in and gave invited presentation titled "New Sorghum Germplasm Resistant to Sorghum Midge" at the Texas Seed Trade Association Production and Research Conference, Jan 27-28, 1997, Dallas, TX
- * Participated in and gave invited presentation titled "The Search for New Sorghum Cultivars and Hybrids Phase II Development and Evaluation of Resistant Sources and Inbred Lines" at 1997 Sorghum Conference, Feb 16-19, 1997, New Orleans, LA

Research Investigator Exchanges

- * Mali - Nov 7-23, 1996 Worked with IER breeding collaborators in use of computer software for breeding program management Evaluated cooperative IER/INTSORMIL research at Sotuba, Cinzana, and Longrolla Rated plots at Sotuba and Cinzana for damage to head bugs as part of a research program to utilize molecular biology in the resistance to head bugs 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 head bugs Developed future collaborative research plan for research on soil toxicity and resistance to insects
- * Honduras/Nicaragua - Dec 2-9, 1996 Evaluated collaborative research at Zamarano, Rapaco, and Comayagua Discussed collaborative research program activities with representatives of the Escuela Agricola Panamericana (EAP) and USAID/Honduras Met with officials of the Nicaraguan Institute of Technology concerning potential collaboration between Nicaragua and the INTSORMIL Central American Program
- * Participated in Sorghum Crop Germplasm Committee (CGC) meeting Feb 18, 1997, New Orleans, LA
- * Participated in U S Ergot Conference, June 11,1997, Amarillo, TX
- * Dr Roger Monk and Mr John Jastor, Pioneer Hi-Bred Intl , Taft, TX, July 1996
- * Dr A Toure, IER, Bamako, Mali
- * Dr G Thomas, Asgrow Seed Company, September 1996
- * Dr Jeff Dahlberg USDA-ARS, Mayaguez, PR, Sept - Oct , 1995
- * Dr Bob Henzell, Queensland Dept of Primary Industries, Australia, and Dr Lynne McIntyre CSIRO Div of Tropical Crops & Pastures, Australia, Sept 1996
- * Mr Antonio J Cristiani, President of Cristiani Burkard, Guatemala, October 1996
- * Mr Sidi B Coulibaly, IER, Bamako, Mali, Sept -Oct 1996
- * Mr Tim Lust, National Grain Sorghum Producers Research Director, and Mr Travis Taylor, Texas Grain Sorghum Board Executive Director, May, 1997

Germplasm and Research Information Exchange

Germplasm Conservation Use

- * Accessions from the Sudan collection and the sorghum conversion program were grown for increase and evaluation Releases from the sorghum conversion program 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 three sorghum midge resistant A/B-line pairs was planted to increase for release Release of the lines, designated A/BTx639, A/BTx640, and A/BTx641 was approved Seed of the lines was distributed to seven U S and one Guatemalan seed company under a pre-release memorandum to allow for evaluation prior to official release
- * Cooperator in the release of 40 converted sorghum lines from the sorghum conversion program
- * Germplasm previously developed and released by this project is widely used by commercial seed companies in hybrid seed production Biotype E greenbug resistant R-lines from this project are widely used in the production of greenbug resistant hybrids
- * Provided computer and miscellaneous 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 L W Rooney, Cereal Chemistry, Dept 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, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
- * Dr W L Rooney, Sorghum Breeding, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
- * Dr B R Wiseman, Entomologist, Insect Biology and Population Management Research Laboratory, P O Box 748, USDA-ARS, Tifton, GA 31793-0748
- * Dr J A Dahlberg, Sorghum Breeding and Germplasm, Tropical Agriculture Research Station, USDA-ARS, P O Box 70, Mayaguez PR 00681-3435
- * Dr C S Manthe, Ministry of Agriculture, Dept of Agricultural Research, Private Bag 033 Gaborone, Botswana
- * Dr R G Henzell, Sorghum Breeding, Hermitage Research Station, via Warwick, QLD 4370, Australia

Publications and Presentations

Abstracts

Katsar C S A H Paterson G C Peterson and G L Teetes 1996 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 Sept 22 27 1996 University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 654 655

Rosenow D T J A Dahlberg L E Clark and G C Peterson 1996 Sorghum conversion program In Proc of the International Conference on the Genetic Improvement of Sorghum and Pearl Millet Lubbock TX Sept 22 27 1996 University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 671 672

Teetes G L G C Peterson R M Anderson K Schaefer and J W Jones 1997 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 Sept 22 27 1996 University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 678

Refereed Journal

Rosenow D T J A Dahlberg G C Peterson L E Clark F R Miller A Sotomayor Rios A J Hamburger P Madera Torres A Quiles Belen and C A Woodfin 1997 Registration of 50 converted sorghum germplasms Crop Sci 37 1397 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 Crop Sci 37 1399 1400

Teetes G L C S Manthe G C Peterson K Leuschner and B B Pendleton 1995 Sorghum resistant to the sugarcane aphid Melanaphis sacchari (Homoptera Aphididae) in Botswana and Zimbabwe Insect Sci Applic 16(1) 63 71

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 1996 Breeding for Resistance to Panicle Pests of Sorghum and Pearl Millet In Proc of the Genetic Improvement of Sorghum and Pearl Millet International Conference Lubbock TX Sep 23 27 1996 University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 255 280

Peterson G C 1997 The Search for New Sorghum Cultivars and Hybrids Phase 2 Development and Evaluation of Resistance Sources and Inbred Lines p 33 37 In Proc of the 20th Biennial Grain Sorghum Research and Utilization Conference New Orleans LA Feb 16 19 1997

Peterson G C B V S Reddy O Youm G L Teetes and L Lambright 1996 Breeding for Resistance to Foliar and Stem Feeding Insects of Sorghum and Pearl Millet In Proc of the Genetic Improvement of Sorghum and Pearl Millet International Conference Lubbock TX Sep 23 27 1996 University of Nebraska, Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 281 302

Teetes G L G C Peterson and K F Nwanze 1997 Genetic Diversity of Sorghum Sorghum bicolor (L) Moench a Source of Insect Resistant Germplasm XX International Congress of Entomology Florence Italy Aug 25 31 1996 (In press)

Miscellaneous Publications

Pietsch D L Synatschk W L Rooney D T Rosenow and G C Peterson 1997 1996 Grain sorghum performance tests in Texas Dep of Soil and Crop Sci Technical Report No 96 05 95p

Breeding Pearl Millet and Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-218

David J Andrews
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Principal Investigator

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Collaborating Scientists

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 Amadou Fofana, Millet Breeder, CNRA, BP 51, Bambey, Senegal
Mr Adama Coulibaly Agronomist, 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
Dr Lloyd W Rooney, Cereal Chemist, TAM 226, Department of Food Science Texas A&M University, College Station, TX 77843
Drs G W Burton and W W Hanna, Geneticists, USDA/ARS, Coastal Plain Exp Station, P O Box 748, Tifton, GA 31793
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, 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 too high for small farmers Seed of new cultivars is a highly cost effective technology even without agronomic support, but they are more effective with, and encourage the use of, other agronomic interventions Where production increases have been obtained in low resource conditions, they have always been dependent on new cultivars Plant breeding is therefore the key, and the catalyst to improving food production in Africa, and has already done so in India

Sorghum is widely used as a grain feed in intensive agriculture, in north and south America, southern Europe, South Africa and Australia, with consequent high levels of breeding research, some results of which can be modified and used in research in developing countries The situation is different for pearl millet, which so far has only been utilized as a forage crop in intensive agriculture However, pearl millet has a more nutritious grain than sorghum, and so has the potential to become a high yielding feed grain with a somewhat different adaptation pattern than sorghum It has frequently been shown in India that pearl millet hybrids can produce five tons of grain/ha in three months, and the same yield has been obtained on a field scale in Kansas

The goals of this project are several to develop parental material of higher yielding ability that can be used in collaborative breeding programs in developing countries, in the U S to increase the genetic diversity in sorghum and to produce the adapted plant type needed to grow pearl millet as a combine feed crop, and to provide students thesis topics from the on-going research, which are relevant to the problems they will face in their research programs at home

Collaborative breeding with pearl millet was continued in Senegal and Namibia the latter with the assistance of the SADC/ICRISAT Sorghum and Millet Improvement Program at Matopos, Zimbabwe Collaborative breeding in sorghum in Botswana is also done with the participation of the SADC/ICRISAT program Breeding material and information, mostly on pearl millet, is routinely exchanged with the ICRISAT programs in India and the West African center in Niger Sorghum germplasm is exchanged with several African breeding programs

In the U S , both applied and basic research is conducted on both crops In pearl millet applied research is principally centered on developing hybrid parents which show high levels of heterosis, lodging resistance and early maturity Basic research is conducted on exploring the usefulness of the new A_4 cytoplasmic male sterility system, which appears to offer advantages in breeding and producing hybrids both in the U S and tropical areas The main thrust of the sorghum program is to introgress new high yielding tropically bred food sorghums into U S grain sorghums and also use the resulting early generation segregating populations for selection in Botswana Three sorghum seed parents have been released in the U S , and eight more are ready for release Three pearl millet seed parents and three restorer parents are also ready for release 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 How best to identify combining ability (hybrid potential) early in the selection process forms the basic research area in sorghum Work has commenced on resistance to low and high temperatures at germination and initial seedling growth

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 make hybrids adapted to the U S

- Training LDC personnel in plant breeding and genetics is an important objective The above breeding approach provides opportunities and material for post-graduate student theses

Pearl Millet

- Because of its numerous advantages emphasis is being given to development of both seed parents and restorers in the A_4 cytoplasmic male sterile system, and to investigating its various attributes

- Selection for Atrazine/Propachlor herbicide tolerance, since pearl millet is sensitive to most sorghum herbicides

- Assessing the adaptation of experimental millet hybrids in the U S with sorghum checks through the coordination of a regional testing program

Sorghum

- A principal selection criteria in breeding hybrid parents for any production environment is combining ability (i e , the capability of the line to make high yielding hybrids) The choice of the tester(s) used to determine this capability is critical, particularly for seed parents Research has been being conducted to see which type of tester might be best

- 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

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) of the cultivar The tolerance of the genotype to the sum of these constraints constitutes adaptation Good adaptation alone however, is not enough since yield potential has to be raised to increase production Though some constraints are more common than others, there are different combinations of constraints in different regions, and hence there are different areas of adaptation which need to be bred for separately Many existing landrace varieties though they are well adapted to low moisture and fertility situations and to numerous pests and diseases, are not efficient in converting the dry matter they produce into grain Their biomass production may be good but their harvest index (HI) efficiency is poor There are breeding stocks which are twice as efficient in this process but they generally perform poorly in African conditions because they have little adaptation or pest/disease resistance A combination of traits conferring adaptation, growth rate, and grain production efficiency is required through breeding, as well as further improvement in basic breeding stocks (particularly seed parents) for grain yield potential per se Combinations (lines/plants) with good adaptation qualities can only be identified *in situ* in developing countries Thus, segregating material generated from crosses with stocks known to perform well in the region concerned, to selected high HI lines, are developed for selection in collaborative projects For sorghum, many cultivars from ICRISAT's breeding programs, while they have raised yield potentials in many LRSA regions, have not, in general, involved much of the high yield potential available from U S combined 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 in the U S

The selection criteria used in developing improved basic breeding stocks are numerous and involve morphological and physiological traits and estimates of genetic combining ability for performance Principal morphological traits involve determinants of seed number/m^2 and seed size Performance data under moisture stress and lower soil fertility are needed Both specific and general combining ability estimates are needed These are principally thought of in the context of hybrid parent development (for pollen and seed parents, respectively), but these estimates are also of use in identifying parents for pearl millet varieties (synthetics), and possibly for indicating parental worth, which is important in generating collaborative material for selection

Hybrids use growth resources, particularly when they are in short supply, most efficiently While varieties in pearl millet are internally heterotic, higher yields are given by hybrids, even those where the best variety is used as a parent Increased yields at the small farmer level, often without other inputs, has been the reason why pearl millet hybrids have been successful in Asia, and provided they are of a stable and durable type, they can also perform in low resource agriculture in Africa The project, therefore, has been examining aspects of top cross hybrid development and production with conventional CMS or protogyny with this use in mind

Research Approach and Project Output

Research Methods

The general approach for both crops is to create diversity by crossing high yielding U S stocks with new germplasm from developing countries or ICRISAT (and in the case of sorghum, from the Kansas State introgression program) This diversity is then used in collaborative breeding projects in host countries to select for per se adaptation, and also in the U S to incorporate new genetic diversity into lines for release In both crops the principal breeding method is pedigree selection combined with test crosses and hybrid evaluation to select for the parental lines that make the best hybrids Winter nurseries are used to expedite the selection process In sorghum some selection for host countries is for varieties also Seed parents are produced in A_1 cytoplasmic male sterile (CMS) cytoplasm in sorghum, but both A_1 (Tift 23A_1 cytoplasm) and increasingly A_4 (monodii cytoplasm) is being used in pearl millet A_4 male sterility is being transferred into lines derived from a Senegalese long headed dwarf pearl millet variety IBMV 8401 This will enable A_4 restorer lines and populations to be extracted from adapted varieties in Senegal with the eventual aim of being able to produce top cross hybrids with derivatives of the best varieties as male parents A similar approach is being used in a collaborative project in Namibia (see SADC region report)

Evidence of stability of performance and adaptation of pearl millet is lacking in the U S A regional grain yield test, with entries from UNL (Nebraska), KSU (Kansas) and ARS Tifton (Georgia) is conducted annually at 7-10 locations in seven states as far north as Oregon to provide this information Pearl millet is sensitive to most sorghum herbicides While "safening" seed might be possible, genetic resistance to Atrazine/Propachlor 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 are determined through growth chamber and early field plantings A food quality B-line population based on ms_7 is being random mated for the second time Fabien Jeutong's Ph D work to compare the effectiveness of various testers to select for combining ability was concluded

Research Results

In pearl millet, the development and evaluation of parental lines, particularly in A_4 cytoplasm continued Emphasis was placed on selecting for earliness, head length and number, grain size and weathering ability and lodging resistance prior to combining ability tests Good progress was made in selecting new R_4 restorers in A_4 cytoplasm to expand the R_4 genetic base Further promising A_4 seed parents were also identified

Table 1 1996 Pearl Millet advanced A_1 hybrid test Mead, Nebraska and Hays, Kansas Data of 6 of 25 entries

Hybrid	Days to bloom	Plant height (cm)	Grain yield kg ha^{1}
1021A × 58057R	62	125	4320
68A × 89 0083R	56	135	4060
59043 × 086R	57	117	3760
1023A × 60007R	61	129	3760
59134A × 58058R	64	119	3750
1021A × 60007R	60	121	3310
Mean (25 entries)	59	115	3320
LSD (0 05)	1 7	11 5	622

Table 2 1996 Pearl Millet A_4 hybrid yield test Mead, Nebraska and Hays, Kansas Data of 8 of 25 entries

Hybrid	Days to bloom	Plant height (cm)	Grain yield kg ha^{1}
89 0083 A_4 × 6RM	61	115	4395
68A × 89 0083R	50	138	4030
86 0018 A_4 × 3RM	61	129	3950
1363 A_4 × 4RM	64	109	3940
89 0088 A_4 × 5RM	60	134	3810
57026 A_4 × 3RM	59	118	3715
60023 A_4 × 4RM	61	115	3660
57218 A_4 × 6RM	64	102	3110
Mean (25 entries)	62	122	3050
LSD (0 05)	2 6	13 6	1050

Among the A_1 hybrids (Table 1) a number made with new parents were equal in grain yield to the best check 68A × 890083, but shorter in height with less lodging

Several of the new A_4 hybrids (Table 2) gave grain yields equal to the check The selfed seed set on A_4 hybrids is superior to all but a few A_1 hybrids

White grained lines have been developed A few have been found that can give hybrids with competitive grain yields to standard gray hybrids There is however considerable variation in how white grain hybrids resist yellowing and discoloration from sunlight and moisture during grain maturation Hybrid 1163A × 89-0083W retained the best white color White grain provides the opportunity to produce attractive flour based and parboiled products Milling recovery rates can be higher since there is no colored pericarp to be totally removed

Over the last few years, a number of genetic traits that can be useful in genetic studies, or as phenotypic markers have been accumulated from various sources and introgressed into early maturing, short height backgrounds In some cases, two or more traits have been moved into the same line These are listed in Table 3

Three hybrids (59022A × 89-0083, 1011A × 086R, 1361A_4 × 6RM) were provided to project UNL-213 for agronomic studies reported in that project Seed of various hybrids has been made in small quantities in isolation plots in previous years, but in 1996 about 150 kg of seed of hybrid 68A × 086R sufficient to plant 50 ha was produced, so that large demonstration plots could be planted One in northeastern Nebraska and another in northern Indiana, near poultry producers have been planted in June 1997

In the 1996 Regional Test, containing 18 millet hybrids from UNL Nebraska, KSU Kansas, USDA/ARS Georgia, and two sorghum checks, the lowest average yields were at Sidney, Nebraska, 1100 kg ha^{1}, and the highest at Crosbyton, Texas, 4940 kg ha^{1} The highest individual hybrid yield at Crosbyton was 6500 kg ha^{1}, 1000 kg ha^{1} more than the best sorghum check Individual millet hybrids also exceeded sorghum yields at Hays, Kansas and Tifton, Georgia, and in the late planting (June 25) at Mead, Nebraska The information from the Regional Tests to date, shows that pearl millet hybrids can give equal or higher yields than sorghum in certain conditions, on sandy or acid soils, in hot dry conditions, or where the growing season is short

In sorghum, continued development of food quality hybrid parents permitted new hybrid combinations to be tested in 1996 (Table 4), several of which exceeded check yields

Fabien Jeutong's Ph D study compared the effectiveness of various testers in selecting for combining ability in emerging sorghum breeding lines Of four types of testers (four unrelated lines, their two-way and four-way crosses, and a population), no single tester was consistent in identifying good combiners over environments For the early evaluation of combining ability, a combination of one single more dispersive line and a sterile F_1 between two testers (easy with A × B, but possible between R_1 lines using A_2 CMS or ms_3) is suggested

Seedling cold tolerance work continued with controlled chamber and field experimentation Several lines of Russian origin and a few from the breeding program were identified with good ability to germinate in cool conditions In a test planted on May 5th when night and day soil temperatures averaged 9° and 14° C, 11 Russian lines, 4 project lines and 1 Chinese line showed more than double the emergence rate of check CK60 Six had significantly higher seedling growth rates in the next six days Test crosses indicate that these abilities are partly dominant Investigations in this area of research will be the M S study of Iskender Tiryaki

Table 3 UNL Pearl Millet dwarf inbred line trait collection

	Single traits or trait combinations																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Seedling Traits																		
Virescent (Yellow)	✓	✓					✓						✓	✓			✓	
White Leaf Sheath											✓							
Trichomeless		✓					✓							✓		✓		
Leaf & Stem Traits																		
Bronze Leaf			✓															
Purple Leaf																		✓
Purple Leaf Margin		✓												✓			✓	
Narrow Leaf							✓											
Twisted Leaf									✓									
Midribless Leaf																		✓
Hairy Leaf								✓										✓
Brown Mid Rib															✓	✓		
Head & Seed Traits*																		
Fat Head				✓														
Bristled Head										✓		✓	✓					
Purple Stigma		✓																✓
White Grain	✓						✓											
Brown Grain					✓										✓			
Purple Grain			✓	✓	✓									✓			✓	✓

* Gray grain unless otherwise stated

Table 4 1996 Advanced sorghum hybrid trial - Mead Data from 13 of 20 entries

Parentage		Plant height	Yield
Hybrid	(Pollen Parent)	(cm)	kg ha^{-1}
N122A×PV290 1	NB9040×(3541×BK348)	116	7410
530A×PV316	NB9040×Segaolane	117	7220
N148A×PV316	NB9040×Segaolane	117	7220
311A×PV290 1	NB9040×(3541×BK348)	107	7160
N122A×93C337 2	NB9040×Segaolane	111	7030
N148A×TX2737	RTX2737	117	7030
901A×1226	SA Food Qual line	97	6900
363A×PV316	NB9040×Segaolane	114	6900
363A×PV290 1	NB9040×(3541×BK348)	106	6840
N122A×PV290 2	NB9040×(3541×BK348)	108	6840
N122A×93C341-2	NB9040×Segaolane	108	6840
Checks			
Pioneer 8500		117	6720
N122A×TX430	TX430	115	5900
Mean (20 entries)		113	6650
LSD (0 05)		4 8	980

By contrast, Peter Setimela has commenced a Ph D study on the inheritance of heat tolerance in sorghum seedlings, using characterized stocks from ICRISAT

Networking Activities

Breeding continued in support of pearl millet projects in Namibia and Senegal In Namibia this consists of (1) converting the best A_1 seed parent to an A_4 seed parent - two backcrosses have been completed to this end and (2) locating R_4 restorer genes in Okashana, the released variety in Namibia so that an identified top cross hybrid can be reproduced with these two parents A_4 restorer genes have been located in Okashana both at UNL and SADC/ICRISAT in Zimbabwe who are also collaborators in this project Seed from (1) and (2) above has been sent both to Namibia and Zimbabwe

Millet breeding work in Senegal has been delayed by a move of the breeding program from Bambey to Tambacounda in a higher rainfall zone Some 20 A_4/B seed parents have now been developed from the Senegalese dwarf population IBMV 8401 Three have already been sent to Senegal, and others with some experimental hybrids will follow Researchers in the pearl millet program in Mali, using a hybrid concept developed earlier in project UNL-218, have identified four protogyny hybrids using selected lines as female parents and Mali varieties as male parents Collaborative research has commenced with planting date studies in Mali to identify the planting dates for the best nick between the parents for hybrid seed production

Two sorghum hybrids made from project parents have been identified in tests in Niger for further increase and testing Seed of parents for both hybrids have been supplied Twenty A/B pairs developed in the Botswana breeding project were introduced, increased and test crosses produced

Conferences/Workshops

Nebraska/Kansas Grain Sorghum Annual Conference, September 17, 1996, Manhattan, Kansas

International Confererence on the Genetic Improvement of Sorghum and Pearl Millet, Lubbock, Texas, September 23-27, 1996

Research Investigator Exchanges

PI visited ICRISAT, Hyderabad, India September 3-15, 1996

Drs W R Lechner (Namibia), Nicholas Mangombe (Zimbabwe), Amadou Fofana (Senegal) and Bhola Nath Verma (Zambia) visited UNL- 218 in Lincoln, September 28-30, 1996

Seed Exchange

Thirty-two pearl millet samples were received from ICRISAT, 11 were sent to Senegal, 18 to Namibia, 11 to Zimbabwe, 4 to Niger Seven sorghums were sent to Niger, 14 to Ethiopia and 17 within the U S

Publications and Presentations

Abstracts

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Thesis

Jeutong Fabien 1996 Effectiveness of classes of testers for evalution of lines as potential parents for grain sorghum hybrids Ph D diss University of Nebraska Lincoln

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Andrews D J W W Hanna J F Rajewski and V P Collins 1996 Advances in grain pearl millet utilization and production research In J Janick (ed) Progress in New Crops New Opportunities New Technologies Oct 22 25 1996 Indianapolis IN ASHS press pp 170 176

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF-212
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Summary

Investigations were done this year on couscous processing protein and starch digestibility of sorghum grain, and milling and flour gel properties of highly digestible sorghum lines An entrepreneurial-scale couscous processing unit was installed at the Cereal Quality Laboratory at INRAN, Niamey, Niger The unit consists of a mixer, agglomerator (rouleur) designed and fabricated by CIRAD, France, couscousierre, and a solar-drier Progress has been made towards optimizing processing of sorghum and millet couscous on the unit and entrepreneurs are to market test the couscous At Purdue, fundamental studies were continued on sorghum couscous to correlate grain properties to couscous quality Sorghum couscous was found to be firmer and stickier than laboratory-made or commercial wheat couscous, although there was a degree of variability due to cultivar The origin of the stickiness property was investigated and a strong correlation (r = 0 89) was found with a soluble starch component and stickiness That component was identified as mainly depolymerized amylopectin Apparently either in the milling process or from enzymatic degradation sorghum forms this soluble starch component that yields sticky couscous Genotypic variation in the stickiness property was found as well as the previous finding that 2% added oil during the rehydration step substantially reduced stickiness especially in those cultivars yielding the most sticky couscous

In our studies on sorghum protein digestibility we have continued work on the highly digestible lines we identified about three years ago This year new lines were identified with improved grain quality where vitreous central portion of the grain was more filled out, though was still variation in the fill within a panicle Milling and food qualities of the modified vitreous-core sorghum lines with the high protein digestibility trait were examined Highly digestible lines containing the modified, hard endosperm fell between floury and normal endosperm in kernel density and milling quality, and some of these lines ranked nearly high as normal vitreous cultivars Textural studies of flour gels showed that the modified, highly digestible lines gave softer gels than either normal or floury types A starch structural study will be done to discern whether starch components are different between the sorghum types and to see whether this may be a genetically alterable trait Little work was done this year on further development of a rapid screening assay for protein digestibility due to loss of manpower however, a non-INTSORMIL funded project with a post-doctoral scientist has just begun towards that goal Earlier work showed that an ELISA assay based on disappearance of the α-kafirin storage protein following a short time digestion was promising as a quick assay This will be continued and using the same principle, other techniques will be explored

Starch digestibility of cooked sorghum flours was studied with the goal of finding ways to increase its digestibility Cooked sorghum flours were found *in vitro* to be about 20% less digestible than cooked maize flour Isolated sorghum starch alone however was as digestible as maize starch Lower starch digestibility in cooked sorghum flour was independent of the bran component, and appeared to be related to sorghum protein In the raw grain, previous studies by others have shown that the starch is less available for digestion due to its tight packing within a protein matrix Our findings indicate that the mechanism creating low starch digestibility in the cooked flour may be different from that of raw though still may involve the protein component

Objectives, Production and Utilization Constraints

Objectives

- Develop an understanding of traditional village sorghum and millet food processing and preparation procedures and determine the grain characteristics that influence the functional and organoleptic properties of traditional food products
- Determine the relationships among the physical, structural, and chemical components of the grain that affect the food and nutritional quality of sorghum and millet
- Determine the biochemical basis for the relatively poor protein and starch digestibility of sorghum grain and many cooked sorghum products
- Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum and millet grain

Constraints

Research on the food and nutritional quality of sorghum and millet grains is of major importance in developing countries Factors affecting milling qualities, food quality, and nutritional value critically affects other efforts to improve the crop If the grain is not acceptable to consumers, then grain yield and other agronomic improvements to the crop are lost In addition, breeding grains that have specific and superior quality traits will more likely give rise to processed food products that can be successfully and competitively marketed This is especially true for sorghum which is perceived in some areas to have poor qualitv 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

Recently, Adam Aboubacar, an INTSORMIL graduate student at Purdue, traveled to Niger to contact local entrepreneurs and NGOs interested in cereal processing He met with Mrs Fofana Aissa Maiga, a private entrepreneur who produces and commercializes sorghum and millet couscous, and Mrs Nayo Wanzaidou, a representative from the NGO Weybi Mrs Fofana uses traditional procedures in her couscous processing operation and both her and Mrs Wanzaidou have shown interest in the couscous processing unit we have installed at INRAN In collaboration with the Cereal Laboratory at INRAN, Mrs Fofana will soon start using the unit to produce couscous that will be test-marketed in Niamey Although the rouleur, which was designed by J Faure at CIRAD and built in France, is expensive, it was originally designed to be fabricated in West Africa If market tests are successful, plans are to work with CIRAD to find a local fabricator to make the rouleur

During his stay in Niamey, Adam conducted a sensory study on five (IRAT-204, Mota Maradi, NAD-1, SC283-10, and SEPON) of the eight sorghum cultivars used in his research on couscous at Purdue, and which are cultivars found in Niger Couscous was produced using the couscous processing equipment installed at INRAN A commercial durum wheat couscous bought at a local store was included for comparison Thirty INRAN employees participated in the sensory test Couscous was evaluated for color, taste, stickiness, and hardness Results indicated that although the sensory panel accepted a wide range of couscous color, there was a clear preference for light-colored couscous Wheat couscous had the highest color score followed by SEPON, NAD-1 and IRAT-204 couscous Couscous from Mota Maradi and SC283-10 had brown and pink color, respectively Differences in couscous taste, hardness, and stickiness were noted among the cultivars The panel judged all the sorghum couscous as harder than durum wheat couscous As for stickiness, members of the panel reported some of the sorghum couscous as less sticky than wheat couscous Overall, consumers liked the uniformity in couscous granular size obtained with the rouleur We also noted that the manner of couscous consumption were dependent upon granules size For example, couscous of fine granules (1-1 5 mm) called ‘dambu’ can be consumed with milk, vegetables, or sauce, whereas couscous of intermediate granules known as ‘burabusko’ (1 5-2 mm) is eaten with either milk or sauce A third type of couscous of coarse granules (>2 mm) called ‘degue’ is often mixed with spice and consumed with milk A desirable feature of the couscous rouleur is that it can be used to produce all three types of couscous simultaneously, which can be marketed as separate products

Laboratory work on the biochemical basis for differences in sorghum couscous quality continued this year Stickiness is the most important texture parameter that affects couscous quality It was previously reported that there are significant differences in stickiness among couscous made from different sorghum cultivars, and that addition of oil to the cooking water considerably reduced couscous stickiness Studies were conducted to determine the cause of stickiness in couscous An investigation of the relationships between the amount of water soluble material extracted from sorghum couscous and stickiness revealed no direct relationships However, the water soluble materials contained considerable amounts (40 to 90%) of carbohydrates which alone highly correlated with stickiness A chromatographic separation of these carbohydrates indicated that they were composed of two major components a high molecular weight (HMW) component that was identified as degraded amylopectin (the larger starch molecule) and a low molecular (LMW) component that was composed of small sugars. When the HMW component was debranched with isoamylase and chromatographed, three fractions were obtained. The proportions of the HMW component and its debranched fractions differed among sorghum cultivars (Table 1). Highly significant correlation coefficients were obtained between couscous stickiness and the proportion of debranched fraction II (r = 0.89). Moreover, drop in stickiness due to oil addition was more pronounced in sorghum cultivars with high proportions of HMW and fraction II (Table 1). It was concluded that the decrease in stickiness observed after oil addition was due to carbohydrate-lipid interactions.

As mentioned above, sensory studies conducted in Niger revealed that couscous hardness varied among sorghum cultivars and consumers scored sorghum couscous as harder than durum wheat couscous. These results confirmed our earlier reported laboratory findings. After an investigation of the fine structure of starch, we found that sorghum cultivars with high proportion of the longest linear chain of amylopectin and cultivars with high apparent amylose content tended to give couscous with harder texture.

Sorghum with High Protein Digestibility

We previously reported (1994-96 INTSORMIL Annual Reports) on the identification of sorghum lines within the 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. Work up to this point indicates that the high protein digestibility and the high lysine traits are not linked and may occur either separately or together in the grain.

Rapid Screening Assay

In order for further development to occur on incorporating this highly digestible trait into a breeding scheme, a rapid screening assay needs to be developed. Last year we reported on an ELISA-based assay that, following a short-time digestion, measures reduction in α-kafirin content. This year, due to a shortage of manpower, little work was continued on the assay, although we did look at the possibility of using an electrophoretic technique to measure the same disappearance of α-kafirin as above. With new non-INTSORMIL funding, a postdoctoral research associate has recently been hired to complete the development of the assay or assays, to test their precision, compare them to a standard method, and to validate them in a breeding program.

Modified, Hard Endosperm High Protein Digestibility Types

As reported last year, modified, hard endosperm phenotypes have been found that contain the high protein digestibility trait, as well as the high lysine trait. These, however, are not normal vitreous (translucent), hard endosperm types, but have a unique endosperm structure where vitreous endosperm is found in the center of the kernel and a dense floury endosperm radiates from that out to the grain periphery and a core floury portion is also found (Figure 1). It was shown in last year's report that the microstructure of the vitreous portion of the modified kernels is different than normal vitreous endosperm. Instead of having starch granules packed compactly into a continuous protein matrix, this type has starch granules densely packed into a discontinuous protein matrix.

From observations made at the Puerta Vallarta, Mexico winter nursery, it appears that grain within the panicle of these modified types is not of uniform vitreousness, grain from the bottom of the panicle had a higher percentage of central vitreous endosperm than at the top of the panicle. Studies need to be done to examine whether or not the non-vitreous appearing kernels at the panicle top are still denser, harder grains than typical floury grains. The effect of environment on percent vitreousness of this grain type must also be determined. Despite the questions that remain regarding

Table 1. Soluble carbohydrates composition and drop in stickiness after 2 % oil addition

Cultivars	Total carbohydrates (%)	HMW (%)	Fractions of debranched soluble starch (%) FrI	FrII	FrIII	Drop in stickiness due to oil addition (%)
IRAT 204	76.4	58.9	0.5	66.3	33.1	66
SC283 10	90.7	55.4	0.6	57.2	42.1	63
SEPON 82	69.6	54.4	1.1	52.1	46.8	68
NAD 1	68.8	52.0	0.4	43.2	56.4	47
Mota Maradi	64.3	36.4	1.0	27.4	71.6	49
P721N	40.4	39.2	2.5	24.6	72.9	20
P851171	50.5	26.0	1.8	32.6	65.6	16
P721Q	52.4	30.9	1.6	34.3	64.1	10

Figure 1 Cross-sections of three sorghum endosperm types normal vitreous (top), modified, highly digestible, vitreous core (middle), and normal floury (bottom)

the modified, vitreous core sorghum phenotypes with high protein digestibility, progress was made in the past year in identifying improved lines Selections were made in Mexican plots in April 1997 for grain type Lines were found containing the high protein digestibility trait that had grain with approximately 70% vitreous endosperm

Milling evaluation, using the tangential abrasive dehulling device, was done on seven modified, highly digestible, four floury, and five normal vitreous sorghum lines selected from the Mexico plots Abrasive hardness index (AHI) values, defined as the time in sec required to remove 1% of the kernel, which are a reliable indicator of grain milling quality, placed the modified kernel group (AHI range, 4 0 to 5 7) in proximity to the normal vitreous group (AHI range, 6 3 to 8 3), and well above the floury group (AHI range, 3 0 to 3 7) (Figure 2) Kernel density values for the modified group (range, 1 30 to 1 34 g/cc) were even closer to the normal group (range, 1 34 to 1 38 g/cc), and further from the floury group (range, 1 23 to 1 27 g/cc) The correlation coefficient between AHI and kernel density was significant at r = 0 87 indicating that density could be used as a fairly good predictor of milling quality This study showed that the modification of kernels to a central vitreous endosperm confers a harder, more dense grain that can mill nearly as well as a normal vitreous grain This finding is very encouraging since it is necessary to have good grain quality if this sorghum genotype is to have practical usage for animal feed or human food

Cooked flour gel properties were also studies on the same 16 sorghum lines used above In this case gels produced at three different flour water ratios from the modified, highly digestible lines were softer (measured as the modulus of elasticity) than gels made from either the normal vitreous lines or all but one of the floury lines Stickiness values (measured as the work required to pull the compressed gel from between a plate and probe) of the modified grain group were similar, though slightly stickier, to the normal or floury groups Differences in gel properties, particularly firmness, exhibited within the modified group may be the result of changes in the starch component - amylose amylopectin ratio or molecular fine structure It is unclear at this time whether the observed textural differences would translate into problems if the high protein digestibility/high lysine types are used for food This needs to be investigated Also further investigation into differences in starches may show that textural properties of cooked porridges as are made in much of Africa can be altered genetically

Protein Digestibility of Normal Sorghum

Year-to-Year Variation

A fairly large variation in *in vitro* protein digestibility was found within a sorghum cultivar (P721N) monitored over seven years Uncooked digestibility values ranged from 69 2 to 89 1% and cooked values ranged from 47 2 to 72 9% The apparent environmental effect was surprising, and points to what we believe are differences in the susceptibility of the protein bodies to enzyme attack Year-to-year

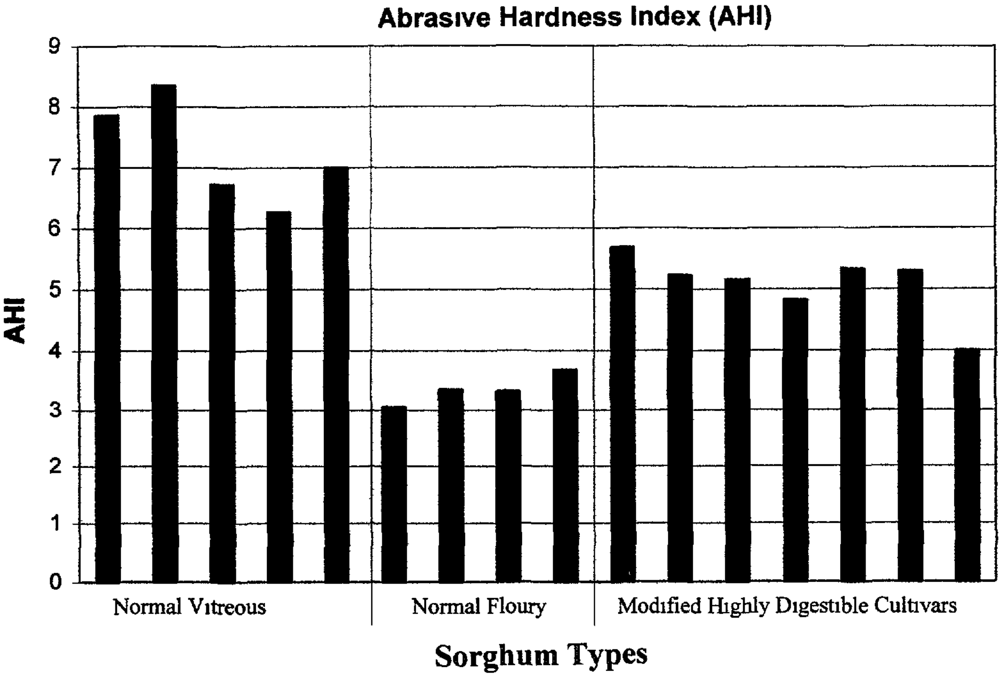

Figure 2 Abrasive hardness index (AHI) values, an indicator of milling quality, of 5 normal vitreous, 4 normal floury, and 7 modified, highly digestible sorghum lines (work done by A Tandjung)

protein digestibility differences were not related to amounts of protein disulfide isomerase, a non-kafirin high molecular weight putative heat shock protein that we identified at the periphery of the protein body, or amounts of the individual α, β, or γ-kafirins However, in sequential extractions of kafirins in incrementally increasing concentrations of reducing agent (to cleave disulfide bonds), there was a negative correlation (r = 0 88) noted between amount of crosslinked γ-kafirin extractable in 0 001% reducing agent (2-mercaptoethanol) and digestibility γ-Kafirin is the enzyme-resistant, highly disulfide-bound protein found at the periphery of protein bodies, and acts to retard digestion of the more easily digested α-kafirin storage protein This finding may indicate that digestibility in normal sorghum cultivars is related to the amount of disulfide-bound γ-kafirin The highly digestible cultivar was not significantly affected by year, probably due to the fact γ-kafirin is not found at the periphery of its protein bodies, but at the base of folds in its structure

Starch Digestibility of Cooked Sorghum Flour

In in vitro experiments using α-amylase as the digestive enzyme showed that starch from cooked sorghum flour pastes was about 20% less digestible than a maize flour paste This supports human studies in Peru that showed 21% of energy consumed from a sorghum-based diet was lost, versus about 13% for maize and 8% for wheat Isolated starches, however, were about equal in digestibility, with sorghum starch even slightly more digestible than maize Pepsin pretreatment markedly increased the starch digestibilities of sorghum cultivars, while little affecting maize Also, cooking sorghum flours in the presence of a reducing agent, sodium metabisulfite, increased starch digestibilities Pepsin treatment after cooking did not increase starch digestibility These results support a view that sorghum protein reduces starch digestibility in cooked flours This hypothetically could be through an interaction with starch after gelatinization or by restricting gelatinization, which would retard its digestion Under the conditions used, we found, using differential scanning calorimetry, that starch was fully gelatinized This leads us to believe there may be an interaction that reduces digestibility Uncovering the mechanism accounting for the lower starch digestibility of cooked flour will allow for methods to be developed to increase digestibility in cooked human foods

Networking Activities

Workshops

* B Hamaker participated in a planning workshop of a new project entitled "Millet promotion through improvement of processing technologies", of the West and Central Africa Pearl Millet Research Network (ROCAFREMI), February 1997 in Accra, Ghana This workshop was convened to design the first year activities of the project and to discuss future plans The focus of the project is on processing of locally grown millet to products for sale to urban consumers

Research Investigator Exchange

* Following a trip of A Aboubacar (Ph D candidate, Purdue) in August 1996 to INRAN, Niamey, Niger to set up a couscous processing unit purchased through Niger InterCRSP funds, B Hamaker traveled to Niamey in February (following the above meeting) to work with M Oumarou and R Seydou in setting up plans for the unit A protocol was developed to optimize processing conditions for sorghum and millet couscous production, followed by sensory testing, and market trials Two food technologists (one each for sorghum and millet) were later hired on a short term basis to carry out the planned work Couscous quality appears to be quite good, and in sensory trials was found overall to be acceptable Some sorghum cultivars gave a couscous of dark red-brown color, and while acceptable to some, efforts are being made through milling or better selection of grain to improve color Sorghum and millet cultivars have also been identified that give light colored couscous A high-quality mixer was bought from the project and sent to INRAN to be used in the flour agglomeration step of the couscous process

* Hamaker and students working on INTSORMIL-related projects (A Aboubacar, L Mamadou, B Buckner, M Oria, G Zhang) attended and presented research findings at the annual American Association of Cereal Chemists meeting in Baltimore, Maryland in September, 1996

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Food and Nutritional Quality of Sorghum and Millet

Project TAM-226

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Summary

The major constraint to utilization of sorghum and millet is the lack of a consistent supply of good quality grain to process Ways of identity-preserved crop production must be devised if products suitable for urban markets are to be successful New cultivars must be grown using procedures to prevent contamination in the field followed by proper storage and delivery to processors

N'Tenimissa, a white, tan plant, photosensitive, value enhanced sorghum cultivar has milling properties similar to local cultivars The color of the flour is improved especially when grain is subjected to high humidity after maturation The tan plant reduces the level of anthocyanins in the decorticated grain and improves color

CERELEG, a weaning food from dehulled pearl millet and cowpea flours (3 1 blend), is still produced and sold by a small food company in Bamako, Mali Addition of 3 to 5% malted sorghum to the weaning food significantly decreased the viscosity of the weaning food

Noodles using 100% sorghum flour had acceptable quality and can be made using equipment available in the home The noodles compared favorably with commercial rice and corn noodles They could be used by celiacs in wheat-free diets An intermediate to hard endosperm, nonwaxy food sorghum with good milling properties gave the best noodles

Progress to evaluate the antifungal proteins of sorghum and the role they play in reducing grain molds and deterioration continues

Objectives, Production, and Utilization Constraints

Objectives

- Develop new food products from sorghum and millet using appropriate technology for use in less developed areas
- Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics
- Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum, and seek ways of modifying its properties or improving methods of processing
- Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance

Constraints

Factors affecting food quality, processing properties, and nutritional value of sorghum and millet critically affect the significance of other attempts to improve the crops If the grain cannot be processed and consumed for food, then the agronomic and breeding research has been wasted

This project relates quality to measurable characteristics that can be used to select for sorghum and millet with acceptable traditional and industrial utilization attributes It has defined quality attributes and incorporates those desirable properties into new cultivars at early stages in the breeding and improvement programs The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptabilities that can generate income for village entrepreneurs

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

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

Sorghum noodles were made from 100% sorghum flour using different cooking and drying methods to optimize the properties of the noodles The method that produced the best noodles used a microwave procedure to heat up the sorghum flour-water dough to 95°C The dough was extruded through a small laboratory, forming extruder and dried under controlled conditions of 60°C/ 100% RH for 2 hrs followed by 60°C/ 30% RH for 2 hrs This method could be used by consumers in developed countries who want to produce noodles or pasta substitutes from sorghum for celiac-sprue (gluten intolerant) diets This technique could be used to develop sorghum products that have a different texture and taste The method could be shortened by drying the extruded noodles in the air overnight but the noodle quality is not as good This information is of immediate use by celiacs who are looking for different nonwheat products to vary their diets

Another method consists of cooking the sorghum flour and water by stirring the mixture over a hot plate, followed by extruding the dough through the extruder and drying the noodles by exposure to air for 12 to 24 hrs The noodles have lower quality using this method of production, but they still 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 Significant modifications of the techniques would be required, but these data show that it is possible to have textured products from non-wheat cereals

Particle size color, presence or absence of black specs and type of sorghum affected the 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 The waxy and heterowaxy sorghums did not produce acceptable noodles A hard endosperm texture sorghum produced the best noodles

The information obtained in this and another study several years ago demonstrate that sorghum and other non-wheat grains can be utilized to produce noodles, provided that special processing steps are taken to gelatinize part of the starch, which is used to hold the other endosperm particles together Retrogradation during drying glues the whole dough mass together Upon cooking prior to consumption, the noodle is rehydrated and holds its structure because of the retrograded amylose present

The best sorghum for noodles has excellent dry milling properties and an intermediate to hard endosperm texture free from anthocyanin pigments A bright yellow endosperm would have an advantage

Extrusion of Sorghum and Sorghum Meal

Food type sorghums made an array of excellent light color, bland tasting extrudates which can be used to produce a variety of ready-to-eat cereals and snacks The texture of the sorghum meal and endosperm type affected extrudate properties significantly It is clear that sorghum can be used easily in extrusion depending upon its availability and cost relative to other ingredients

Sorghum sorghum meal and corn were subjected to accelerated aging to determine the affect of long-term storage on processing properties The grains were stored in sealed containers at 50°C for 15 days or longer The changes occurring during aging at 50°C caused significant differences in the properties of the meal and decorticated whole grain The starches were more tenaciously bound by proteins and the extrusion properties were significantly altered Aging significantly reduced the expansion of extrudates which resulted in higher bulk densities and reduced rapid viscosity values This information explains the phenomena observed in industry where corn and sorghum meals with similar specifications give significantly different extrudates The phenomenon occurs when extrusion is done at low moisture levels At higher moisture levels and longer equilibration times, the extrudate properties do not differ so much between aged and fresh meals

The information on changes in starch and protein during storage explains why extrusion often gives variable results, because the same thing happens when harder texture sorghums are used compared to softer ones The interaction between starch and protein is a major factor that affects quality of these grains The conditions used in extrusion need to be adjusted to counteract these differences which are not understood by most industrial processors

Our results indicate that the Rapid Viscosity Analyzer (RVA) is a quick method that provides useful information on the extrusion properties of meal, and helps to explain why there are differences in extrudate properties from various meals These findings have been utilized by the food industry in the U S

Objective Methods for Determining Tortilla Texture

A method to objectively measure tortilla texture was developed and evaluated using commercial tortillas The objective rollability method consists of measuring the force required to roll a tortilla around a dowel The method was developed because it mimicked the rolling of a tortilla around a filling Tortillas that break or crack, leaking the filling on the hands, are of poor quality The objective rollability method had a coefficient of variation of 8 5% and was sensitive to changes in rollability during the first 24 hrs of storage It has excellent potential for use to determine differences among tortilla additives and tortillas made from different grains and grain mixtures It will be applied to measure the staling of sorghum and corn tortillas and blends of the grains Two other methods have been devised and will be tested on sorghum and corn tortillas These methods will allow us to determine if there are any inherent differences between corn and sorghum tortillas in staling properties

Weaning Food Systems

CERELEG, a weaning food containing dehulled pearl millet flour, cowpea flour and corn flour is manufactured by a small businessman in Mali The Malian food technology laboratory has conducted cooking and feeding trials in several villages in Mali The current CERELEG formulation produces a gruel that is viscous, with a low nutrient density Therefore, we have evaluated the use of malted sorghum to reduce the viscosity and improve the palatability of cereal-legume weaning foods In our lab, we have tried to answer critical questions that affect the utilization of malt to reduce viscosity and liquefy the products The information we generated has been used to adjust the Malian procedures to achieve the best product with a minimum of effort

Sorghum malt was produced in the laboratory from Dorado, a white sorghum The total dry matter losses during malting were 11 5% The malt was ground and used to determine the factors affecting liquefaction of weaning foods To study the conditions that occur during cooking of weaning foods, we used the RVA where we could vary the methods of cooking in a standardized manner and measure changes in viscosity accurately over time simulating various cooking procedures The RVA was utilized to answer critical questions on malt levels required, pretreatment of the flours, the significance of different cooking procedures and the storage properties of malt (Figure 1)

We used CERELEG and CERELAC as examples of commercial weaning foods for comparisons CERELAC is a commercial weaning food made in Ghana by Nestles, Ltd Weaning foods which were heated required significantly less malt and reduced time to reach a desirable viscosity level Twenty percent solids weaning foods required 10% malt to liquefy them into a suitable consistency for drinking For most of our work, 15% solids could be reduced into acceptable weaning foods by 3% malted sorghum in 10 min or less The viscosities of the weaning foods cooked without malt varied significantly CERELEG had the highest viscosity compared to the other weaning foods CERELEG, treated with 3% malted sorghum flour, required additional cooking time to reach acceptable viscosity and had greater viscosity when it was cooled to room temperature (30°C), probably because it had lower heat treatments during processing than the other products The experimental weaning foods from millet, waxy sorghum and nonwaxy sorghum were similar in cooked viscosities after malt treatment

The roasting of the flours is necessary to obtain improved taste It eliminates the cowpea flavor and also makes the weaning food starches more susceptible to rapid hydrolysis by the malt It is feasible to add malt to decrease the viscosity and enhance nutrient density of weaning foods fed to children The malt quality is critically important because malting losses are high and microbial loads are sometimes high

The cooking of the weaning foods, following the usual procedures used in village food preparation of porridges, is effective for production of weaning foods with low viscosity The malt enzymes provide sufficient activity to reduce the viscosity to the desired level In addition, the malt and flour can be added to cold water and cooked over the fire with stirring which is even more effective

The Novartis (Ciba-Geigy) Foundation, and personnel from the IER food technology lab, has used some of this information to plan and conduct weaning food trials in villages near Cinzana, Mali to introduce the concept of producing liquified weaning foods from cowpeas and millet flour They found that sorghum malt liquefied the weaning foods effectively, but that they could find a more reliable source of malt from pearl millet than sorghum in that area of

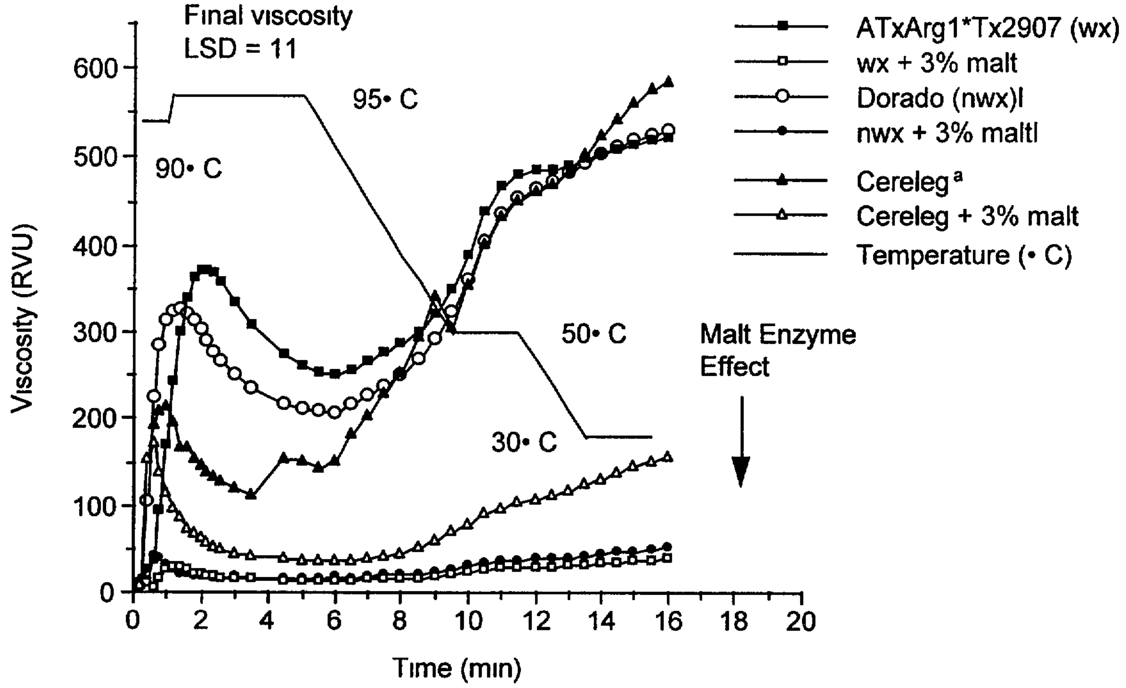

Figure 1 Pasting properties of sorghum and commercial weaning foods (15% solids) with and without 3% malt at 10°C/min

[a]Cereleg commercial pearl millet cowpea weaning food produced in Mali

Mali We found the pearl millet and sorghum malts used in Mali had markedly lower levels of diastatic activity compared to our malt Pearl millet malt was better than the sorghum malt which had very low enzyme activity This indicates that acquisition of malt may be difficult, especially since high enzyme activities are required to decrease the levels of malt used in the weaning foods

We devised a very simple inexpensive viscosity test to check malt activity that could be modified for use at the village level

Malt from sorghum or pearl millet is produced for brewing in Mali in most areas However, the association of malt with beer production may be detrimental to adoption of these techniques in village level food processing Addition of 5% malted flour to CERELEG would produce weaning foods from CERELEG comparable in viscosity to CERELAC, when they are cooked using traditional procedures The laboratory in Mali could assist the producer of CERELEG to implement this technology and determine the economic feasibility of producing the product Currently, CERELEG sales are decreasing and might be improved by adding malt, coupled with improved advertising and marketing activities

Utilization of Sorghum in Baked Snacks

We have demonstrated that waxy and nonwaxy sorghum flour can be utilized in the production of baked low-fat tortilla chips and corn chips A pilot plant procedure for production of low-fat baked chips was used to evaluate different ingredients to improve the texture of baked chips and tortilla chips

Baked tortilla chips tend to have a very hard and brittle texture They have a very compact structure because they don't expand during baking In an attempt to make baked chips more crunchy and friable, raw and gelatinized waxy and normal rice and sorghum flours were used By adding waxy flours, the amylopectin content of masa is increased which produces a soft, cohesive dough that modifies film formation, sheet extensibility and puffing during baking The snacks prepared with this dough have a crisp, fragile texture which is significantly improved over normal baked chips

Raw and gelatinized rice and sorghum flours were substituted for part (20%) of the nixtamalized corn flour (NCF) used to prepare baked chips and tortilla chips Waxy rice and sorghum flour chips had a gelatinized continuous phase containing significantly greater numbers of small air cells with thin cell walls which gave them a layered appearance They required less force to break and were more friable than the control (Figure 2)

Baked chip texture can be improved by using gelatinized waxy flours (rice or sorghum) By using these additives the baked snacks develop a porous structure that allows them to break into many pieces during the first bite These findings are extremely useful in establishing that waxy sorghums have significant potential for use in production of baked snacks which is a growing market in the U S and elsewhere The waxy sorghum hybrids released recently by TAES could compete favorably with waxy rice and allow sorghum farmers access to value-added markets

Dry Milling Properties of Sorghum

Sorghum samples from several performance trials were analyzed and evaluated for milling characteristics The new food-type sorghums consistently had equal or improved grain yields, improved milling yields and the color of the decorticated kernels was far superior to those of white sorghums with purple plant color It is clear that certain parents improve the milling properties of their hybrids significantly

In cooperative work with a dry milling company in Botswana, we confirmed that many of our food type sorghums did not have a bright white endosperm Many of them had various levels of yellow pigments in the endosperm which caused the porridges (pap, sadza) of Southern Africa to have an undesirable yellow color We evaluated the International Food Sorghum Trials grown at Lubbock, Texas in 1994, 1995 and 1996 for endosperm color and for milling properties Only a few of the sorghums actually have a bright white endosperm, most have some yellow in the endosperm This yellow is apparently different from that of the yellow endosperm characteristic

Dr William L (Bill) Rooney, Sorghum Breeder, College Station, initiated crosses to determine the heritability of these yellow pigments and to determine its relation to the yellow endosperm characteristic In the past, we were not concerned about endosperm color as long as the pericarp was easily removed with little or no anthocyanin pigments in the grits More emphasis will be put on pure white endosperm sorghums with tan plant color

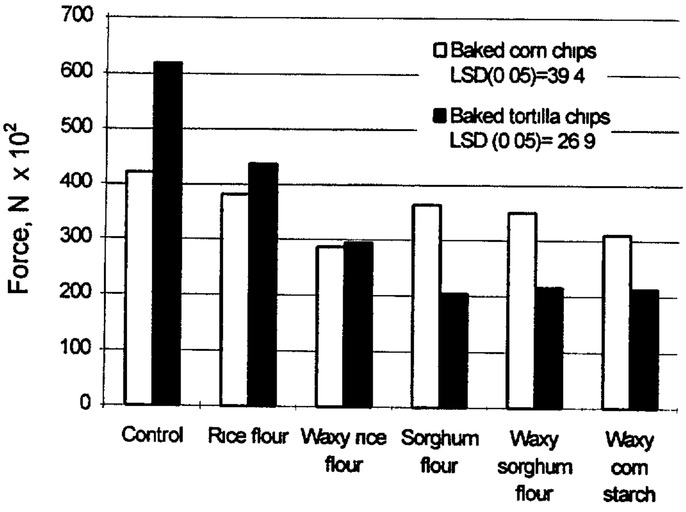

Figure 2 Effect of waxy ingredients (20% level) on baked corn and baked tortilla chip texture (force values are the average from three replicates and six duplicates)

Some experimental red tan plant sorghum hybrids had good dry milling properties and produced decorticated products with significantly reduced red stains The yield levels and improved appearance of the grain and milled products of the tan red sorghum hybrids make them extremely promising for areas that cannot grow white sorghums

Role of Antifungal Proteins (AFP) in Minimizing Grain Molding of Sorghum

Molds significantly affect the yield and quality of sorghum for food processing The combination of grain molds and insects often destroy grains in West Africa We have attempted to find ways of decreasing the weathering and mold damage on white or red food type sorghums We have been attempting to understand the role of AFP in conferring mold tolerance Thus far, it has been nearly impossible to select for mold resistance We are hoping to utilize biotechnology techniques to enhance our progress Understanding the role of AFP would assist in that goal

We have demonstrated that a combination of AFP from sorghum are inhibitory against grain molding pathogens in vitro This year we demonstrated that fungal pathogens at different stages of growth and development exhibit different levels of tolerance to AFP, i e , spore germlings are more susceptible to inhibition by AFP than are fungal hyphae Thus, bioactivity of AFP depends upon the stage of development of the pathogen Thus, presence of AFP at the time of fungal infection (spore germination assay) is more inhibitory than during fungal colonization (hyphal elongation and hyphal rupture assays)

We found *F moniliforme* was markedly inhibited at protein concentrations as low as 160 ppm AFP using spore germination inhibition or hyphal rupture evaluations *C lunata* and *A flavus* required higher AFP concentrations for inhibition in these assays when compared to *F moniliforme* Further, *A flavus* did not exhibit hyphal rupture nor hyphal elongation inhibition when treated with AFP

While the levels of AFP in mold-resistant and mold-susceptible sorghums differ significantly, their role in protecting seeds, in vivo, during caryopses development is not clear AFP increased from not detectable to trace levels during the first 10 DAA Upon imbibition AFP move from the endosperm and can leach out of immature (10 DAA) caryopses Hence AFP may not be a significant factor in defending developing caryopses against pathogens since AFP levels are the lowest in developing caryopses 5-10 DAA when fungal spores more easily infect sorghum caryopses

Sufficient AFP (260 ppm) are in physiologically mature caryopsis of Malisor 84-7 to inhibit fungi in vitro These proteins, however, are distributed in the endosperm and may not be available to react against fungi However we have shown that AFP in the endosperm are mobile when wetted, e g , by rain and are retained by the components in the pericarp in mature caryopses Thus, the concentration of AFP in the pericarp could be increased 2 to 10 fold during this mobilization process, thereby, enriching AFP concentration and strengthening the caryopses defense mechanism Therefore sorghum caryopses may contain sufficient amounts of AFP to inhibit grain molding fungi in vitro, and with some speculation, in vivo The actual inhibition probably occurs in certain cells of the caryopsis so it is possible that the AFP do affect mold development under high moisture conditions

We observed increased levels of AFP during the initial stages of seed germination and plant growth It is possible that AFP are deposited in developing endosperms primarily for the protection of the next generation, i e , the protection of seeds during storage and germination Research is in progress to elaborate the nature of seed-pathogen interactions as it pertains to AFP

Enhancing the levels of AFP at the earlier stages of caryopses development could help minimize caryopsis infection Advances in genetic techniques to create transgenic plants offer promising alternatives to enhance seed AFP levels Results from our investigations indicate that any strategy undertaken should consider changes in these proteins during caryopses development and the stage of development of the pathogen during infection to have maximum inhibitory effect

Sorghum Improvement Research

This project cooperates closely with other members of the sorghum program to incorporate the best quality characteristics into new cultivars Samples from the breeding nurseries and from the food quality tests grown at different locations are tested for kernel characteristics and for processing properties such as decortication and nixtamalization The alkaline cooking tests are especially sensitive and pick up off-colors easily

From this research, Texas A&M has released several inbreds that produce white, tan plant sorghum hybrids with excellent food and feed processing quality For example, recent work in Mexico has confirmed that the new food sorghums had significantly higher yields of grits compared to existing commercial sorghum hybrids In addition, the color of the grits from the white food sorghums was significantly improved These sorghums produce excellent quality grain when grown under dry conditions Because of reduced anthocyanin pigments, the grain can withstand some humidity during and after maturation However, these sorghums need more resistance to molds and weathering to be grown in the hot humid areas of the world, including the Coastal Bend of Texas and Tamalipas in Mexico The work to evaluate the role of AFP in sorghum molding and weathering is critically important

Networking

Southern Africa

- * 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 paper was submitted for presentation at the September 1997 SAAFoST Congress in Pretoria Ms Beta is conducting Ph D research at the University of Pretoria
- * In South Africa, Lloyd Rooney has collaboration in the SADC area with Professor John Taylor, University of Pretoria, South Africa who has a project on sorghum and millet from the European Economic Community We are coordinating our efforts to target former INTSORMIL trained students in the region Trust Beta (Zimbabwe) and Leda Hugo (Mozambique) are working on Ph D degrees in food science at University of Pretoria They received M S degrees in food science from Texas A&M University

Mali

- * Major changes in Mali relate to the price and availability of wheat for bread and biscuits There is an economic demand for sorghum, millet or maize flour to extend wheat flour in biscuits (cookies) and French breads An FAO study recommended that maize should be used because it was potentially available for flour production Sorghum should be used but its poor image combined with a lack of available supplies precluded its use Acceptable white food sorghum is just not available for processing
- * Ms A Berthe, Food Technologist, IER, Food Technology Lab participated in the genetics conference in Lubbock, Texas and spent one week in our laboratory developing research plans, accessing information and techniques on food processing We sent a balance back with her, plus other supplies
- * Dr Oumar Niangado, Director General, IER, Mali and other high-level administrators visited our laboratory to discuss value-added research activities in food processing
- * L W Rooney traveled to Mali, funded by the Texas A&M USAID SPARC program, to assist in the dry milling of identity-preserved maize to produce grits for brewing The maize milling project has ramifications for other cereals in Mali because successful demonstration of the concept of identity-preserved grains would enhance our efforts to produce sorghum and millet products of high quality While there, progress in obtaining value-added sorghum products from N'Tenimissa was reviewed
- * The grain of N'Tenimissa, the recently released white, tan photosensitive sorghum, processed into food products of high quality The yield of decorticated grain was similar to that of local improved cultivars in several nurseries and farm trials conducted in Mali in 1996 The color of the milled products was equal to or significantly improved over the local cultivars It was especially improved in situations where weathering and molding caused the purple anthocyanins to stain the endosperm of the local sorghums
- * Flour from N'Tenimissa has been used in a number of laboratory products successfully, but insufficient quantities of grain with acceptable purity were produced Preliminary trials in a commercial bakery to produce biscuits were not completely successful due to inadequate milling of the sorghum Too many black specs from the hilum and off-type grains (contamination) were in the flour This problem illustrates the need for strict control of the grain from planting through processing if high-quality products are to be produced We need to produce large quantities of the grain for proper processing to demonstrate its commercial usefulness
- * A new cereal and legume composite weaning food called CERELEG is currently being sold in Mali by a small businessman The viscosity of the cooked weaning food is too high, hence our work on sorghum malt to reduce the viscosity and improve nutrient density is of practical importance The work with Novartis described elsewhere is a start to placing this technology into the villages

Honduras, Mexico and South America

- * Dr Lloyd W Rooney and Dr Helbert D Almeida-Dominguez, Research Scientist, Cereal Quality Laboratory at Texas A&M University, assisted Dr Francisco Gomez in procuring equipment for a food processing laboratory at EAP in Zamarano Samples and other items were exchanged between the laboratories The acquisition of extrusion and tortilla cooking equipment at EAP is a major step forward to increase knowledge of utilization in Central America We hope to have another student from EAP or to continue work with Mr Francisco Bueso when he returns to EAP in September 1997, after completion of his M S thesis on AFP
- * L W Rooney has a cooperative project with Dr S Serna-Saldivar, Professor and Head, Food Science, Instituto Tecnologico y de Estudios Superiores de Monterrey (ITESM), Monterrey, Mexico, to evaluate the usefulness of the new improved food sorghum hybrids in wet and dry milling and as adjuncts in brewing Dr Serna-Saldivar and three M S students conducted sorghum and maize analyses in the Cereal Quality Laboratory for two weeks We have provided samples of sorghum for planting and for analysis in addition to the use of our laboratory for analytical tests
- * L W Rooney presented a one day workshop on Food Quality of Sorghum and its potential use in the Mexican food industry at a U S Feed Grains Council spon-

sored meeting in Zacatecas, Mexico Another presentation was made to food processors from Colombia and Venezuela Our research activities in composite tortillas, snacks, etc , with sorghum was reviewed with significant interest in sorghum potential value as food This interest was stimulated by recent high prices in wheat flour Mexico produces significant quantities of sorghum which could be used as human food The Grain Sorghum Producers Association is interested in following up with market development activities to capitalize on the new food sorghums

North America

- * Several papers were presented at the annual American Association of Cereal Chemists conference in Baltimore Dr Helbert Almeida Dominguez and several students participated in the Food Technology Exposition in Orlando, FL L W Rooney presented sorghum quality/utilization discussions to Texas Sorghum Producers Board Members, to sorghum production conferences in San Antonio, to several U S Feed Grain Council market development teams from Columbia, Mexico, 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 two short courses on Snack Foods Production and Maize Quality Evaluation in which information on sorghum utilization quality was discussed as part of the program Several food companies visited the laboratory and were exposed to sorghum properties
- * L W Rooney gave an invited presentation to the American Seed Trade Association Sorghum and Corn Research Conference on The Food Properties of Sorghum L W Rooney gave an invited lecture to the Celiac-Sprue National Convention on the utilization properties of food sorghums in gluten intolerant diets Celiacs cannot consume wheat gluten and have a strong interest in alternative grains The food sorghums provide a useful, desirable alternative grain for use in these diets Jowar Foods, Inc is targeting this market for their products from sorghum
- * L W Rooney presented an invited paper, “New Food Type Sorghums”, to the U S Feed Grains Council sponsored Value-Added Grains Conference in Phoenix Arizona The concept of identity-preserved production and marketing of grains is expanding significantly in value-added corns such as the high-oil corn hybrids Our development of food type, waxy, heterowaxy and nonwaxy sorghums fits into this marketing scheme
- * Several posters were presented at the International Conference on Genetic Improvement of Sorghum and Pearl Millet in Lubbock, TX and a paper was presented on the major constraints that affect sorghum and millet utilization

Training, Education and Human Resource Development

- * Mr Haiyan Zhao a visiting scientist from the People’s Republic of China completed a nine month study program on the post harvest technology of sorghum He returned to the National Research Center for Sorghum in Liaoning, China where he is involved in the industrial utilization of sorghum for food and feed He obtained information on a wide variety of food processing techniques including tortillas, snacks, pasta and other products from sorghum He also worked with Dr Waniska and others on weathering and grain mold resistance studies in relation to grain quality
- * Several students from Mexico have used our facilities for part of their research projects especially those from Monterrey Institute of Technology
- * A Honduran graduate student, Mr Javier Bueso, EAP graduate identified by F Gomez, is nearing completion of his M S degree in food science and technology He is continuing the work on the role of AFP on grain mold resistance in sorghum which is lead by Dr Waniska In addition, the field research was collaborative with the sorghum breeding program led by Bill Rooney
- * Five graduate students worked on INTSORMIL related research, although they were only partially financially supported Projects include milling properties of sorghum, snack foods, steam flaking, pasta technology, weaning food production, extrusion and grain molds
- * Two Ph D and two M S students graduated in food science and technology They returned home or accepted positions in the U S food industry

Publications and Presentations

Abstracts

Asante S A R D Waniska C M McDonough and L W Rooney 1997 Development of weaning foods from cereals and legumes using indigenous food processing technologies Institute of Food Technologists Annual Meeting and Food Expo June 14 18 Orlando FL

Quintero Fuentes X H D Almeida Dominguez and L W Rooney 1997 Evaluation of the structure and texture quality of baked chips Institute of Food Technologists Annual Meeting and Food Expo June 14 18 Orlando FL

Ek Couoh N B H D Almeida Dominguez and N G Almeida Dominguez 1997 Properties of extruded food type sorghum malt instant flours GSPA 1997 Sorghum Conference February 16 19 New Orleans LA

Bueso F J R D Waniska W L Rooney and R A Frederiksen 1997 Assessment of the activity of antifungal proteins against grain molds in sorghum caryopses in the field GSPA 1997 Sorghum Conference February 16 19 New Orleans LA

Asante S A H Z Acosta L W Rooney and R D Waniska 1997 Physicochemical properties of starches from sorghum with different amylose amylopectin ratios GSPA 1997 Sorghum Conference February 16 19 New Orleans LA

Kunetz C F H D Almeida Dominguez L W Rooney R D Waniska, and C M McDonough 1997 Processing variables affects on sorghum noodle quality GSPA Sorghum Conference February 16 19 New Orleans LA p 116

Rooney L W 1997 Milling properties of sorghum 1997 GSPA Sorghum Conference February 16 19 New Orleans LA p 63

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Berthe A C M McDonough L W Rooney and R D Waniska 1996 The couscous quality of different grains used in Mali International Conference on Genetic Improvement of Sorghum and Pearl Millet September 23 27 1996 Lubbock TX USA University of Nebraska, Lincoln NE 68583 0748 INTSORMIL Publication 97 5 p 643

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Quintero X H Almeida Dominguez C M McDonough and L W Rooney 1996 Effect of food additives on texture and microstructural characteristics of baked chips AACC 81st Annual Meeting September 15 19 Baltimore MD Cereal Foods World 41(7) 576

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Rooney L W 1996 Sorghum and millets In Cereal Grain Quality R J Henry and P S Kettlewell eds Chapman & Hall London p 153 177

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Host Country Program Enhancement

Honduras and Central America

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Objectives, Production and Utilization Constraints

Objectives

- Conduct maicillo research including breeding nurseries, advanced yield tests and on-farm demonstration trials with new maicillo technologies
- Conduct nurseries to select for resistance to most common sorghum pests in Honduras
- Evaluate new herbicides with potential use in sorghum
- Develop and promote sorghum grain standards for Central America to enhance commercialization
- Support the Latin American Sorghum Commission (CLAIS) network
- Promote the development of a competitive sorghum seed industry
- Publish the results of grain sorghum performance trials for CLAIS Central America in the NOTICLAIS Newsletter
- Continue to enhance the agricultural experiment and training station at Zamorano
- Train next generation sorghum scientists, technicians and producers for Central America

Constraints

In the period 1990-93, sorghum production in Central America grew 18% at an annual rate of 4 42% On the other hand, maize-the most important cereal crop in the region only grew 5% in the same period, at a yearly rate of 1 16% (NOTICLAIS, 1996) Assuming a constant rate of increasing of 4 42%, the estimated sorghum production for the year of 1996 should be 507,947 t ha^{1} a significant increase of 18% over the period of 1994-1996

Several factors are responsible for the outstanding performance of this cereal, and we shall address the most important promoting and constraining factors This unique and deliberate multiple-factor phenomenon has also brought about a significant increase in production efficiency Even though the land devoted to sorghum production has increased, this increment has especially come from a more efficient land use, for instance, sorghum planted as a rotation crop after maize and rice In 1996, the sorghum growing area approached 300,000 ha with an average grain yield of 1,401 kg ha^{1}, representing a very sustainable increase when compared to grain yields obtained during the last decade (FA0- WASYT, 1997)

Other factors responsible for this growth are new technologies promoted by INTSORMIL in collaboration with the regional CLAIS network There is a constant supply of superior genotypes with very high yield potential and outstanding adaptation to tropical environments, from both the private and public sectors, for different levels of production and for different utilization purposes In 1996, utilization of improved cultivars (hybrids and varieties) reached 3507 t ha^{1} with a market value of $4 6 million (U S) (FAO, 1997)

New production technologies are fast being adopted by farmers who have a tremendous multiplying power in their respective communities Appropriate planting dates, minimum tillage, seed treatments, fertilizer application and weed control are important technologies being disseminated at a sustainable rate

This dynamic growth of the sorghum industry since 1990 is also caused by changes brought about by the globalization of international markets and regional and local agricultural policies enforced to support this important phase of agricultural development Two countries in Central America, Honduras and Nicaragua are experiencing an important enhancement of their sorghum production capabilities, and three others are developing important systems of utilization

The estimated sorghum production for the year 2000, utilizing the preceding indexes would be 603,883 t ha^{1} The expected yield shall surpass the 2 t ha^{1}, or an encouraging 33% increase (UPSA, 1994), providing that trends remain stable

Utilization

Sorghum is successfully replacing maize in animal feed and releasing an equivalent amount of white maize for human consumption Estimated sorghum consumption by the agroindustry in Honduras has increased 1361% for the time period of 1985 to 1993 from a meager 4091 t ha^{1} to 55681 t ha^{1} These values represent an average increase of 5732 t ha^{1} per year On the other hand, utilization of maize by the agroindustry has been leveled off at 100,000 t ha^{1}, primarily because of sorghum and feed wheat replacement in animal rations (UPSA, 1995)

Similar trends have been observed for the whole region where sorghum consumption versus maize has increased 2 3 to 1 For the time period of 1990-93, sorghum consumption in the region increased 16 3% while maize increased 7 2% These data illustrate the importance of sorghum as part of the cereal production and utilization system in Central America Recent studies conducted in Honduras indicate that the poultry industry is the most important consumer of grain sorghum for meat and egg production In this regard, El Salvador is developing a fast growing poultry industry with exporting capability

Countries with high growth rates such as Honduras, are experiencing an increase in poultry meat consumption rate per person The poultry industry reports a 67% increase in the period of 1988-94, from 6 kg per person in 1988 to 10 kg per person in 1994 Estimated poultry meat consumption for 1996 was 11 4 kg per person

New alternative uses of sorghum need to be developed to encourage sustainable growth of the industry 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 digestibility and to 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 also needs to be promoted, a 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

Marketing

Trends in increasing sorghum utilization have made this cereal a key commodity to overcome maize shortages and consequently, an important food security crop New Central American free market policies require that sorghum and maize prices fluctuate according to world prices, applying an import tax within the range of 5 to 45 percent, to promote local production and reduce speculation

Grain quality standards for regional commercial transactions are needed to promote market prices Agricultural commodity exchange offices are already established in each Central American country with demanding grain quality standards The Honduran Sorghum Project in collaboration with INTSORMIL and CITESGRAN/Zamorano has developed and proposed new sorghum standards, that with proper distribution should become regional standards This instrument is of paramount importance and should be used by a very general audience throughout Central America

As stated before, a very important regional market is being developed, where Honduras and Nicaragua are the main sorghum exporters, and El Salvador and Costa Rica are the importers This is a logical evolution of Central American agricultural free market economies Honduras and Nicaragua s GNPs are based on agricultural commodity outputs and possess, by far, the most suitable and available lands for agricultural development including sorghum production

Sorghum Landraces (Maicillos)

Conservation and Enhancement of Maicillo Diversity "Maicillo Criollo" is the local name for tropical landrace sorghum populations found in semi-arid regions of Central America They are cultivated along the Pacific side of the isthmus, from southeastern Guatemala through El Salvador and southern Honduras and south to Lake Nicaragua Maicillo for the most part, is remnant of tall, photoperiod sensitive sorghums brought to the new world during the colonial period The maicillos are an unexplored gene pool that cover some 235 000 ha or 67% of the sorghum acreage in Central America Although maicillos are of African descent, they 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, maicillo is slowly being replaced by higher yielding but uniform sorghum cultivars This process not only threatens the extinction of many undiscovered useful genes, but increases the probability of an epidemic occurring

Low Yield Potential National sorghum yield in Honduras has increased from less than one t ha^{1} to 1 1 t ha^{1} in the last seven year period Not only is this a reflection of the adverse environment in which sorghum is grown, but it is also a result of the preponderant use of landrace sorghum populations which have low but stable yield The inability of maicillo criollo to respond to management practices with increased grain yield is the primary constraint to sorghum production Before new technologies, like soil and water conservation interventions, can improve soil fertility and become economically feasible, the genetic potential of traditional cultivars to respond with increased grain production must be enhanced Increase in sorghum yield and area is primarily due to the utilization of improved cultivars (hybrids and varieties), which are boosting sorghum production in Central America

In the past ten years, maicillo breeding efforts have produced a significant amount of superior genetic combinations They are now being introgressed successfully into the original maicillo populations and with superior exotic lines, rendering a higher yield potential to be used by modern sorghum production technologies

Traditional Farming Systems Maicillo is an old world crop that has adapted to neotropical slash and burn agroecosystems More than 60% of the sorghum planted in Central America is late maturing landrace populations that are intercropped with early maturing maize Although maize is the preferred staple it is often intercropped with sorghum by subsistence farmers in hot erratic rainfall areas as a hedge against drought Maicillo's sensitivity to photoperiod and its ability to withstand shading are essential for its adaptation to traditional maize intercropping systems In contrast, introduced cultivars require genetic modification before they can be used in these systems

Precise studies to understand the nature of the interactions between the new enhanced maicillos and the new soil conservation strategies proposed by different institutions are needed Specifically, biomass production and partition, nutrient removal, and soil and nutrient losses, under different soil conservation practices such as stone walls and vetiveri grass line barriers

Photoperiod Sensitivity Maicillo Criollo has an acute sensitivity to photoperiod and day lengths of 12 h or less which is required for floral initiation In Central America, floral initiation occurs during the first fortnight of October regardless of spring planting date Because of maicillo's short day requirement, it fails to flower before the first frost in the U S Consequently, its improvement must be carried out within its domain in the Tropics (12-15°N lat) Additionally, the photosensitive response prevents maicillos from spreading beyond their very defined agroclimatological range For maicillos to produce good quality edible grain, dry conditions during maturity must occur Other high rainfall areas with different precipitation patterns need appropriate sorghum types to take advantage of better environments for biomass production Precise studies on the allelic makeup of maicillo populations are needed to develop specific genotypes

Improved Sorghum Cultivars

Cultivar Evaluation Commercial seed companies that market improved varieties and hybrids require an unbiased evaluation of their materials for yield and adaptation Seven seed companies Asgrow, Cargill, Cristiani Burkard, DeKalb, ICI, Pioneer, and Seminal are now marketing a wide diversity of hybrids Multilocation testing is of paramount importance to expose new hybrids to farmers and seed distributors Publications and field days are key to exposing farmers to the newest most adapted cultivars and guide the national certification offices to allow specific hybrids to be marketed

Parental Lines for Hybrid Production The seed industry in Central America is experiencing a revitalization through the new open market initiatives Even though international seed companies are doing an excellent job in disseminating sorghum hybrids, national small seed industries are demanding parental lines for hybrid production Parental lines for the new red grain sorghum hybrid developed by INTSORMIL are being increased for distribution for commercial seed production upon agreement with INTSORMIL

Seed Availability The Central American open market is promoting an active exchange of agricultural goods, including crop seeds, among participant countries Furthermore, some Central American companies are moving into the southern Mexican and south American markets of sorghum seed This represents a good opportunity to export tropical-adapted hybrid sorghum seeds developed in Central America Uniform seed standards are becoming important to promote seed exchange among these different regions A close collaboration with every national seed agency as well as the international seed association is needed to advise on seed standards AOSCA (International Association of Seed Certification Agencies) standards provide the baseline support to use uniform standards

Management Practices Exploiting high yield potential, bred into the improved varieties and hybrids through enhanced management practices, requires systematic on-farm testing and demonstrations The low average grain yield (2 5 t ha^{1}) attained with improved cultivars is a reflection of several agronomic malpractices They range from land protection, planting dates, seedbed preparation practices, plant densities, weed control, early season pest control and harvest time

Pest Management

Insect Pests An early season lepidopterous pest complex, called the langosta by Honduran farmers, is an important constraint to sorghum and maize production in the region The fall armyworm, along with other lepidopterous larvae—*S eridania Metaponpneumata rogenhoferi* and *Mocis latipes*—wreak havoc each spring by chaotically attacking seedling fields with little or no warning Understanding the complex, its species diversity, density, time of occurrence, and origin, is necessary to develop an adequate control strategy

New low-toxicity seed treatment insecticides provide outstanding early season pest control This technology needs to be demonstrated and transferred to ensure appropriate plant densities and increased yields

Ergot In 1996 the disease named "ergot" appeared, caused by the fungus *Claviceps africana* This new disease in Central America has caused alarm in other South American countries, as well as in Australia, where special quarantine and control measures are being implemented We do not anticipate an important effect in the sorghum industry in Central America, since very little hybrid seed is produced Nevertheless as the sorghum industry is moving into the seed production business, some control measurements need to be applied Public awareness activities in the region have to be implemented as well

Sorghum Downy Mildew Sorghum Downy Mildew (SDM) is a recently introduced disease that is endemic in the region Not only is maicillo susceptible to SDM, but the threat of this disease is compounded by the existence of the most virulent pathotype, P5, of *Peronosclerospora sorghi* reported in the Americas which was discovered at Las Playitas Experiment Station, Comayagua, Honduras in 1986 Because maicillo and most sources of resistance in the U S are susceptible to P5, the pathogen threatens the stability of sorghum production in Honduras and Central America The introduction and deployment of resistant genes offers the best alternative for control Evaluation of commercial and experimental entries in Comayagua is providing an insurance against this disease

Anthracnose Anthracnose poses a major disease threat in Honduras and probably throughout Central America, therefore, a program to increase the level of resistance to sorghum is an urgent need Deployment of a susceptible hybrid in the Olancho area, for example, can be devastating Consequently, the anthracnose reaction of all commercial hybrids needs to be obtained if for no other reason than to avoid the growing of an otherwise excellent hybrid that may have a susceptible reaction to anthracnose The maicillo sorghums have been evaluated for their reaction to *Colletotricum graminicola*, the pathogen causing anthracnose Pathotypes attacking maicillos genetically resemble those attacking *Sorghum halapense* in the U S Evaluation of commercial hybrids to anthracnose damage in traditional farming systems is of great importance for the region Concurrently, a program on the extent of pathogen variability, much like was done for the downy mildew pathogen is being implementing for Honduras However, aspects of this program should include the evaluation of isolates from other countries in Central America, since isolates from Honduras have been shown to be genetically similar (Rosewich, 1994 personal communication)

Leaf Blight Even though leaf blight is not a wide spread disease, it has the potential to cause significant losses at higher altitudes There have been some trends that indicate a slow but steady increase in leaf blight susceptibility, specifically in Tx623, Tx626, and some commercial hybrids bear ing susceptible parents A systematic screening scheme and gene deployment is needed to anticipate epidemics

Weed Control Using high yielding sorghum cultivars offers an excellent possibility to invest in more efficient weed control strategies New discoveries by the agrochemical industry offer better economic and ecological weed control alternatives Knowledge of these products by the sorghum industry in Central America will promote registration of the product, market availability, better weed control, and higher yields

Research Approach and Project Output

The Honduras/Central America Sorghum program is a small program with headquarters at Zamorano Panamerican Agricultural School At Zamorano the Sorghum Project is joined with CITESGRAN (International Center for Seed and Grain Technology) headed by Dr Francisco Gomez (until July 1997) This arrangement favors a multidisciplinary approach to solving sorghum production and fosters utilization

The program continues to be very productive Much of its success stems from the continuity and stability provided by multi-institutional arrangements and the sorghum seed industry, as well as providing expertise to the Agronomy Department at Zamorano The program has established an elaborate network of collaborators in Honduras that includes government, seed and grain industries, NGOs, universities, and farmers At present, four sites are used to evaluate commercial hybrid performance and are also utilized to screen maicillo breeding materials for an array of biotic and abiotic stress factors Numerous other collaborators and sites are used to validate on-farm new sorghum cultivars and other technologies Multilocation testing is essential for developing cultivars with broad adaptation and resistance to multiple diseases

Two technical thrusts that are the focus of this project are a) conservation of local landrace sorghum populations and their enhancement, and b) development and adaptation of high yielding improved cultivars The first thrust deals with maicillo or photoperiod sensitive sorghum and the success of one activity depends upon the other Our approach to conservation is a passive, in situ approach, whereas enhancement is an active, more aggressive approach The second thrust deals with insensitive sorghum germplasm and has achieved great importance in augmenting production and productivity

Utilization and Marketing

Marketing and Sorghum Grain Standards The sorghum grain standards developed jointly between CITESGRAN and INTSORMIL are now being examined by public opinion and obtaining the necessary feedback to formalize them Implementation and diffusion of these standards will not only promote a more orderly exchange of grain sorghum but also a better market quality

Grain Quality and Processing With the help of ASHA CASP, and INTSORMIL, we continue to design and equip a grain processing unit with extruder and tortilla equipment that will be used to process different types of cereal including sorghum Training, product development, and marketing will be the main objectives The Cereal Quality Laboratory at Texas A&M is fully involved in developing a curriculum in grain processing for Zamorano students Mr Javier Bueso, a student at TAMU, is ready to go back to Zamorano and join CITESGRAN to develop, in collaboration with Dr L W Rooney, a grain processing curriculum Ing Bueso has developed expertise in sorghum grain quality, specifically on antifungal proteins (AFP) and sorghum food processing in collaboration with L W Rooney His major finding while at TAMU were that high levels of chitinase and sormatin in sorghum kernels did not confer increased mold resistance to sorghums by themselves Neither sormatin nor chitinase significantly correlated with grain mold resistance at physiological maturity Sormatin and chitinase may play other roles in the sorghum kernel besides protection against mold since they accumulate at high levels even in very low mold environments The effectiveness of sormatin and chitinase as antifungal agents appears to depend on the degree of protection other kernel traits may provide against mold attack

Conservation, Enhancement and Production of Sorghum Landraces

Conservation

The success of all breeding programs depends on available genetic resources When working with unique cropping systems, such as sorghum-maize intercropping, it is essential to have access to germplasm that is adapted to these peculiar conditions Central America accommodates an array of such genetic resources that is cared for in a gene pool that spans some 200,000 ha Our objective is to continue to conserve, even enhance, this genetic diversity in-situ where it will continue to evolve and serve humankind

Replacement of maicillo by exotic photoperiod insensitive germplasm represents a threat to genetic diversity, and to the maize-maicillo intercropping system used by small farmers in the semi-arid regions of Central America Our approach strives to conserve maicillo in-situ and is relevant to areas where landrace populations dominate traditional farming systems Its success hinges on our ability to upgrade local landraces populations that are then returned to farmers' fields

Our Sorghum Project has assumed the responsibility for conserving this sorghum gene pool The goal of our conservation effort is to create a mosaic of maicillo, enhanced maicillo, and improved variety fields in which genes flow freely among these different kinds of sorghum Ostensibly, an informal network of village level landrace custodians will care for this germplasm as they have cared for maicillo The creation of enhanced maicillo cultivars and their subsequent deployment on-farm, not only is intended to increase genetic diversity in-situ, but to stave off maicillos replacement by introduced cultivars not adapted to local cropping system and with a narrow genetic makeup

A long term program was initiated in 1981 to genetically enhance and reduce genetic erosion in the maicillo germplasm, through systematic deployment of enhanced maicillo cultivars as vectors of elite exotic alleles Deploying these elite alleles for yield, quality and resistance to biotic stresses among maicillo populations are the first steps in conserving the adaptative gene pool of maicillo Quantification of the degree of fixation of the exotic elite alleles deployed in previous years will help us determine threshold levels for the survival of elite maicillo alleles Enhanced maicillos were first tested on farmers' fields in 1987

In situ conservation of maicillo germplasm has contributed several useful traits to sorghum world gene banks In addition, there is some indirect evidence that different alleles at the Ma_1 locus are responsible for the acute photosensitivity response present in the maicillo populations Although the value of these genes is still not known they are genetic resources that would have been lost had we disregarded maicillo These traits were found through a team effort forged by the INTSORMIL scientific network

Enhancement

Our enhancement work is based on a set of short-, mid-, and long-term goals Each time frame is concerned with a different kind of sorghum Short-term goals deal with the introduction and release of elite cultivars, whereas mid-term goals deal with the development of enhanced maicillo varieties Long-term goals concentrate on developing maicillo hybrids

Germplasm releases

Previous near-term goals have been met with the introduction and release of three food-type cultivars “Tortillero’, hybrid “Catracho”, “Sureño” and a sorghum-sudangrass forage hybrid “Ganadero” (ATx623*Tx2784) Our present short-term goals are to round out our sorghum portfolio with the release of a red-seed grain sorghum hybrid (ATx626*R8503), and three broomcorn varieties This next generation of releases reflects a change in our attitude towards development which is shifting from self-sufficiency to self-reliance To put this germplasm into the farmers' hands a cooperation with the seed industry is being pursued

A set of four DMVs is planned to be released in March 1998 during the PCCMCA meeting at Nicaragua This set is made up from a unique combination of Texas A&M, ICRISAT, and the local developed DMVs In addition to high yield potential, they possess outstanding grain quality and a good level of resistance to local stresses

Breeding and Evaluation of Enhanced Maicillo Varieties

Development of enhanced maicillo varieties or photoperiod sensitive sorghum dominates our mid-term goals This activity is the crux of our conservation effort because it creates the plant vectors that will further the introgression of new genes into the maicillo population in-situ, while simultaneously improving crop yields Specific maicillo breeding objectives are 1) reduce plant height which, in effect, shifts the stem to panicle sink ratio in favor of producing more grain, 2) add tan plant color which reduces the amount of polyphenols in the pericarp and thereby improves grain quality for making tortillas, 3) increase resistance to foliar diseases like rust and cercospora which enhances forage quality as well as grain yield, 4) incorporate resistance to sorghum downy mildew which is endemic in the region and threatens stable maicillo production, 5) select for longer panicles and better head exertion which augments yield through higher seed number, and 6) maintain several important maicillo characteristics such as maturity, white seed color (w/o testa), and shade tolerance Other characteristics that have carried over from maicillo, but we have not directly selected for, are resistance to anthracnose and an increased level of soluble carbohydrates (Brix) in the stem Because photoperiod sensitivity is maintained in enhanced maicillo cultivars this work can only be done in the region

We use three locations to screen segregating populations We select for drought stress and shade tolerance at Rapaco, resistance to sorghum downy mildew at Comayagua, and resistance to foliar diseases at Choluteca In 1996 we planted about 10 ha of nurseries at these three locations and made over 5600 individual head selections Most selections are tan plant with white grain and most were 2-3 gene dwarfs (dw)

Napolean Molina, a Zamorano student sponsored by INTSORMIL to conduct research in collaboration with the Sorghum Project, studied the phenotypic structure of a new set of crosses between enhanced maicillo and some new exotic lines from TAMU/TAES and ICRISAT Ninety-three F_2 progenies were characterized by plant height, grain and plant color, presence of pigmented testa, maturity, and other agronomic characteristics His training culminated with 2532 individual heads selected across three environments Progenies of the cross S04*DMV241 were the best performing based on the number of individual heads harvested This new germplasm capitalizes on the best DMVs and elite lines developed by the Sorghum Project, INTSORMIL, and ICRISAT scientists which have been previously evaluated for grain yield and adaptation to tropical environments Most of these F_2 selections showed high grain yield potential and quality

As superior lines are identified in more advanced generations, F_6-F_7, they are placed in our International Improved Maicillo Yield Trial (EIME) This multilocation yield test, referred to as EIME in Spanish, is used to select materials for on-farm demonstration plots The 1996 EIME consisted of 22 entries, including five new lines previously selected under multilocation testing The trials were planted at three locations in Honduras Comayagua, Rapaco, and Zamorano (Table 1)

Zamorano and Comayagua produced the highest grain yield (4000 kg ha ^{1}), while Rapaco the driest environment, showed the lowest (2300 kg ha ^{1}) Better environmental conditions at Comayagua promoted taller plants on the average (2 47 m) while at Rapaco, low and irregular rainfall caused shortness (1 70 m) Zamorano's plant heights were intermediate (2 09 m)

Almost all DMVs have white translucient grains and tan or red plant color making them suitable for human consumption Foliar disease and downy mildew resistance of these DMVs are outstanding and appropriate for forage production

Table 1 Average grain yield of 22 maicillo cultivars in the EIME, over three locations in Honduras, 1996

Entry	DMV	dw	Color	Pedigree	Grain yield kg ha ^{1}	Days to bloom*	Plant height m
9	242	3	wt/t	[(Sepon77*Sta Isabel) 6*ICSV151] 5 7 2 4 b	3921	93	1 41
17	228	3	wt/t	{[SPV346(81LL691*Billy)]*(SC414*P N)} 41 1 2 2 b	3663	127	1 52
7	236	3	wt/t	{[(SC326*SC103)Lib]SC1207} 10 2 1 5 b	2719	132	1 56
8	243	3	wt/t	[(Sepon77*Sta Isabel) 6*ICSV151] 6 1 1 2 b	2045	92	1 59
16	219	3	wt/t	{[SPV346(81LL691*Billy)1*(SC414*P N)} 25 3 4 b	3823	122	1 67
6	244	3	wt/t	[(Tx435(MB9*Liberal)] 3 3 1 1 b	2621	103	1 73
13	245	3	wt/t	[(Sepon77*Sta Isabel) 6*ICSV151] 6 2 1 1 b	2735	95	1 75
				Average	3075	109	1 61
18	MC	2	w/p	ES727	2878	126	1 92
11	239	2	wt/t	[(Sepon77*Sta Isabel) 6*ICSV151] 6 2 1 2 4 4 b	3477	128	1 96
12	241	2	wt/t	[(Tx435(MB9*Liberal] 1 2 1 4 b	2524	114	1 98
5	137	2	wt/r	(TAM428*Porvenir) 29 2 3 b b	5180	118	2 01
19	MC	2	w/p	Lerdo Ligero	4139	101	2 02
10	238	2	wt/t	[(Sepon77*Sta Isabel) 6*ICSV151] 6 2 1 2 4 1 b	3128	127	2 04
4	198	2	wt/r	(TAM428*Porvenir) 29 1 1 b b 1 b	5328	123	2 18
				Average	3963	118	2 01
15	213	1	wt/t	{[SPV346(81LL691*Billy)]*(SC414*P N)} 7 1 b	4398	128	2 24
2	221	1	wt/r	(SureñoCaturra68) 3 3 2 1 b	3770	118	2 29
1	179	1	t/t	(SPV346*GigantePavana) 1 1 2 b	4517	124	2 36
14	218	1	wt/t	{[SPV346(81L~91*Billy)]*(SC414*P N)} 4 1 1 b	3611	124	2 41
3	210	1	wt/t	(TAM428*MC100) 2 2 b	3861	117	2 43
				Average	4031	122	2 35
21	MC	0	wt/p	Porvenir	3298	124	2 87
20	MC	0	wt/p	Peloton	3841	132	2 96
22	MC	0	wt/p	San Bernardo III	3410	120	3 00
				Average	3516	125	2 95

*Plantings were done in the first fortnight of June at all three locations

Since one of the objectives of enhancing the maicillos criollos is reduction in plant height, the EIME trials contained three distinct height groups 3, 2 and 1 dw, in addition to the original maicillos which are 0 dw These different DMVs are the core of ongoing improvement In 1996 a thesis project by an Ingeniero Agronomo student at Zamorano consisted of the evaluation of the progenies derived from crosses made in 1995, between these DMVs and new exotic introductions from TAMU and ICRISAT

On average 2 and 1 dw showed superior grain yields (4000 kg ha ^{1}) than the 3 dw (3000 kg ha ^{1}) Best 3 dw performer was a new DMV line with the pedigree [(Sepon77*Sta Isabel)-6*ICSV151]-5-7-2-4-b) that yielded almost 4000 kg ha ^{1} The pedigree of this line combines the maicillo criollo Santa Isabel, a line from ICRISAT and ICSV151, a drought tolerant line first evaluated in Rapaco in a drought nursery set up by Dr D T Rosenow

Gigante Mejorado as well as Porvenir Mejorado showed outstanding performance across all five locations One new enhanced maicillo derived from Sureño*Caturra crosses, showed excellent potential Other new enhanced maicillo-Sepon 77*Santa Isabel-derivatives and TAM428*MC100 expressed excellent grain yield advantage in at least two locations Seeds of this new generation of maicillos are being tested on farmers' fields through our on-farm demonstration system in 1996

Production of Enhanced Cultivars

Commercial Hybrid Testing Central American Governments have privatized the seed industry The national sorghum program assists this endeavor by conducting a commercial hybrid performance test for private seed companies and the public sector in Central America This testing program began in 1989 and is the only public listing of commercial cultivars available, their performance, and distributors for any crop in Honduras and Central America This is another example of how the Sorghum Project continues to lead by example

The commercial hybrid performance test has helped foster the fledgling Central American sorghum industry in several ways First, it allows the commercial seed companies to up-grade their hybrids Thus, farmers have access to better adapted hybrids with higher yield potential Second, new companies desiring to participate into the Central American market can use the test to attract dealers Third, the performance test reduces the risks farmers perceive when accepting new technologies This is especially true when farmers attend field days and see the hybrids for themselves Fourth, farmers often adopt some of the management practices we use to achieve higher yields, i e , treating seed with insecticide, adjusting plant densities, and using higher fertilizer rates Fifth, the Agricultural Offices use these results to grant seed import permits Sixth, credit institutions are beginning to look at our reports and consider the possibility of making loans to sorghum producers Presently, seven sorghum seed companies in Latin America Agroceres, Asgrow, Cristiani Burkard, Dekalb, ICI, Pioneer, and Seminal subscribe to our service

Each company subscribes to this service by paying an evaluation fee for every hybrid they submit In 1996 testing took place in 13 locations in Central America Comayagua, Zamorano, Catacamas, and Las Acacias in Honduras, Tiquisate, Chiquimulilla and Cuyuta in Guatemala Posolteca and Managua in Nicaragua, San Cristobal in the Dominican Republic, and El Ejido in Panama This is the second time that our efforts are crossing borders in Central America This evaluation is the backbone supporting the regional network CLAIS

Data from these evaluations are published annually in the form of a bulletin named "Comportamiento de Sorgos Graniferos" (Grain Sorghum Performance Trials), and 500 copies are distributed among the sorghum audience

By scanning Table 2, the enormous yield potential that commercial hybrids possess to increase sorghum grain yield in Mesoamerica becomes apparent Superior hybrids averaged close to 7 t ha ^{1} Similarly, Zamorano Rojo, a red grain sorghum hybrid developed by INTSORMIL scientists, averaged 6 1 t ha ^{1} Zamorano Rojo is highly competitive with commercial germplasm Zamorano is producing seed of the parental lines of this new hybrid The idea is to initially produce foundation and certified seed, then when any local seed company requests seed of the parental lines, they will be sold and production will be supervised to assure quality seed

The "Grain Sorghum Performance Trials" publication is greatly enhanced by field days sponsored by the commercial companies Selected farmers attend the field days and are shown the genetic potential as well as the superior management practices such as precision planting, fertilization program and selective weed control

Genotype Environment Interactions of Commercial Sorghum Hybrids Yield data collected from the "Sorghum Performance Trials", were analyzed for the magnitude of their interaction with the environment Data were subjected to five methods for measuring this interaction using the methodology available from the AGROBASE 4TM software, purchased by INTSORMIL Previously, estimated grain yields were adjusted using the nearest neighbor analysis technique Five stability indexes were calculated measurement of cultivar superiority, variance stability with and without covariance, rank differences, and the traditional Eberhart and Russel method We postulated that those cultivars in the first ten places in at least three of the methods utilized, were the most stable It was concluded that the hybrids Platino, SR93, XM5155, Diamante, Marte85, ICI737, Platino and Jupiter had the highest more stable grain yield across the 13 environments evaluated in 1996 This infor-

Table 2 Average grain yield performance of 30 grain sorghum hybrids at twelve locations in Mesoamerica during 1996 (t ha ^{1})

Hybrid	Company	Average	Guatemala	El Salvador	Honduras	Nicaragua	Dom Rep	Panama
Marfil	Asgrow	6 8	4 9	5 0	4 6	8 7	11 6	6 0
P 8346	Pioneer	6 6	4 9	5 3	4 3	8 2	11 1	5 7
Esmeralda	Asgrow	6 4	5 3	5 0	4 7	7 2	10 7	5 2
D 68	Dekalb	6 3	4 7	4 9	4 4	8 0	10 1	5 6
Platino	Asgrow	6 2	5 0	4 5	5 7	7 0	10 0	5 3
Zamorano Rojo	INTSORMIL	6 1	4 8	5 6	4 0	7 4	9 6	5 6
DK 55	Dekalb	6 1	5 4	4 5	4 8	6 4	9 4	6 1
CBX 896 17	Cristiani	6 1	4 8	4 9	4 6	8 5	8 1	5 7
XM 7175	Asgrow	6 1	4 6	4 9	4 8	8 2	9 0	4 9
CBX 896 10	Cristiani	6 1	5 0	4 9	4 6	8 6	7 6	5 8
SR93	Seminal	6 1	5 1	4 8	4 1	7 6	9 0	5 9
XM 5155	Asgrow	6 0	4 8	4 8	3 8	7 7	10 0	5 1
CBX 896 3	Cristiani	6 0	5 5	4 4	4 6	6 2	9 5	5 7
Marte 85	Cargill	6 0	5 0	4 6	4 5	7 6	7 9	6 1
Jupiter	Cargill	5 9	4 9	4 2	4 8	7 3	9 3	4 9
CBX 896 9	Cristiani	5 9	4 8	5 4	4 4	7 5	7 3	6 0
AG1018	Agroceres	4 8			4 8			
AG2005 E	Agroceres	4 8			4 8			
CBX 896 20	Cristiani	5 8	5 0	4 7	5 0	6 5	8 2	5 6
ICI737	ICI	5 8	5 0	4 1	4 8	7 8	8 2	4 9
Diamante	Asgrow	5 8	5 1	4 6	4 4	7 3	8 2	5 0
ICI730	ICI	5 8	4 9	3 9	4 4	7 9	7 4	6 1
ICI770	ICI	5 7	4 9	4 8	3 9	8 0	7 5	5 4
Apolo	Cargill	5 7	4 9	4 5	4 5	8 1	6 8	5 3
CBX 896 68	Cristiani	5 6	4 8	4 4	4 9	7 7	6 6	5 2
Mercurio	Cargill	5 5	5 1	3 6	4 1	7 2	8 2	5 0
P 8527	Pioneer	5 5	4 8	3 6	4 6	7 3	7 3	5 7
X 528	Dekalb	5 4	4 6	5 9	4 7	5 2	7 1	4 9
X 9504	Dekalb	5 3	4 6	4 3	4 6	6 4	6 6	5 4
Average		5 9	4 9	4 7	4 6	7 4	8 6	5 6

Locations Guatemala = 3 Honduras=3 Nicaragua=2 Panama=2 Dom Rep =1

mation is key to commercial companies as well as to extension services to recommend the same hybrid for different environments

On-Farm Research and InterCRSP Collaboration

On-Farm Demonstration Plots Our on-farm testing program is an integral part of in-situ conservation Not only does this activity enable us to collect maicillos from farmers most likely to tradein their old cultivars but it provides the mechanism whereby enhanced maicillo cultivars—the vectors of exotic genes—are introduced into the maicillo populations Since maicillo is a living system our approach to conservation stresses the deployment of an array of enhanced maicillo germplasm, by testing different cultivars on-farm each year, rather than formally releasing varieties which would eventually saturate the formal seed market and slow the introgression of new genes into the maicillo population

Every year we conduct several on-farm demonstration plots to expose small farmers to enhanced maicillo cultivars planted with a gradient of new improved production technologies New technologies are enhanced maicillos, chemical protection to the ' langosta" insect complex, and 60 kg ha ^{1} of nitrogen applied at floral differentiation (last week of September)

In collaboration with the Soil Management CRSP, the Sorghum Project began in 1996 to capitalize on the information previously generated to understand sustainable soil management practices and the effect of using new sorghum technologies

Agronomy Soil Management-INTSORMIL InterCRSP Project In 1996 these two CRSPs joined efforts to support the Sorghum Project to promote new sorghum technologies and soil conservation practices This joint efforts is based on the premise that in order to upgrade grain and forage yield in the maicillo growing 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

It is very important to scientifically understand the relationships between some protection practices being deployed by several NGOs and USAID projects The steep slopes where maicillos are grown offer a unique opportunity to use the soil conservation practices developed by LUPE/Soil Management CRSP The soil improvement capability of these practices can be measured Increasing sorghum productivity is the best measurement of sustainability in this region

A very synergistic activity was officially implemented with Dr Thomas Thurow, a Texas A&M Soil Management scientist, and one of his former students, Ing Hector Sierra, who obtained a M S from TAMU Hector became involved with maicillos when he was collaborating with the Sorghum Project in Choluteca in 1990 Hector is now measuring the effectiveness of increasing maicillo productivity by using vetiver and stone barriers He is generating data on biomass production, agronomic performance, changes in soil fertility, soil losses and economic parameters

Plant Protection

Ergot Upon the discovery of ergot in Central and North America, the INTSORMIL Technical Committee decided to approach this new constraint by supporting collaborative research to identify the basic host plant resistance mechanisms of this disease and to identify those traits that confer resistance For this purpose, Jorge Moran, a Central American young scientist will attend Texas A&M University to study promising alternatives to control ergot Mr Moran will work with Drs William Rooney and Richard Frederiksen, who are studying this new constraint Ing Moran's study will concentrate on evaluating resistance to *C africana* from different sorghum genotypes and on characterizing major resistance mechanisms Support for this study is also provided from the USDA Sorghum Germplasm Committee

Weed Control

Four troublesome weeds 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 was sponsored by the Sorghum Project to conduct studies on the degree of control and phytotoxicity of these herbicides Through this study the 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 atrazina at preemergence

Low Input Ecologically Defined Management Systems for Insect Pests on Sorghum

Research emphasis of the Sorghum Project and MSU-205 during the 1996 growing season in Honduras considered the role of natural enemies (parasites) of the lepidopterous pests as regulatory agents in order to assess their significance in biological control Less than 2% of the armyworm population on sorghum and corn was paratized by insects during the early part of the growing season when the crops are most vulnerable to insect damage A nematode, *Hexameris* sp , parasited 0 to 68% of the armyworms, but the larvae were still able to cause extensive damage to the crops Weed infestation did not influence parasited or parasitization of the lepidopterous defoliators in a significant way This information indicated the limited role that biological control might play in developing integrated insect pest management strategies for the lepidopterous caterpillars on sorghum and corn in this agricultural ecosystem in southern Honduras It may possibly relate to other areas in Central America with similar insect pest constraints to grain production in similar agricultural environments

Institution Building

To build a superior research capability in this region, it is also necessary to strengthen regional institutions Since 1985, Zamorano has offered the best opportunity to host a sorghum project Because of this partnership, Zamorano has become a leader in sorghum research in the area In Addition, the Sorghum Project has provided funds for scholarships, networking, field equipment, teaching, computer equipment, statistical software and travel

Special Projects

The Sorghum Project has been successful in establishing several special projects thorough collaboration with CITESGRAN (International Center for Seed and Grain Technology) These activities augment the effectiveness, stability and outreach of the program These are the commercial hybrid performance tests sponsored by private seed companies, supporting the new seed plant and grain processing plant These projects are administered by the EAP and managed by Dr Gomez, and are exemplary of the kinds of sustainability we are trying to build into the program

Seed Plant at Zamorano With the help of different institutions and donors, Zamorano is building a new modern seed plant with the objective of upgrading seed science and technology in Central America The Sorghum Project has actively participated in designing, construction and equipment purchase Once this new facility is fully operational, training of Central American scientists and technicians will be carried out regularly This facility is expected to boost the establishment of regional seed companies to produce sorghum seed as well as improved services

Sureño update Sureño (PI 561472 and NSSL 259979 51) has found widespread acceptance throughout the sorghum growing regions in Honduras It is the first sorghum cultivar released by the SAR that has found its way into informal seed markets Consequently, it not only survived but continues to increase in acreage share with nominal institutional help Seed production continues to be a problem but can be overcome through a push from the new seed plant at Zamorano and upgrade of the seed industry

Broomcorn Update The INTSORMIL project has successfully developed three broomcorn cultivars that are now available to producers in Central America Nicaragua is the most important country where broomcorn is grown Sustainable contacts are underway to support several NGOs and government programs to supply basic seed as well as technical assistance One Nicaraguan agronomist is to be trained at Zamorano during the fall of 1997

Training and education

Graduate Training for Regional Sorghum Scientists To sustain this ongoing activity, it is necessary to continually supply well-trained sorghum scientists Now that the political situation in Central America favors regional scientific exchange, it is necessary to identify and train young scientists at the EAP, then promote further graduate studies in the U S Under this philosophy, this project maintains active collaboration with Zamorano Texas A&M University, Mississippi State University and the University of Nebraska

In 1996 two students from Zamorano were awarded half-tuition scholarships to conduct research in sorghum breeding and production Napoleon Molina, a Honduran, conducted research on breeding enhanced maicillos, while Juan Hidalgo, a Salvadoran, studied promising sorghum weed control herbicides Both students conducted outstanding research and graduated in April 1997 Two new students, one from Honduras and the other from Nicaragua, were awarded tuition scholarships to conduct sorghum research in 1997

Oscar Vergara, an Ecuadorian-Honduran, and Roberto Cordero, a Nicaraguan, are conducting their graduate studies at Mississippi State University and their research in Honduras They are studying biological control strategies for M *rogenhoferi* a sorghum lepidopterous early pest Patricio Gutierrez, at the University of Nebraska, and Javier Bueso, at Texas A&M University, finished their course work and will be defending their thesis in August 1997 Gutierrez's work on his Ph D dealt with the physiological characteristics of DMVs while Javier Bueso worked on antifungal proteins in the sorghum grain

Training in Experiment Station Management Sorghum scientists in the region are constantly facing the lack of experiment station management capabilities These scientists, in addition to conducting their own sorghum research, are frequently asked to manage the experimental station where they conduct research Basic knowledge of planing and running an experiment station needs to be built into the sorghum scientist curriculum, due to the lack of trained specialists INTSORMIL is devoting some expertise to help Zamorano build an experimental station with a dual purpose, research and teaching students and training in field plot techniques Proper field operations are of great importance to the on-farm demonstration process deployed in high yielding sorghum producing areas Implementing a totally mechanized experiment station at Zamorano will serve to demonstrate basic agronomic practices, such as plant densities, weed control, and fertilizer application to sorghum producers Procurement of equipment for precision planting, soil preparation, and harvesting is being pursued

Networking

CLAIS The Latin American Commission for Sorghum Research (CLAIS) is being rejuvenated to assume a coordinator role in the area Central American research and extension systems are now reorganized to include more participation of the private research and extension systems National Centers are now forming strategic alliances with the private seed industry New scientific and technical personnel are being hired that will benefit from CLAIS coordination and technical assistance INTSORMIL remains the only source of technical collaboration with NARS

CLAIS holds its annual meeting at the PCCMCA forum This year this meeting took place in Panama City during the month of March At this meeting, representatives of the public and private sector discussed several aspects of the sorghum industry There were representatives from the six Central American countries and Brazil They presented several research papers on topics related to breeding, production, weed control and ergot

The official CLAIS newsletter was presented and distributed among the participants The first number consisted of 21 articles classified in eight categories, and 500 copies have been distributed to date These activities continue to strenghten CLAIS, and is becoming more important for the sorghum industry to disperse information Electronic communication is slowly being developed, especially with commercial companies that have the facilities to use this means of communication

PCCMCA The 45-year old Central American and Caribbean Agricultural forum is undergoing the consequences of a decrease in public funding INTSORMIL participation in this forum to rejuvenate CLAIS and the sorghum group requires special efforts

Electronic Linkages New information highway technology is becoming available in Central America through e-mail and INTERNET connections The CLAIS network can benefit by connecting to the worldwide sorghum data base at US universities, ICRISAT and other sorghum projects through the region E-mail communication technology and an electronic newsletter are seen as a preliminary step to link regional sorghum projects and the sorghum industry

Scientist Exchange

Dr Gomez and Jorge Moran traveled to Panama in March to coordinate the CLAIS meeting at the PCCMCA

Dr Gomez and Jorge Moran traveled to Brazil in June to attend the Global Conference on Ergot

Publications and Presentations

Publications

Gomez F and J Moran 1997 1996 Grain sorghum performance tests for the PCCMCA (In Spanish) Tech Rep N¼AG 9702 Escuela Agricola Panamericana El Zamorano Honduras

Gomez F and J Chanterau Breeding photoperiod sensitive sorghums 1997 In Proc of The International Conference on Genetic Improvement of Sorghum and Pearl Millet, 22 27 September 1996 Lubbock Texas USA University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 66 70

Gomez F 1996 Grain Standards for Central America ZAMORANO/PRODEPAH/ INTSORMIL

Gomez F 1996 Ergot Update in Central America Proc PCCMCA Panama Panama. March 17 21 1997

Molina, N 1997 Population analysis of F2 populations derived from enhanced maicillos and exotic lines (In Spanish) Ingeniero Agronomo Thesis Escuela Agricola Panamericana April 1997 Zamorano

Hidalgo J C 1997 Evaluation of the chemical control of four weeds in sorghum (Sorghum bicolor) in the Zamorano Valley (In Spanish) Ingeniero Agronomo Thesis Escuela Agricola Panamericana April 1997 Zamorano

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

NOTICLAIS Official Newsletter of the Latin American Commission of Sorghum Researchers Gomez F Editor Zamorano 1997

Sierra, H 1996 Effectiveness of rockwall terraces on soil conservation and crop performance in southern Honduras Master thesis Texas A&M University College Station August 1996

Presentations

Gomez F Breeding photoperiod sensitive sorghums 1997 In Proc of The International Conference on Genetic Improvement of Sorghum and Pearl Millet 22 27 September 1996 Lubbock Texas USA University of Nebraska Lincoln NE 68583 0748 USA INTSORMIL Publication 97 5 p 66 70

Gomez F 1996 Ergot Update in Central America Sorghum meeting PCCMCA Panama, Panama March 17 21 1997

Moran J and F Gomez 1997 Ergot in Honduras Global Conference on Ergot Sete Legoas Brazil June 1997

Moran J 1996 Evaluacion de la interaccion genotipo ambiente en los hibridos graníferos de sorgo del PCCMCA 1996 Sorghum meeting PCCMCA Panama, Panama March 17 21 1997

Mali

Darrell T Rosenow
Texas A&M University

Coordinator

Dr D T Rosenow, Sorghum Breeder, U S Country Coordinator, Texas A&M University, Texas Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX

Mr Sidi Bekaye Coulibaly, Agronomy/Physiology, Mali Host Country Coordinator, IER, B P 438, Sotuba, Bamako, Mali

Collaborative Program

Program Structure

The program in Mali is a coordinated effort between INTSORMIL and IER It is multi-disciplinary and multi-institutional in scope and includes all aspects of sorghum and millet improvement, production, and utilization Each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart and in concert with and as a part of the overall IER Mali research plan Major INTSORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress, and plan future collaborative activities with their Malian counterparts Occasionally, IER scientists travel to the U S for research review and planning These plans are reviewed by the country coordinators, consolidated, and coordinated with IER research project plans for approval or modification This insures that the research fits into the annual overall IER strategic plan The plans then become part of the annual Amendment to the MOA The USAID sponsored bilateral IER/Texas A&M, SPARC project has assisted IER in research project development, execution, and research financial management for the entire IER program including other donor funding and agencies

Memorandum of Agreement

The original Memorandum of Agreement formally establishing INTSORMIL collaboration with IER and authorizing transfer of funds was signed in Mali on October 10, 1984 A revised MOA was signed in 1996 at the beginning of the current INTSORMIL five-year Project The annual Amendment to the MOA, which consists of the 1996-97 work plan and budget was developed jointly by the country coordinators in April-June, 1996, and approved by IER and INTSORMIL in August, 1996

Financial Input

The USAID Mission has provided significant financial support to the total IER research program, of which sorghum and millet are a part through the SPARC Project which is due to end in 1997 IER and SPARC make decisions on which specific project or locations are funded by SPARC, depending on needs, and where INTSORMIL country funds are allocated Eventually, plans are for all external funding to be managed thru the SPARC/IER financial system Approximately 50% of the yearly Mali Country Budget is transferred directly to Mali from the INTSORMIL Management Entity The remainder is retained at Nebraska and used for major equipment purchases, supplies, IER scientist travel, IER scientist short term training, or special needs as they arise Also, some individual U S INTSORMIL investigators transfer pass-through funds to Malian counterparts or purchase equipment or supplies for Mali directly from their project funds

Collaborating Institutions

* Institute of Rural Economy (IER), Bamako, Mali
* Texas A&M University
* University of Nebraska
* Purdue University
* Kansas State University
* SPARC (USAID/TAMU) Project
* USAID/Bamako
* ICRISAT/WASIP/Mali
* WCASRN (Regional Sorghum Network)
* Soil Management CRSP (formerly TropSoils)

Research Disciplines and Collaborators

Germplasm Enhancement - Sorghum - Aboubacar Toure, S B Coulibaly, Abdoulaye G Diallo, Mody Diagouraga (millet), IER, D T Rosenow, G C Peterson, G Ejeta INTSORMIL A Toure is currently on a sorghum biotech Post Doc with Texas A&M UniversityTexas Tech University (TAMU/TTU)

Crop Protection Systems - Entomology - Yacouba Doumbia, IER, G L Teetes, INTSORMIL, N Diarisso, TAMU student (IER)

Crop Protection Systems - Pathology - Mariam Diarra, Ousmane Cisse (Sorghum), Mamadou N'Diaye (Millet), IER R A Frederiksen, INTSORMIL, M Diourte - KSU student (IER)

Crop Protection Systems - *Striga*/Weed Science - Bourema Dembele, IER, G Ejeta, INTSORMIL

Crop Production Systems - Agronomy/Physiology/Soils - Adama Coulibaly, Sidi Bekaye Coulibaly, Abdoul Wahab Toure, Zoumana Kouyate, Mamadou Doumbia (Soil Lab) IER, S C Mason, J W Maranville, INTSORMIL, Abdoulaye Traore, (IER)(Agronomy), University of Nebraska (UNL) student, Samba Traore, (IER)(Weed Science/Agronomy) UNL student

Utilization and Quality - Mde Aissata Bengaly Berthe, IER, L W Rooney, INTSORMIL

Economics - Bakary S Coulibaly, IER (Purdue student), J H Sanders, INTSORMIL

On-Farm Trials - S B Coulibaly, Lamine Troare, Keriba Coulibaly, Oumar Coulibaly, Antime Sagara, IER

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 and marketing and poultry feeding which would help stabilize prices

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology, *Striga*, food processing, and food technology, 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 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/Texas Tech 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, 1996 (along with Dr Rosenow) to assist in planning the 1996 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 three weeks, and Drs Darrell Rosenow and Gary Peterson for two weeks, where they assisted in making selections in breeding progenies planted at Samanko and Cinzana, evaluated yield trails, and on-farm trials and N'tenimissa increases 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 germ plasm 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 (CE151=IRAT204 and CE90)

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, they are 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 Kila 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 but in 1996 only Advanced trials were organized

New breeding crosses are made annually, sometime in the winter off-season In 1996 there were 61 new F$_1$ populations selected for use There were 1267 individual plant selections made in F$_2$s, 293 made in F$_3$s, 321 made in F$_4$s and 36 made in F$_5$s The F$_5$ selections are routinely then grown as F$_6$s in the off-season and seed increased for use in yield trials the next year

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 guineas 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)] looked outstanding and will be advanced immediately to designated 96CZ-F4P 98 and 96CZF4P-99 yield trials in 1997 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$_2$s and F$_3$s

In the Advanced Early test involving 32 entries, MIK-SOR 86-30-48 (very tall, true guinea line developed thru mutation breeding by Dr Bretoudeau at the School at Katiabougou) produced the highest yield That line along with 93-EPRS-GI-8 (Malisor 84-5*ICSV 1063-5-1), 93-EPRS-GI-10 (M84-7*TRPSS49), and 93-EPRS-GI-13 (Lakaheri* CE90) were selected for use in the crossing bloc The Advanced Medium Trial of 64 entries was grown at four locations The performance and pedigrees of the 16 experimental lines plus 2 checks is shown in Table 1 In the 23 entry Advanced Trial, tall, late maturing guinea type cultivars produced the highest grain yield (Table 2)

Table 1 Mean performance across four locations of the top yielding 16 entries in the Advanced Medium Maturity Test, Mali, 1996

Designation	Pedigree*	T ha^{1}	Days to flower	Height meters
93 SP F6 GII 11	(M84 7*E 036 1) 3	3 16	84	2 14
CGM 39/22 1 2	ICRISAT/CIRAD	3 16	86	3 27
CEM 326/11 5 1 1	ICRISAT/CIRAD	3 04	77	2 48
CGM 19/9 1 1	ICRISAT/CIRAD	2 98	84	2 81
94 EPRS GII 1059	(M84 7*Nagawhite) 74 1	2 90	81	1 89
94 EPRS GII 1015	(M84 7*Nagawhite) 74 1	2 75	80	1 80
93 EPRS GII 21	(E36 1*M84 7)	2 71	87	1 61
95 EPRS GII 1055	(ICSV1079*(85E0361*ICSV1086))	2 71	78	1 87
94EPRS GII 1030	((DMV1380DM87*M84 7)*Gombola)	2 71	79	2 22
94EPRS GII 01088	(ICSV1079*(85e0361*icsv1086))	2 65	75	2 29
93 EPRS GII 111	(E36 1*M84 7)	2 55	80	2 04
94 EPRS GII 1069	(M84 7*85F4 175 1	2 54	87	1 56
94 EORS GII 1119	MIP 90 25 3	2 54	89	3 75
95 EPRS GII 1011	(F2 20*Vartan 16 (M50009)) 3	2 53	74	2 34
93 EPRS GII 113	(E36 1*M84 7)	2 50	88	1 89
MIK 86 30 41	MIK 86 30 41	2 49	87	3 98
CSM388	Check local improved	5 65	86	3 69
Tomoin local	Farmer local	1 95		
Test mean		2 22		

MIP and MIK lines are from Dr Bretoudeau

Table 2 Performance across two locations of the top seven yielding experimental entries in the Advanced Late Test, Mali, 1996

Designation	Pedigree	T ha^{1}	Days to flower	Plant height (m)
N tenimissa	(B Soumale*87CZ Zerazera)	2 14	93	3 51
94 EPRS GII 1007	MIP 88 15 1	2 07	95	3 71
94 EPRS GII 1040	MIP 90 30 1	2 06	95	3 61
94 EPRS GII 1050	(M84 7*CSM388)	1 92	95	2 45
94 EPRS GII 1072	(M84 7*CSM388)	1 83	95	2 87
94 EPRS GII 1126	(CSM388*Sureño)	1 65	95	3 08
94 EPRS GII 1077	(CSM388*Sureño	1 63	95	2 73
MIK 86 30 42	MIK 84 30 42	1 54	94	2 81
Foulatieba	Local landrace	1 44	111	3 99
Temoin local	Farmer local	1 27	82	2 53

Table 3 Elite Sudan Sorghums which looked good at Sotuba and Samanko, Mali

93SX No	IS No	PI Number	Name/Other Designation
53	2294	217718	Wad Beshir
95	2341	217781	Wad Yabis
142	3462	570764	Barking
210D	3541	570994	Nyithin
466	9289	571041	Wad Akr 51/3
634	9787	571193	Wad Akar 2
701	9859	571252	A50/Gezira Sta
721	9882	571270	A105/Gezira Sta
736	9902	571285	A212/Gezira Sta
748	9914	571295	A264/Gezira Sta
757	9928	571303	A337/Gezira Sta
1721	22413	56859	PIA 91 1
1765	22457	569903	Zerz Zerz/PIA 145 2
1899	22815	570037	S 15
2170	24982	570308	AB 7

Approximately six ha of N'tenimissa was planted at seven different locations to increase grain for utilization research and value-added product development Problems with harvesting (before off-type purple plants removed), head bugs, and grain mold damage at two sites reduced the quantity of acceptable grain to about 2,000 kg for utilization research and future on-farm trials

Forty-eight of the most elite cultivars selected from 3000+ Sudan Sorghum Collection were planted at Sotuba and Samanko (ICRISAT) to evaluate for adaptation and potential use in breeding programs for Mali and West Africa Some looked excellent with the best 15 listed in Table 3

Millet Breeding

Mody Diagouraga, technician at Cinzana, continued the pearl millet breeding effort with some assistance from Dr Oumar Niangado, IER Director General Plans are to plant a pilot hybrid seed production block in 1997

Entomology

Studies continued on the bio-ecology of head bug and evaluation of breeding lines for resistance Several new breeding lines were identified by visual scoring as having equal or better resistance than Malisor 84-7 These included 94-EPRS-GII-147, 94-EPRS-GII-157, 94-EPRS-GII-1004 (M84-7*ICSV16-5), 94-EPRS-GII-1077 (CSM388*Sureño), 95-EPRS-GII-1070 (M84-7*Dorado), 94-EPRS-GII-1071 (M84-7*Bimbiri S), 94-EPRS-GII-1015 (M84-7*NagaWhite), 94-EPRS-GII-105, and 95-EPRS-GII-1057

Observations of head bug damage in on-farm trials indicated for the third consecutive year 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 and Cinzana The 118 progenies are being used by Dr Aboubacar Toure in his Post Doc research to identify molecular markers for head bug resistance Excellent segregation for resistance was present in the cross In 1997, additional F_3 progenies from CIRAD/ICRISAT will be evaluated, in a cooperative effort among IER, INT SORMIL, CIRAD, Texas A&M, and Texas Tech 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 scoring Scores were consistent among different persons, across replications, and across locations Grain from bagged heads and open pollinated heads was harvested from all F_3 entries to attempt to relate quantitive traits such as seed weight and germination to visual scores Three other populations were planted for possible use for the molecular marker study, but were determined not useable The cross (Tx436*BTx635) did not show much resistance, (BTx635*S-34) did not show good segregation for resistance, and (Tx436*R6078) did not show much resistance, and the segregation for pericarp color confounded the visual scoring

Pathology

Studies on the effect of seed treatments during seed storage showed that Apron Plus® (10 g kg ^{1} of seed), Sidiolan (2 5 g kg ^{1}), and Super hamoi (2 g kg ^{1}) improved seed quality as measured in the Cereal Technology Lab Selected breeding lines were screened for resistance to anthracnose and sooty stripe Some tolerant genotypes were identified, but most entries were more susceptible to anthracnose than sooty stripe Some investigations showed that farmers do not have a reliable traditional method to control sorghum long smut Gon (Canavalia ensiloformis) again proved effective as a seed treatment in reducing covered kernel smut in sorghum

Agronomy/Physiology

Rotation with cowpea increased pearl millet grain and stover yield by approximately 30% over continuous pearl millet and other cropping systems Stover nitrogen concentrations were the highest from the millet-cowpea rotation as well as agronomic efficiency of nitrogen use (fertilizer use efficiency) The data indicate that crop rotation combined with low amounts of fertilizer nitrogen results in increased yield and efficient use of fertilizer nitrogen Crop residue management treatments had no influence on pearl millet grain or stover yields over a five-year period

Three radiation mutation lines from A Bretoudeau along with their parent CSM388 and a farmer local were evaluated under three nutrient regimes at several on-farm locations P fertilizer increased yield only 13 kg ha ^{1} while with both N and P, yields increased 126 kg ha ^{1} The mutation lines and CSM388 responded better to fertilizer than the farmer local However, yield levels were low indicating that improved soil preparation and moisture conservation is needed for new cultivars to demonstrate their potential on farm and make efficient use of fertilizer

The Advanced Early and Medium trial entries were evaluated for drought and high heat tolerance in the soil bin charcoal pits during the 1996 off-season at Cinzana Lines derived from (M84-1*M84-5), (ICSV16-5*Lakahiri) (M84 1*ICSV1079), (M84-7*CSM388), and the mutants MIK-86-30-46 and MIP 94-25-60 showed excellent survival under water stress and high temperature 16 days after planting

A 46 entry paired plot screening nursery for soil toxicity was grown at a new site on the Cinzana station The site had less toxicity than the previous site with stands obtained in most plots One Durra from northern Nigeria OH/84-3/5 looked very good along with the previously reported Gadiaba/Cinzana and Lakahiri, Durra types from northern Mali Several other Durra OH' lines from N Nigeria also showed promise Future evaluation will be in the more severe toxic field, and will look at the effect of rotation with cowpea and peanut

Weed Science/Striga

Several *Striga* field screening trials were conducted at different locations in Mali Evaluation of lines from the IER sorghum breeding program generally showed little difference among entries, but a couple showed numbers of emerged *Striga* plants equal to SRN 39, the resistant check In screening the Southern Mali local guinea cultivars, some with the local name of Seguetana (*Striga* tolerant), CMDT30, CMDT39 CMDT45, CMDT48, and CMDT79 showed good tolerance with an infestation equal to that of SRN39

In a field trial at Cinzana, eight *Striga* tolerant INTSORMIL sorghum lines from Purdue were evaluated for several traits The eight lines showed *Striga* resistance equal to SRN39 and much better than the checks CSM228 and Tiemarfing (Table 4) The constraint on the eight *Striga* tolerant lines is grain quality which was not good compared to local cultivars

In a cropping study sorghum intercropped with cowpea reduced *Striga* emergence and biomass compared to sole sorghum but there was no effect upon grain yield

Grain Quality/Utilization

Many quality and utilization studies were done in the food laboratory in Sotuba, including evaluation of grain from the yield trials In general, the local guinea cultivars and checks and the Bretoudeau mutation derived true guinea lines had the best quality, based on decortication

Table 4 Performance of introduced *Striga* tolerant lines at Cinzana, 1996

Variety designation	Days to 50% flower	Grain yield (kg ha^{-1})	Days to *Striga* emergence	No. *Striga* plants at harvest (#/m^2)
P9401	74	1244	53abc	12d
P9402	75	1733	57ab	52cd
P9403	81	1467	57ab	19d
P9404	74	1538	52abc	47cd
P9405	78	640	62a	7d
P9406	74	871	40c	70bc
P9407	74	898	55ab	26cd
P9408	73	756	55ab	48cd
CSM228	72	373	45bc	266a
Tiemarfing	78	1742	60a	124b
SRN39	73	1485	39c	33cd
Significance	NS	NS	S	HS
CV%	6.1	60.9	16.4	34.8

Table 5 Means of milling and quality traits of grain from sorghum cultivars grown at four on-farm trials in Mali in 1996

Trait	N'tenimissa	Local guinea	N'Darila	Dusasuma	89 SK
1 000 kernel wt (g)	21.4	20.5	21.3	21.3	
Decortication yield (3 min) %	86	85	75	82	72
Decortication yield (5 min) %	69	79	54	72	54
Vitrosity score[1]	2.8	3.1	3.0	3.1	3.4
To consistency[2]	1.5	1.0	1.0	1.2	2.0
To color	good	good	good	good	good

[1] 1-5 score 1 = vitreous 5 = soft
[2] 1-5 score 1 = very good 5 = poor

yield and grain hardness. The non-guinea breeding lines, generally, were much poorer and appeared marginal at best for use when grown under significant head bug/grain mold pressure. N'tenimissa and sister selections were intermediate in overall quality. In some trials, with overall good quality grain, its performance was nearly equal to the local guineas, but where head bug damage was very severe, it fell down fairly close to some of the better non-guinea lines. The same type information was obtained from grain samples from on-farm demonstrations (Table 5), but in those, decortication yields of N'tenimissa were close to that of the local guinea. This indicates that the head bug resistance level of N'tenimissa may be good enough for farmer use.

Lack of large enough quantities of pure, high quality grain of N'tenimissa hampered the evaluation in planned pilot production studies with private companies in the Bamako area. In reduced scale studies with GAM, (Generale Alimentaire du Mali, the major bread and cookie producer in Bamako), cookies made with 5% and 10% N'tenimissa flour (substituted for flour from imported wheat) were good quality taste and texture, but the GAM manager had some concern over black specks in the flour which were apparently due to a mixture with grain from non-tan plants. The likely source is outcrosses, as all N'tenimissa grain has always been produced under open pollination. The next step is to try 20 to 30% N'tenimissa flour in the cookies. Bread made by GAM with 5 to 10% sorghum flour was acceptable and preferred over a wheat/corn flour mix.

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. A separate company (GMM-Grands Moulins du Mali) mills all the grain into flour for use by GAM. This will require some extensive effort and coordination among several groups to accomplish. Hopefully, the new USAID supported project (soon to be awarded) in Mali, to encourage and develop private business, will look at this enhanced use potential of new tan-plant guinea cultivars.

Crunch was also made from sorghum, and the varieties Wassoulou and Lakaheri produced superior crunch compared to N'tenimissa. Some women associations and small entreprenours are processing crunch for selling. In another study, parboiling improved dehulling yield, especially for floury varieties.

On-Farm Trials

The official IER On-Farm group conducted on-farm trials involving new sorghum breeding lines in the Kayes Region (North, early-maturing varieties), Koulikoro Region (Medium-maturing varieties), and Sikasso Region (Southern Mali-late maturing varieties) In the North 89CZ-F_4-21AF, 89-CZ-F_4-137, Malisor 92-1, and CSM63E were compared to the local check Yields were low due to drought with no significant difference among cultivars In the Koulikoro Region, N tenimissa, N Darila, and CSM388 were compared to the local check Again there was no significant difference among cultivars, but N tenimissa did produce equal yields with CSM388 (improved local) and the local check In Southern Mali, three improved (mass selected) local cultivars were compared with the local check, with one, Foulatieba, having significantly higher yield (1 05 t ha ^{1}) compared to the local (0 80 t ha ^{1}) The other two, Seguetana and Kassoroka, had yields equal to the local check

N'tenimissa was also provided to WCASRN (regional sorghum network) and was distributed in Mali and other West African countries in on-farm trials, but no data are available

Also, N'tenimissa and Seguetana Cinzana (a *Striga* tolerant improved local guinea) were included in several World Vision on-farm trials in the Bla area of Mali Again, no data on these were reported However, we did visit two of the World Vision on-farm sites near Bla and made headbug damage ratings (Table 6) They included N'tenimissa, Seguetana Cinzana, P9403, and a farmer local Although planted late, and stands were not good, they provided some useful information on the performance of new cultivars in on-farm conditions It was very dry, so there was no grain mold present on grain damaged from head bug feeding It appeared that both Seguetana Cinzana and N'tenimissa would produce comparable or slightly higher yields than the local check

The PVO, World Neighbors, has worked with 20+ communities in the Segou region for several years, and have been involved with IER scientists and extension agents (PNVA) Their on-farm activities include distribution and testing of pearl millet and sorghum cultivars and evaluating several IER crop management technologies (cover crops, intercropping, improved fallow systems, and improved manure management) World Neighbors employees indicate widespread adoption of an early season improved local sorghum (CSM219) and the IER developed pearl millet cultivars (IBV8001, Composite Souna Sagnon and Benkadinyo), improved manure management (corralling animals at night, composting with crop residues), and use of improved intercropping systems These interactions have also identified felt needs of these communities for development of improved long-season cultivars of sorghum and pearl millet with desirable good quality

Table 6 Grain quality damage ratings on two World Vision on-farm trials near Ble, Mali, 1996

	Head bug damage rating[1]	
Variety	Site #1	Site #2
Seguetana Cinzana[2]	3	2
N tenimissa	4	3
P9403	7	7
Local check	Late	Late

[1] 1 9 scale where 1 = no damage 10 = grain completely deteriorated

[2] Seguetana Cinzana is a typical local guinea and should represent the head bug resistance present in most local cultivars

Economics

One surprising finding was the income controlled by women was reduced with the introduction of new technologies in southern Mali The women were involved in the new technology, and this reduced their hours on their private plots The compensation for their new work did not offset the income from private plots In Mali, the price of cereals increased more than that of inorganic fertilizer with the devaluation This should help stimulate the use of inorganic fertilizers on sorghum Studies on the process of technology adoption indicates the need for longer season new cultivars in order for the cultivars to generate a return on fertilizer

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 collaborative program Training in computer use was provided by G C Peterson Subscription to ASA and CSSA were provided for researchers at Cinzana, Mopti, and Sotuba

Several Malian students at INTSORMIL institutions should make important contributions upon their return to Mali Mr M Diourte in pathology at KSU and Mde N Diarisso in entomology at TAMU should return to Mali in 1997, and Mr A Traore in agronomy at Nebraska should return in 1998 to strengthen the IER research program Mde Salimata Sidibe Coulibaly returned with an M S in food technology from North Carolina A&T 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 -TAMU, Soil Management CRSP) who is now Director of the IER Soil Laboratory

New students in training include Mamadou N'Diaye at Ohio State in pathology and Niabe Teme, who will complete a B S and then M S at Texas Tech Dr A Toure accepted a two-year Post Doc Fellowship in sorghum biotechnology at Texas A&M Adama Coulibaly (M S - KSU) assumed the responsibility of Minamba Bagayoka in millet agronomy, and is the National Coordinator in Mali for pearl millet

The contribution of Dr Moussa Traore, (Ph D INTSORMIL/Nebraska), former physiologist and Mali Country Coordinator, and 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 TAMU in breeding (currently on a sorghum biotech Post Doc at TAMU/TTU) is a sorghum breeder with IER, and has served as INTSORMIL Country Coordinator and is a member of the INTSORMIL Technical Committee, and has served as Head of the Mali national sorghum program Mr Sidi Bekaye (M S - Nebraska) currently serving as the INTSORMIL Host Country Coordinator, is the head of the Mali national sorghum program, and also is now 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 (twice) and G C Peterson, sorghum breeders, Dr L W Rooney, food scientist Dr G L Teetes, entomologist, Dr R A Frederiksen, pathologist, all from Texas A&M, Drs J D Maranville and S C Mason, agronomists from Nebraska, Dr J F Leslie, pathologist from Kansas State, and J H Sanders, economist, from Purdue

Several IER scientists traveled to the U S in September 1996 to attend the INTSORMIL PI Conference (Sept 20-22) and the INTSORMIL/ICRISAT sponsored International Workshop on Genetic Improvement of Sorghum and Pearl Millet (Sept 22-27) at Lubbock, Texas They included S B Coulibaly, Y Doumbia B Dembele, A W Toure, A Coulibaly, and Mde A B Berthe from IER in Mali IER scientists in training which attended the PI Conference and Genetic Improvement Conference included Mde N Diarisso, Mde Salimata Sidibe Coulibaly, Aboubacar Toure, and Niaba Teme Several scientists spent extra time in the U S working with their U S collaborators Dr Aboubacar Toure participated in two INTSORMIL Technical Committee meetings during the year

Networking

The research accomplishments in Mali are immediately and directly transferable to most countries in West Africa Work on sorghum and millet food technology applies to Africa and many areas of the world Head bugs are common to West Africa while drought and grain mold are world-wide problems Exchange of elite germplasm with useful traits is an excellent means of networking among breeders

Efforts are underway to utilize existing networks to extend technology to the region in both sorghum and millet Steve Mason and Frank Gilstrap have participated in the ROCAFREMI (pearl millet network) meetings to develop collaborative activities with the millet network Jerry Maranville represented INTSORMIL at the WCASRN (sorghum network) General Assembly meeting in March 1997 and Darrell Rosenow visited with the Steering Committee and Coordinator during his two trips to Mali These contacts resulted in an 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 The Steering Committee Chair, Dr Yagoua N Djool from Chad, attended the Genetic Improvement Conference in Lubbock A cooperative Workshop with INTSORMIL, IER, WCASRN, and ICRISAT on Sorghum Characterization is planned for fall, 1997, at Cinzana in conjunction with the growout of the Mali Sorghum Collection

There has been a long history of collaboration with ICRISAT in Mali, and collaboration has been excellent with Drs D S Murty, J C Chantereau, and A Ratnadass Arrangements have been 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), USA, CIRAD, and Mali programs (IER and ICRISAT), arranged, and packaged in May, 1997 for planting at both the Cinzana Station and Samanko (ICRISAT Center)

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, 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 will increase 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, Soils Management CRSP (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 new white-seeded, tan-plant Guinea type breeding cultivar, N'tenimissa, performed well in on-farm trials Its 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 headbug resistance, but based on observation in on-farm trials it appears to be good enough at the farm

- 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 outstanding appearing 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 extensive evaluation These should be equal to locals in grain traits but with tan plant color

- Several mutant-derived Guinea type, breeding lines developed by the Dr Alhousseini Bretoudeau, a geneticist at the Agriculture School at Katiabougou, showed promise for nitrogen-use-efficiency and grain yield

- Agronomic studies on pearl millet indicate that crop rotation combined with low amounts of nitrogen fertilization results in increased yields and the most efficient use of fertilizer nitrogen

- Crop residue management research over a five-year period showed that crop residue had no influence on pearl millet grain or stover yields and had little influence on soil pH, carbon, and cation exchange capacity Leaving crop residues on the soil surface did result in higher soil phosphorus levels

- World Neighbors employees indicate widespread adaption 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 to 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 headbug resistance showed excellent differentiation for headbug damage

- Nine new sorghum breeding progeny showed headbug resistance equal to that of Malisor 84-7

- Observations indicate that headbug infestations in on-farm trials is much lower than in Station Nurseries This means that sorghum with somewhat lower levels of headbug resistance may well work at the farm level, even though they may show significant damage under certain Station infestations

Previously Reported Accomplishments

- 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 D Axtell and Tahirou Abdoulaye
Purdue University and INRAN/Niger

Coordinators

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Description of Collaborative program

This is an interdisciplinary, multi-institutional collaborative research program which involves INRAN and US/INTSORMIL institutions

A major interCRSP activity was completed in 1996 with AID/Washington support in coordination with the Niger AID Mission INTSORMIL activities included a seed production project of the new sorghum hybrid NAD-1 at Lhossa and *Striga* research using INTSORMIL/INRAN tested *Striga* resistant varieties at the Konni station Cropping systems research was initiated with the Soil Management CRSP and the Peanut CRSP at Hamdallaye and a new site, Gaya, near Bengou Laboratory supplies and equipment for the cereal quality lab and seed production project were procured

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 Active collaboration with ICRISAT (Dr Ousmane Youm) and INRAN (Kadi Kadi) in field biology and laboratory studies on millet head miner is in progress (See research findings)

A Regional Seed Workshop has been approved for fall 1998 in Niger, which will include seed production specialists from developing countries as well as seed experts from the developed world There is urgent need throughout Africa for a seed workshop which is the major limiting factor constraining the adoption of new technologies in Africa, according to studies by ICRISAT (D Rohrbach) and by USAID/Africa Bureau

There are several interdisciplinary activities involved in this program These include sorghum and millet breeding, agronomy, pathology, physiology, food quality, and economics U S INTSORMIL Principal Investigators develop research plans and budgets with INRAN collaborators on an annual basis Each plan is then translated into French and submitted to Dr Samba Ly, Scientific Director

Sorghum/Millet Constraints Researched

Production and Utilization Constraints

Drought, insect pests, long smut and *Striga* are the major constraints in Niger Extremely high soil temperature leads to difficult problems in crop establishment Sand blasting of young seedlings is also a complicating factor Plant breeding for tolerance to these major constraints is one of the most feasible solutions New cultivars must be acceptable for tuwo preparation A number of useful collaborative research activities have been developed in Niger between INTSORMIL principal investigators and INRAN scientists

Research Methods

The collaborative research program in Niger includes sorghum and millet breeding, entomology, agronomy, pathology, physiology food quality and economics Research methods appropriate for each of these disciplines are used for this research program

Research Progress

During this year, the INTSORMIL/Niger socioeconomic program has been concentrated on investigating fertilizer related issues in the Boboye and Gaya region Boboye is located about 100 km east of Niamey Gaya is about 300 km southeast of Niamey and borders on both Nigeria and Benin It has the highest rainfall in Niger (700-800 mm on average)

Soil fertility is one of the key constraints to crop production increase in Niger Population pressure has broken down the traditional soil fertility maintenance technique In most southern regions of Niger (crop growing areas) fallow is shortened because most of the land available is in use Organic fertilizers capability for soil fertility restoration had been shown to be limited (McIntire et al , 1992, Sanders et al 1996, Abdoulaye, 1995) Supply of organic fertilizers is limited and organic fertilizer can only be viewed as good complement for inorganic fertilizer Abdoulaye (1995) has indicated that introduction of new cultivars will increase demand for soil fertility The increased demand can be met only by use of inorganic fertilizers because of supply constraints on organic fertilizer The supply of large quantities of manure (7 5-10 t ha ^{1}) can be met only on limited cropping land Therefore, if any increase in production is to be achieved, it has to include an increase in the use of inorganic fertilizers on cereal crops

One objective of recent fieldwork was to compare inorganic fertilizer (Urea) price to millet and sorghum prices in two distinct regions of Niger As stated above, the Gaya region has higher rainfall and higher yields compared to Boboye Sorghum is produced only in small areas in Boboye, whereas in Gaya sorghum is widely produced Two periods are identified here The ante-devaluation and post-devaluation years The analysis used market prices of millet and sorghum and urea prices in the two regions to show the importance of relative prices and the new trend of those prices since the CFA devaluation in 1994 Implications for agricultural research are also drawn

Tables 1 and 2 show both millet and sorghum real prices for the past six years in the two research sites (Boboye and Gaya) For Boboye until 1994, millet prices have been higher than sorghum prices because of greater consumer preferences for millet However, since 1994 sorghum prices have became slightly higher than millet This apparently resulted from an increase in the quality of sorghum grain on the markets (Kapran, 1997) In Gaya high demand for sorghum (due to high consumption) and import from Nigeria of high grain quality sorghum made sorghum prices almost always equal to millet prices

Table 1 Annual millet and sorghum real prices[a] (FCFA/kg), Boboye

Years	Millet	Sorghum
91	107 34	103 22
92	120 94	113 38
93	102 72	92 95
94	79 33	80 85
95	84 14	86 59
96	94 77	96 68

Source S A A Boboye

[a] Price used 1996 CPI (consumer price index) as base (1996=100) CPI = 137 8 in 1996 (1990=100) from IMF 1997

Table 2 Annual millet and sorghum real prices[a] (FCFA/kg), Gaya

Years	Millet	Sorghum
91	89 91	97 30
92	106 67	102 92
93	85 85	85 85
94	75 07	71 93
95	74 43	74 64
96	98 90	101 90

Source S A A Gaya

[a] Price used 1996 CPI (consumer price index) as base (1996=100) CPI = 137 8 in 1996 (1990=100) from IMF 1997

In both regions real prices of millet and sorghum have been decreasing since 1992 The biggest increase came in 1992 because of the bad cropping season of 1991 In and after good harvest years cereal prices are very low This is another constraint to higher investment for production increase Whenever higher production is attained, prices collapse because the increased supply is not met by an adequate increase in demand Demand is inelastic with respect to price

However, real prices began to recover in 1995 One year after the CFA devaluation millet and sorghum real prices started to increase The most important indicator for profitability of intensive cultivation of new cultivars (millet and sorghum) is the relative price ratios between cereal prices and inorganic fertilizer price If the rate of increase in millet and sorghum prices is not higher than the rate of increase in input prices, there is reduced incentives for buying inorganic fertilizers

Both millet and sorghum relative prices have been declining from 1992 until 1994 While nominal prices were increasing, relative prices are decreasing until the year of the devaluation (Figures 1 and 2) Starting in 1994, crop prices are recovering but still lower than their 1991 levels The initial impact of the CFA devaluation of January 1994 has substantially discouraged the fertilization of the cereals In the two years following the devaluation the profitability of using inorganic fertilizer on cereals has been slowly recovering, but still has not reached the pre devaluation levels

For both crops, Gaya's prices are increasing faster than Boboye's Since the region of higher production potential (Gaya) is receiving higher prices, there is more incentive there for intensive crop production The increase in production will require new millet and sorghum cultivars and increased use of inorganic fertilizers

If this upward of trend of cereal to relative fertilizer prices is to continue, then increases in farmers investments in new cultivars and inorganic fertilizers can be expected Decision makers have to find ways to make inorganic fertilizers more readily available to farmers

Price increases can also come from the increased value of traditional cereals New uses for these crops will be very important in order to increase their value Increased research in industrial uses (food processing, food industries) and their uses in livestock and poultry husbandry are worthwhile Increased research is also needed on alternative uses of millet and sorghum as forage or in poultry food Breeding programs must emphasize improved quality for both grain and fodder

Mutual Research Benefits

Extensive use of drought tolerant germplasm from Sahelian countries, including Niger, have been used extensively

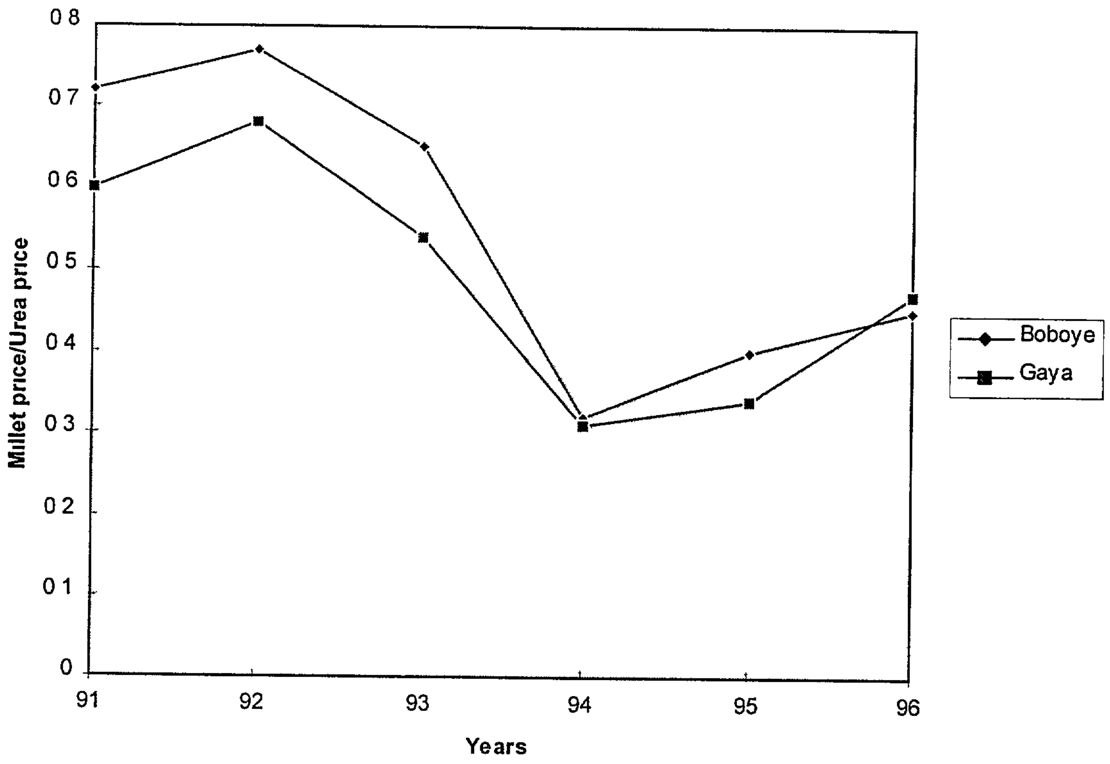

Figure 1 Millet to urea relative prices (millet price/urea price), 1991-1996

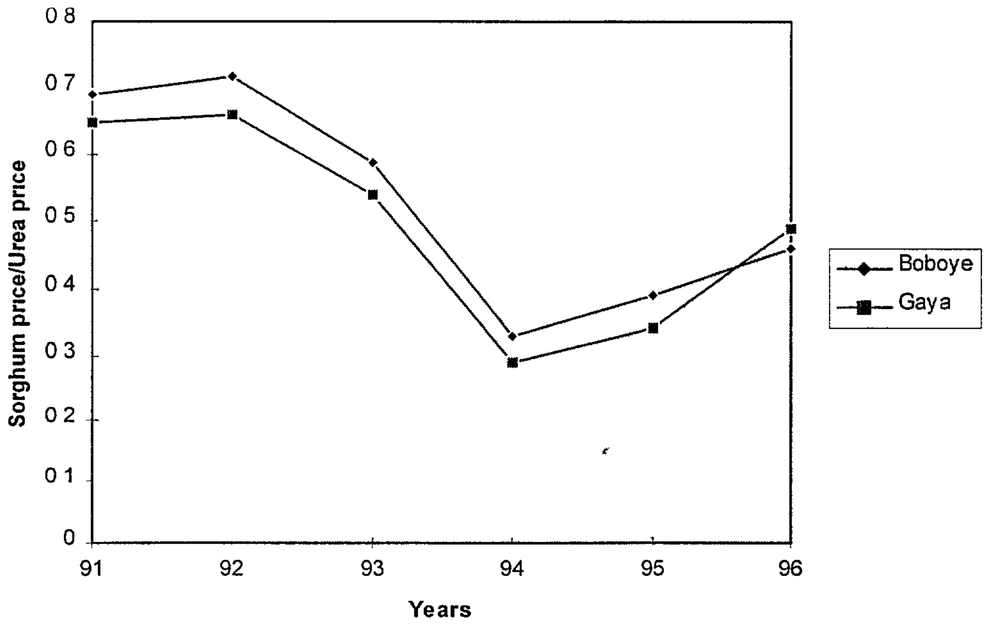

Figure 2 Sorghum to urea relative prices (sorghum price/urea price), 1991-1996

by the private and public sectors in the U S The principal benefit to Niger is an efficient and productive research program in INRAN developed through training and collaborative research activities with INRAN staff

Institution Building

In support of its research activities, the INTSORMIL/Niger program purchased the following supplies several types of jab planters, table top handsealers, bird nets, and Euro-Kenwood stand mixer The Niger country program was also provided a Honda G-200, 5 0 HP water pump from McKnight funds

When INTSORMIL first began collaborative research relationships with INRAN there were only a few highly trained Ph D level scientist in the organization Over the past 16 years this situation has changed dramatically within INRAN INRAN has matured and grown significantly as a research organization over the past 20 years INTSORMIL has played a 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 Ph D training programs They now have a critical mass of excellence in research capability for the agricultural sciences When one looks at progress in institutional developments over a longer time frame, it is easy to be optimistic about the future of INRAN/INTSORMIL collaborative research A total of six Nigeriens have received Ph Ds and six have received M S degrees under this program

The Niger InterCRSP provided funding for the purchase of a couscous processing unit, fabricated at CIRAD, France, which is installed in the Cereal Quality Laboratory (LQC) at INRAN The unit consists of a flour agglomerator (rouleur), a combined grain decorticator and flour mill, a solar dryer, a couscous steamer, and a plastic sealer for packaging The unit is being used to improve processing techniques to produce good quality couscous from millet and sorghum and a mixture with peanut and other legumes The unit is also used as a demonstration and testing tool to local entrepreneurs who are interested in commercial production of couscous

Ouendeba Botorou completed his Ph D at Purdue University and returned to INRAN as scientific director He has now been employed by ROCAFREMI (West African Millet Network) to serve as coordinator for the regional millet program in West Africa

Abdoulaye Tahirou, Ag Economist, received his Masters degree at Purdue University and returned to Niger in October 1995 He is now associated with DECOR/INRAN and is the INRAN/INTSORMIL Niger country coordinator He, along with Mohamadou Abdoulaye, are conducting studies based on identification of socioeconomic constraints which can reduce adoption of new technologies by farmers In addition data are collected on farmers' reaction on new sorghum varieties in order to give feedback to breeders The activities are conducted as part of the INRAN farming system research program

Several U S PIs and INRAN trainees traveled to Niger

July 1996 - Adam Aboubacar
October 1996 - Lee House
November 1996 - Frank Gilstrap
January 1997 - Bruce Hamaker
March 1997 - John Axtell, Jerry Maranville, Steve Mason and John Sanders
April 1997 - H Kadi Kadi and Issoufou Kapran

In addition, several INRAN scientists participated in the INTSORMIL Principal Investigators Confererence and/or the International Conference on the Genetic Improvement of Sorghum and Pearl Millet hosted by INTSORMIL/ICRISAT in Lubbock, Texas, September 20 - 27, 1996 Moussa Oumarou, Ouendeba Botorou, Issoufou Kapran, Seyni Sirifi, Abdoulaye Tahirou, Mamane Nouri and Bakary Coulibaly Abdoulaye Tahirou, INRAN/INTSORMIL host country coordinator, spent one week after the conference at Purdue University to work on research and administrative matters

The highlights of the conference were not only the technical presentations but also the host country sessions that allowed a thorough dialogue among participants of current and future collaborative research in each host country, including Niger

To develop the 1998 workplan, a conference between all INRAN and INTSORMIL PIs, is scheduled, tentatively at Purdue, during the spring of 1998

Currently there are five Nigerien students being trained in U S institutions These include

I Kapran, Sorghum Breeding, with J Axtell, Purdue
H Kadi Kadi, Entomol , with F Gilstrap, Texas A&M
M Nouri, Agronomy, with S Mason, Nebraska
I Kollo, Pathology, with R Frederiksen, Texas A&M
A Aboubacar, Food Science, with B Hamaker, Purdue

This will provide a strong, interdisciplinary research team for INRAN in future years

Networking

The major constraint for adoption of new technologies in West 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 by INTSORMIL will be the West African Seed Production workshop to be held in Niamey September 27 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

Pathology - A Kollo and R Frederiksen

Issoufou Kollo, spent the summer in Niger to conduct field trials and laboratory experiments on Acremonium wilt of sorghum (*Acremonium strictícum*) This research is part of the work for a Ph D degree Field trials were conducted at the Konni research station and in farmers' fields His work focuses on the association between nematodes and *A strictícum* Issoufou Kollo returned to Texas on August 21 1997 to attend the fall semester

Agronomy -Seyni Sirifi and J Maranville

For N fertilization trials, no interaction was found between N rates and genotypes for on panicles, grain, or biomass yield This might be caused by the large variation among and between treatments due to rainfall patterns, drought, and diverse other reasons Coefficients of variations (CV) were very high in trials of the two agro-ecological zones They were 69 91, 89 50 and 50 74% for panicle, grain and biomass yields respectively at Bengou station At Tillakaina station, the CV s were 40 42, 46 28, and 29 85% for the same variables respectively At Bengou station genotypes NAD-1 were 1300, 770 and 3516 kg ha ^{1} respectively Yields were very low compared to those obtained 1995 The 1995 panicles and grain yields were about four times greater than those of 1996 for most of the genotypes (e g 4380 kg ha ^{1} panicle yield and 2331 kg ha ^{1} grain yield were produced by NAD-1 in 1995, against 1300 kg ha ^{1} and 769 kg ha ^{1} respectively, In 1996) N rates did not significantly affect yield of the three variables Although in ab solute means 100 kg ha ^{1} urea rate produced the higher panicles grain and biomass yields

At Tillakaina station panicles, grain and biomass yields were also low, but pretty close to those obtained in 1995 The local variety did not perform well compared to the improved ones Genotypes NAD-1 and SEPON 82 were the most productive among the genotypes tested in 1995 and 1996 N rates did not influence panicle, grain and, biomass yields either at Bengou or at Tillakaina But in terms of absolute values, the 50 kg ha ^{1} urea rate tend to increase panicle, grain, and biomass yields

For the row spacing trials, interaction was not observed between row spacing and genotypes Row spacing did not significantly affect panicle, grain, or biomass at Bengou and Tillakaina stations Genotypes differed in panicle, grain, and biomass yields in Bengou's trials, whereas they differed only in grain yields at Tillakaina As in the fertilization trials, genotypes NAD-1 and the land race variety were more productive at Bengou, while NAD-1 and SEPON 82 performed better at Tillakaina

The main characteristics of the 1996 cropping season were late planting and drought throughout the season These environmental conditions seriously affected production of sorghum and other crops in all agro-ecological zones of Niger Production of all rainfed sorghum was lower compared to the previous year Although reduction in yield was observed in the two experiments in both location sites, it is important to note that trends in genotype performance looked the same in 1995 and 1996 Some of these trends are as fol lows

- No interaction was found between genotypes and N rates and between genotypes and row spacing
- N rates did not affect panicle, grain, and biomass yields, but in absolute mean values, 100 kg ha ^{1} urea in the moist zone (Bengou), and 50 kg ha ^{1} urea in the dry zone (Tillakaina) gave higher yield in panicle, grain and biomass
- High planting densities (0 80m × 0 80m × 0 40m) seemed to be more productive in the moist region (Bengou), whereas low planting densities (0 80m × 0 80m × 0 60m) looked more productive in the dry area (Tillakaina) in absolute mean values

Cereal Quality and Processing

M Oumarou, A Aboubacar, M Mounkaila,
M Maiga, and B Hamaker

During the past year, equipment for millet and sorghum couscous processing were installed at the INRAN Cereal Quality Laboratory (LQC) for the purpose of research and demonstration to local entrepreneurs, cooperatives, and NGOs interested in cereal transformation The equipment included a flour agglomerator (rouleur) a solar dryer a mixer a steamer and a plastic sealer In September 1996 Adam Aboubacar traveled to Niger to train LQC scientists on the use of the rouleur, which is the most important piece of equipment in couscous processing

Two research technicians have been hired by INTSORMIL/Niger to work, one on sorghum couscous, and the second on millet couscous Their work consisted of the determination of processing parameters (amount of water for flour agglomeration speed of rotation of rouleur etc) important for optimum couscous yield Two sorghum (NAD-1 grown at two locations and SEPON 82) and two millet (Souna III and HKP) cultivars were used Preliminary results indicate that for both sorghum and millet, the amount of water required for flour agglomeration depends on the cultivar used By using the right amount of water for each cultivar and the proper speed of rotation of the rouleur, high couscous yield (>85%) of desirable particle sizes were attained The dark color of some of the couscous produced was of concern when presented to consumers Couscous from NAD-1 (grown at Maradi location) had a dark and red color Better couscous color was obtained with NAD-1 (grown at Tillaberry location) and SEPON 82 The color of SEPON 82 and Souna III couscous significantly improved when their flours were fermented prior to couscous manufacture More work is being done on grain type, proper milling, washing, and other factors related to couscous color

Agronomy - M Nouri and S Mason

A two-year experiment to determine the dry matter accumulation and nutrient uptake of the pearl millet cultivars Haini Kirey (local), Zatib (improved tall), and ¾ Haini Kirey (improved short) grown under low yield conditions of no fertilizer and plant population of 10,000 hills per ha, and high yield conditions of 5 Mg ha^{1} manure, 23 kg ha^{1} nitrogen, 18 kg ha^{1} phosphorus, and plant population of 20,000 hills per ha were completed Plots were sampled bi-weekly, plant parts separated, dried and weighed, nutrient concentration, dry matter and nutrient uptake and partitioning, and crop growth and nutrient uptake rates

Average grain yield was 0 6 Mg ha^{1} greater and average dry matter production was 90 g m^{2} greater in 1995 than in 1996 due to rainfall differences Few differences were found among pearl millet cultivars except that the short variety ¾ HK produced 50 to 125 g m^{2} less dry matter than the other cultivars, and Haini Kirey produced the greater grain yield than other cultivars in 1995 Yield conditions had a large impact on dry matter production in both years with high yield conditions increasing dry matter production from 135 to 473 g m^{2} in 1995 and from 92 to 335 g m^{2} in 1996 Under high yield conditions, dry matter was translocated out of the stem and leaves to the head 80 to 95 days after planting, while under low yield conditions the stem and leaf dry matter either remained constant or actually increased from 75 to 105 days after planting Crop growth rates increased throughout the growing season with rates being greatest near physiological maturity These results are consistent with those recently published (Payne, W A 1997 Managing yield and water use of pearl millet in the Sahel Agron J 481-490) suggesting that ≥20,000 hills/ha, ≥40 kg ha^{1} nitrogen, and ≥18 kg ha^{1} phosphorus is required to optimize pearl millet grain yield, even in dry years Pearl millet cultivar differences, in spite of the large difference in genetic background, had much smaller impacts on grain yield and dry matter than did the production level inputs

Entomology - H Kadi Kadi and F Gilstrap

Research accomplishments on Millet Head Minor (MHM) Although the 1996 cropping season was characterized by scarce rainfall and drought spells, important results were obtained on MHM biology in the field and laboratory Rainfall started as early as April, with a yearly total of 543 9 mm Results revealed that MHM fed the different diets died during the different stages Total mortalities caused by the key factors were high with real mortalities greater than 90% Because of high larval mortality, fewer pupae developed and adults emerged when MHM were fed the millet-based diets Pupal mortality and larval mortality were the key factors for MHM stages in the diets Variations in key mortality factors of life stages of MHM fed the different diets may be attributable to the diets' nutritional quality and to the conditions within the rearing chambers

MHM survival and fecundity in the laboratory indicated that the mean numbers of days for longevity and oviposition were two to six days Extreme temperatures killed many MHM developing in the rearing chambers Results of temperature effects on emergence of MHM adults in the laboratory showed that under optimal conditions (28°C, 70% RH, and 12 12 (L D)), 50% of pupae incubated in the rearing chambers developed to emerge adults

Field experiments on MHM cohort development on enclosed millet spikes revealed that the MHM larval stages caused severe damage to the millet spikes Late planting of an early maturing millet variety resulted in less MHM damage and could be good management practice against MHM Mean numbers of days for adult longevity on the spikes were 3 8 and 4 days for males and females, respectively The total survivorship period for MHM in the exclusion cages was between two and six days MHM showed similar survivorship trend in a laboratory in rearing chamber maintained at 26, 28 and 30°C, 70% RH, and photoperiod 12 12 (L D) Mean oviposition period was estimated at 2 4 days per female The mean number of eggs oviposited per female was 29 6 Under laboratory conditions, MHM was found to oviposit mean number of eggs between 119 and 173 The optimal conditions for MHM survival and development may be under medium temperature, ranging between 26 to 28°C

From an experiment to assess larval parasitism, we found that *B hebetor* was attacking mostly full grown MHM larvae that had already caused severe damage to the pearl millet spikes Between two to three adults emerged per MHM larva

These results were preliminary Additional works are needed to confirm these important findings on MHM biology in laboratory and field For this purpose, the experiments conducted in 1996 will be repeated in 1997 with more redefined experimental design The overall results obtained in 1996 were presented in a report entitled "1996 Progress Report'

Research Accomplishments

The sorghum breeding program is being continued by INRAN technical staff while I Kapran is completing his Ph D studies A major effort during the past year has been to demonstrate the production ability 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 1998

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Dr Emmanuel Monyo, Pearl Millet Breeder, Bulawayo, Zimbabwe
Dr John R N Taylor, Department of Food Science, University of Pretoria, South Africa

Collaborative Program

Organization

Each sub-project (breeding, pathology and food quality) is planned in conjunction with NARS collaborators Where ICRISAT/SMIP has scientists in the research discipline, these are also involved

Financial Inputs

To date the MOU with SACCAR has not been finalized, which has meant that regional funds have been used to obtain and send appropriate equipment supplies, and for travel and conference attendance It is likely that the MOU will now be made with ICRISAT/SMIP

Collaboration with Other Organizations

Research on pearl millet and sorghum breeding is organized with NARS in collaboration with ICRISAT/SADC/SMIP center at Matopos, Zimbabwe, which ensures complementarity to existing ICRISAT and NARS programs

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, and the availability of matching INTSORMIL resource persons 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 southern African (SADC) region Sorghum is also used to make opaque beer Sorghum is the major cereal in Botswana and parts of Zambia, and pearl millet is the major cereal in Namibia Most of the usual constraints associated with low resource agriculture are present These include low yield potential, infertile soils, variable moisture availability, numerous pests and diseases, and poor market facilities There are established grain quality attributes which must be maintained or improved in new varieties

Research Methods

Breeding

Sorghum varieties and seed parents continued to be selected and evaluated in the Botswana sorghum breeding program Seed parents derived by joint SMIP/DAR Botswana work from segregating INTSORMIL populations grown in Botswana have been tested in hybrid combinations in 1996-95 and 1996-97 Pearl millet breeding continued with three-way research collaboration between Namibia, ICRISAT/SMIP and INTSORMIL aimed at producing adapted A_4 tropical hybrids for Namibia with possible spill-over effects in other SADC millet

Plant Pathology

Sorghum disease nurseries, other sorghum nurseries, selected sorghum lines, and advanced generation breeding germplasm were evaluated at two sites in Botswana (Sebele and Mpandamatenga) to identify sorghums with improved drought tolerance, and resistance to sugarcane aphids and disease From similar nurseries in 1996, the DAR plant pathologist, entomologist, and sorghum breeder selected materials that had the best overall adaptation and pest resistance for Botswana These selections were re-evaluated for these and other traits again in 1997 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 degree program at the University of Nebraska During his absence, the sorghum nursery and yield trials were planted, but no results are available at time of reporting Each of the 30 seed parents developed at SMIP from Botswana/INTSORMIL stocks were crossed to 5 testers The resulting 150 hybrids and 5 checks were evaluated at two locations in Zimbabwe Yields of up to 6 t ha^{1} were measured, with 19 hybrids equaling or exceeding the check yields The seed parents that meet other agronomic criteria besides yield will be available in 1998 Numerous hybrids will be possible with these using existing regionally adapted male parents The second backcross was completed on the best SADC pearl millet seed parent ICMB 88006, to convert it to an A_4 seed parent Two approaches are being used to develop R_4 (restorer) male parents for Namibian pearl millet hybrids The first is to locate R_4 genes in Okashana-1 through test crosses onto A_4 seed parents, then use these crosses as cytoplasm donor parents in backcrosses to Okashana-1 to change it to an R_4 male parent population This work is being done in Nebraska and the second backcross completed At this stage, seeds were sent both to Namibia and ICRISAT/SMIP The second approach was to generate a diverse range of R_4 lines by crossing a number of SADC lines and populations, including the [Okashana-1 × Maria Kaherero] farmer population, to Nebraska Pearl Millet population 3 (NPM-3, a dwarf R_4 source population) and then test crossing derivatives About 70 derivatives were found which gave fertile A_4 crosses This work has been done at ICRISAT/SMIP Matopos Using some of the partially converted parents from UNL and ICRISAT/SMIP, some test cross hybrids have been made in Namibia which will be evaluated next season

Pathology

As in 1996, several lines and other germplasm showed excellent adaptation to the Sebele area of Botswana in 1997, but neither year provided the level of drought stress required to adequately evaluate late season drought response The released variety, Mahube, was used as a local virus-susceptible check in the International Sorghum Virus nursery planted at Sebele and it, along with several other virus-susceptible standards, had a lot of virus-infected plants with redleaf necrosis (RLN) The cool temperatures associated with occurrence of RLN also contributed to an apparent pollen-sterility, leading to both a reduced seed set and some ergot development in late-blooming sorghums in several nurseries This cool temperature sterility needs to be considered when producing hybrids late in the season because it will not only increase problems with ergot, but will also simultaneously promote a lower production and quality of seed as it encourages outcrosses In Zimbabwe leaf blight occurred at damaging levels in collaborative nurseries and some national breeding trials at both the Henderson and Gwebi stations Sorghum hybrid WSH-1, which has leaf blight-susceptible ATX623 as the female parent, was killed by leaf blight at Gwebi Some other national sorghum lines and high yielding varieties and hybrids for Zimbabwe have a high susceptibility to leaf blight, which breeder N Mangombe wants to eliminate from future sorghums being developed for areas of Zimbabwe where the disease is frequently a problem The level of sooty stripe on susceptible material at the Panmure station in Zimbabwe and at Golden Valley and Mansa stations in Zambia indicated the need to also avoid high susceptibility to that disease At Mansa in 1997, sooty stripe was the primary pathogen and anthracnose, which normally predominates here, developed rapidly towards the end of the season Entries in TAM-228 collaborative nurseries generally had responses (mostly resistant, but some susceptible) to both diseases that were similar to those observed in other years across several locations However, every plant of a previously untested group of sorghums from Nebraska was either killed by sooty stripe at Mansa or so severely damaged that the few remaining leaves were killed by the late-developing anthracnose

Food quality

Ms Trust Beta, University of Zimbabwe, has characterized the physical and chemical properties of the major sorghum varieties grown by small holders in Zimbabwe An abstract entitled "Phenolic Compounds and Kernel Characteristics of Zimbabwean Sorghums" was accepted for presentation at the Fourteenth SAAFoST Congress and Exhibition scheduled in September 1997 in Pretoria, South Africa Ms Beta has worked with the National Agricultural Research Service and ICRISAT/SADC SMIP at Matopos She has enrolled in a Ph D program in food science and technology at the University of Pretoria, under Professor John Taylor, with Lloyd Rooney, INTSORMIL, as co-advisor Her Ph D research is on the processing properties of Zimbabwean sorghums, especially for dry milling and malting The effects of various processing treatments to reduce the phenolics in selected sorghums is a major concern This work is partially conducted at the University of Pretoria and at CSIR in Pretoria

Mutuality of Benefits

The productivity 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 are now of vital interest to U S scientists Nutritional components of food quality researched in collaborative projects are often synonymous with aspects of livestock feed values

Institution Building

Funding Support

Difficulty was experienced in finalizing a Memorandum of Agreement with SACCAR This is needed to allow INTSORMIL funds to be expended in the SADC region for budgeted costs This is expected to be resolved shortly 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

Training of Host Country Researchers

Ms Trust Beta, University of Zimbabwe, entered a Ph D program in food quality research at the University of Pretoria, under Dr Taylor, and co-advised by Dr Lloyd Rooney Some research equipment for characterization of grain quality was provided by INTSORMIL

Mr Peter Setimela, sorghum breeder, Department of Agricultural Research, Sebele Research Station, Botswana, commenced a Ph D program on the genetics of seedling heat tolerance in sorghum at the University of Nebraska with Professor David Andrews, under project UNL-218

Host Country and U S Scientist Visits

Dr Lloyd Rooney participated in the SADC workshop on food technology of sorghum and millets, Harare, Zimbabwe, (January 29-30, 1996) and visited the Department of Food Research at the University of Pretoria, South Africa

Dr Gary Odvody traveled to the SADC region from April 11-28, 1997 to review research progress on collaborative disease projects and nurseries in Botswana, Zambia, and Zimbabwe In Zambia he met and traveled with Drs B N Verma and M Chisi (sorghum breeders) and G Kaula (sorghum pathologist) to evaluate sorghum nurseries at Golden Valley, Mt Makulu, and Mansa Additional travel and disease survey on sorghum was done in the commercial farming region in the Mazabuka area, Southwest of Lusaka In Zimbabwe, he traveled with E Mtisi (plant pathologist) and N Mangombe (breeder) to evaluate both collaborative and national trials for leaf blight at Henderson and Gwebi stations and sooty stripe at Panmure Additional meetings were held with D Frederickson (plant pathologist) to review current pearl millet research and future research projects on ergot of sorghum In Botswana, disease and adaptation ratings were conducted on collaborative nurseries at the Sebele station with P Ditsipi (plant pathologist) and C Manthe (cereal team leader/entomologist) A survey of sorghum and other crops at and near the Good Hope experiment station in Southern Botswana was conducted with P Ditsipi Meetings concerning collaborative research and related activities were also held with B Matilo (plant pathologist), L Mazhani and G Maphanyane (Botswana DAR Administrators), B Ndunguru (Director of SACCAR), and with Robert McCollough (USAID/ADO in Gaborone)

Travel costs were paid for four SADC scientists to participate in the International Conference on Genetic Improvement of Sorghum and Pearl Millet", sponsored by INTSORMIL/ICRISAT at Lubbock, Tx, September 23-27, 1996, and to visit sorghum and pearl millet research at the University of Nebraska, Lincoln, NE

TAM-228 helped meet some of the trip expenses for Esther Mtisi (PPRI/RSS, Harare, Zimbabwe) to attend the All

Africa Crop Science Congress, January 13-17, 1997 in Pretoria, South Africa to present the paper, "Control of covered kernel smut on sorghum in Zimbabwe"

TAM-228 paid expenses for Dr Debra Frederickson (Dept of Biol Sciences, University of Zimbabwe, Harare) to attend the Congress of the South African Society for Plant Pathology, January 19-22, 1997, to present the paper *Pseudomonas syringae* , cause of severe foliar leafspots and streaks on pearl millet in Zimbabwe

Dr Lloyd Rooney accepted an invitation to participate in the Food Congress by presenting a paper on Constraints to Utilization of Sorghum and Millet for Food " He will interact with Prof John Taylor, Department of Food Science and Technology, University of Pretoria and his students, including Ms Trust Beta and Leda Hugo, Mozambique, and others The University of Pretoria and CSIR have responsibility to train food technology students for the Southern African region The potential to conduct a short course on sorghum food quality in Southern Africa in 1998 will be explored

Equipment for grain quality evaluation was purchased for Ms Trust Beta However, most of her research has been conducted at Matopos, University of Pretoria, CSIR and using other facilities at the University of Zimbabwe

Networking

An efficient sorghum and millet network exists in the SADC region, conducted by the ICRISAT/SMIP program The Memorandum of Understanding with SACCAR will establish INTSORMIL, alongside the SMIP program, with access to the network INTSORMIL plans 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

Research Accomplishments

Sorghum hybrid tests with seed parents developed at SMIP Matopos from Botswana/UNL germplasm will identify seed parents and hybrids for 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 The first hybrid trials will commence in 1997-98

Information on the severity and distribution of major sorghum diseases and viruses in Zambia, Zimbabwe and Botswana was broadened Several released lines were susceptible to red leaf necrosis virus in Botswana, leaf blight in Zimbabwe, and sooty stripe and anthracnose in Zimbabwe and Zambia A research project to study sorghum ergot was initiated with the severity of Zimbabwe

Horn of Africa

Project PRF - 211

Gebisa Ejeta
Purdue University

Program Coordinators

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Peter Esele, Uganda Country Coordinator, Serere Agriculture 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 has had a productive collaborative program with the Agricultural Research Corporation (ARC) in Sudan Our collaboration has resulted in an array of technical developments that have impacted 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 complement the existing relationship with the Agricultural Research Corporation of Sudan With these MOAs, 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, consulting 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 many scientists in the region Scientists from the region will also have the opportunity to obtain 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 buyins 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 for possible financial assistance to the 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	890	1236	100	280	1000	280
Kenya	120	745	90	85	682	58
Sudan	4684	85	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 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 (5-10 years fallow/2-4 years cropping). In some areas, other crops are often grown in an intercropping system with millet and sorghum to maximize production. Over the last 2-3 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

Sorghum Breeding - Abdel Latif, N Nour and Osman E Ibrahim

Germplasm Enhancement Progenies (175) were evaluated for yield potential As a result of single plant selection, 102 promising derivatives were identified and advanced to the next season for further evaluation Segregates (173) from different population, (F_2, F_3, F_4, F_5, F_6, and F_7) were evaluated for adaptation and yield potential The results showed that, out of 173 segregates, 54 promising derivatives were identified and advanced to the next season

During 1996 crop season the sorghum breeding program at Gezira Research station continued to focus on varietal and hybrid development and evaluation, with emphasis on breeding for grain yield potential, stability, and quality, drought resistance and avoidance (earliness) and improvement of most popular, adapted and preferred local land races for adaptation to combine harvesting, by backcross (BC) and pure line selection (PLS) methods of breeding

Breeding to incorporate drought resistance and avoidance (earliness), with reasonable and stable yield potential, receives paramount attention in the breeding program However, screening and testing for drought is often practiced under very harsh and erratic drought field conditions Rapid and reasonably efficient screening techniques are required

Synthesis of new experimental hybrids involved restorer lines from the local program and selected female parents isolated from ARC/INTSORMIL collaborative 1995 AIB lines observation nursery The standard/variety hybrid multilocation testing has been restricted to Gezira, Rhad, Samsam and Damazin Research Stations There is a need for extending this testing to cover other important agro-ecological zones in the country

As a result of the 1996 step-wise testing, a number of superior hybrids have been selected and advanced to the next level of testing After several years of standard and on-farm multilocation testing, one open pollinated variety (89/OSF_5 2451) and one hybrid (87/OSH5283) were officially approved for farmer use, by the Sudan National Variety Release Committee on October 19, 1996 The new cultivars were renamed Tabat for 89/OSF_5 2451 and Rabbih for 87/OSH5283 Both cultivars were acceptable to the farmers In fact the new cultivar Tabat was grown on more than 8000 acres during 1996 crop season, well ahead before being officially released

Advanced Sorghum Hybrid Trial Twelve new experimental hybrids together with Hageen Dura-1 as control, were evaluated for yield at three different locations, Wad Medani, Abu Naama, and Damazin

At Wad Medani, several hybrids were identified and selected The best yielding hybrids include PEX 606(4312 kg ha ^{1}) and HYD-2 (3904 kg ha ^{1}) Hageen Dura-1, the standard check, gave an average grain yield of (3037 kg ha ^{1})

At Abu Naama, the trial was affected by water logging at an early stage of growth The best yielding hybrids were HYD-5 (2894 kg ha ^{1}), PEX202 (2867 kg ha ^{1}), and PEX303 Hageen Dura-1 gave an average grain yield of 1719 kg ha ^{1}

At Damazin, no reliable data were obtained due to the severe drought during flowering and grain filling stages

Advanced Sorghum Variety Trial Eight open pollinated varieties, including two checks (Engaz and Wad Ahmed) were evaluated for adaptation and yield potential at two different locations Wad Medani and Damazin

The data was recorded only from Wad Medani, since at Damazin the trial was a complete failure, due to the severe drought during the flowering and filling stage

The results at Wad Medani showed that, only one variety (A-672) out-yielded Engaz and Wad Ahmed The yield increments attained were 20% and 13% over Engaz and Wad Ahmed respectively Engaz gave an average grain yield of

2244 kg ha ^{1} The average grain yield attained from Wad Ahmed was 2537 kg ha ^{1}

Pathology - El Hilu Omer

Emphasis of the programs was heavily directed towards germplasm evaluation for disease resistance in both sorghum and pearl millet

Sudan Sorghum Germplasm Entries (564) of Sudan sorghum collection were subjected to evaluation against leaf blight, anthracnose and long smut The first two diseases were evaluated under natural conditions of the Gezira environment, whereas individual panicles representing each entry were artificially inoculated with the long smut organism Selected disease free entries were grouped according to maturity for more thorough evaluation this season

International Anthracnose Virulence Nursery (ISAVN) Out of the 17 cultivars tested, including two locals, six cultivars showed definite resistance to the local isolate of the pathogen

Sorghum Seed Dressing This is an on-going activity where candidate products for commercial release are tested for efficacy against covered and loose smut and eventual registration of the best products

Preliminary Millet Downy Mildew Screening Trial (PMDMST) Twenty nine cultivars, including three local checks obtained from ICRISAT (India) and Matopos (SADC/ICRISAT/SMIP), were screened for downy mildew resistance All introductions are known to possess tolerance to downy mildew elsewhere All test entries were subjected to induced infection With the exception of the three locals, all introductions remained tolerant to the disease throughout the seasons and were superior to the locals in yield

Advanced Millet Downy Mildew Trial (AMDMT) ICMV 221, ICMV 88908, ICTP 8203, ICMV 82132, ICMV 155, WC C75 and SDMV 89004 excelled the locals in disease resistance, but differences in yield were not significant

Millet Seed Dressing Metalaxyl at 4 g a i /kg seed gave excellent protection against downy mildew up to 45 days after sowing The product at this rate is non-phytotoxic

Striga - A G T Babiker

Four experiments were undertaken with the objective of developing an integrated *Striga* control strategy that offers several options to farmers

Screening for Striga Resistance And Tolerance

Exotic varieties Seven *Striga* resistant varieties were planted at the Gezira research Station (GRS) under irrigation SRN 39 and Gadam ElHamam (G/H) were included as controls Nitrogen (0 and 43 8 kg ha ^{1}) was applied as urea at planting In the absence of nitrogen, *Striga* emergence, 45 days after planting, varied from 18 plants/m^{2} on G/H to 5 plants/m^{2} on P 9407 Emergence *Striga* on SRN 39 was 6 plants/m^{2} Nitrogen reduced *Striga* emergence by 52-65% on P 9401, P 9402, P 9406 and SRN 39 Nitrogen has no effect on the parasite on P 9403 and G/H However, it increased *Striga* emergence by 20 and 26 on P 9404 and P 9408, respectively Nitrogen increased height of all varieties by 13 to 50%, number of heads by 74 to 324% and straw yield by 32 to 87%

Local varieties Seventeen local varieties, including the recently released high yielding varieties, Tabat and Engaz, were screened for reaction to *Striga* under rainfed conditions at Simsim SRN 39 was included as a control *Striga* emergence was early on the local varieties, Abdella Mutafa, Korakolo, Ajab Sedo and Tabat Delayed emergence was displayed on SRN 39, Safra and G/H Sixty days after sowing the local varieties Korakolo and Gadambalia bloom (a short variant of Korakolo), Ajab Sedo and Tabat supported high infestation (71 to 78 plants/m^{2}) Safra, Tetron, Mugud and ICSV 207 sustained low to moderate *Striga* population (23-52 plants/m^{2}) SRN 39, on the other hand, demonstrated the lowest incidence of parasitism Among all varieties G/H gave the highest grain yield (843 kg ha ^{1}) followed by SRN 39 (719 kg ha ^{1}) The local varieties Wad Ahmed, Safra, and Tetron Mugud gave moderate yields (505-585 kg ha ^{1}) Lowest grain yields were obtained from Engaz (181 kg ha ^{1}) and Tabat (35 kg ha ^{1})

Effects of Sowing Dates on Striga

Seven varieties were used Two sowing dates, first week of July and a month later, were employed *Striga* counts were made 60 and 90 days after first planting Early in the season Korakolo and Abu Sabeen, irrespective of sowing date, supported high *Striga* infestation *Striga* population on Korakolo and Abu Sabeen was 64 and 65 plants/m^{2} for early planting and 6 and 7 plants/m^{2} for late planting *Striga* infestation on SRN 39 and Wad Ahmed was 27 and 34 plants/m^{2} for early sowing and 0 to 1 plant/m^{2} for late sowing At 90 days from first planting *Striga* infestation on G/H was 132 to 14 plants/m^{2} for early and late planting, respectively Infestations on early planted Abu Sabeen, Milo, Korakolo and Engaz was 60 to 42 plants/m^{2} *Striga* infestation on SRN 39 was 19 and 2 plants/m^{2} for early and late sowing, respectively *Striga*, invariably, reduced crop stand Early and late sown Abu Sabeen displayed 47 and 39% loss in stand, respectively Early sown Milo, Korakolo, SRN 39 and Wad Ahmed exhibited 29 to 31% loss in stand The corresponding figures for the late sown crop were 12 to 39% Late sowing increased straw yield of G/H, Abu Sabeen, Korakolo, and SRN 39 by 25 to 225%, decreased straw yield of Milo by 32%, but had no effect on that of Wad Ahmed and Engaz

Effects of Herbicides and Rates on Striga

The local varieties G/H, Engaz, and Wad Ahmed were used in this experiment *Striga* infestation on all varieties varied from moderate (37-41 plants/m^2) early in the season to heavy (54-111 plants/m^2) late in the season The highest *Striga* infestation was sustained by Tabat Garlone at 0 36 kg ha ^{1} effected moderate to satisfactory control (62 to 78%) of *Striga* on all varieties early in the season Late season control was poor (44 to 47%) on G/H and Engaz and satisfactory (71 to 85%) on Wad Ahmed The herbicide at the high rate gave excellent and lasting control (79 to 98%) of *Striga* on all varieties The herbicide irrespective of rate reduced the number of *Striga* fertile capsules by 34 to 50% on G/H, Wad Ahmed and Tabat However a low reduction (4 to 14%) was attained on Engaz Low straw yield was invariably obtained from the untreated control The highest and lowest straw yield was obtained from Wad Ahmed and Tabat, respectively Garlone increased straw yield of all varieties Straw yield showed a progressive increase with increasing herbicide rate The yield increments varied from 2 to 4- fold for G/H to between 1/2 and 1- fold for Engaz

Effects of Application Time on Herbicidal Efficiency

Two sorghum varieties G/H and Abu Sabeen, were employed Garlone (0 6 kg/ha) was applied at 2, 4 and 6 weeks after sowing as soil directed sprays Three weeks from sowing few *Striga* plants were observed on Abu Sabeen and none on G/H Urea at 43 8 kg/ha had little effect Garlone, irrespective of crop variety or application time, effected good to excellent control (73 to 98%) of *Striga* for most of the growing season Abu Sabeen was more vulnerable to the parasite damage G/H Unrestricted *Striga* parasitism reduced stand of Abu Sabeen by 86% and that of G/H by 49% Urea had inconsistent effects Garlone reduced the loss in crop stand to between 26 and 38% in G/H and to between 43 and 59% in Abu Sabeen The herbicide increased the number of heads of both varieties by 200 to 300% Straw yield of G/H was increased by 60 to 120% and that of Abu Sabeen by 170 to 250% Grain yield of both varieties was increased by 100 to 300% in comparison to the respective untreated control In general, the herbicide treatments made at two and four weeks after sowing were more effective in suppressing *Striga* and increasing sorghum growth and yield than the corresponding treatment made at 6 weeks

Mutuality of Benefits

With our new regional research concept we are putting in place a program where neighboring countries are benefiting from research advances made in neighboring countries by participating in confirmatory studies leading to identification of emerging technologies that have wider application potential Projects are also emerging with basic research questions that can advance knowledge with potential benefit to sorghum research in the U S Research on *Striga* elucidating basic mechanisms of resistance related to the intricate biological relationship between host and parasite, research on control of plant diseases using local plant products, and research on methods to alleviate food quality problems in high tannin sorghums may all have potential benefit to sorghum and millet research in the U S Exchange of raw germplasm for improved breeding lines from U S breeding programs, of course, enhances the research underway in the U S with potential benefit to be mutually useful to both U S and host country sorghum/millet agriculture

Institution Building

Research Equipment

In support of the new Horn of Africa initiative, the following equipment was purchased and shipped to Ethiopia

Mettler Balance
Hygrothermograph
Altimeter/Barometer
Table Top Sealer
DMLS Microscope and accessories
Overhead projector

Host Country Scientists who Visited the U S

Under the auspices of the Management Entity, eight host country scientists attended the Principal Investigators Conference in Lubbock, Texas, September 20-22, 1996 These included Abdel Gabbar Babiker, Abdelmoneim Ahmadi and Abdelatif M Nour from Sudan, Aberra Debelo, Senait Yetneberk, and Girma Tegegne from Ethiopia, and Peter Esele from Kenya

Drs Debelo and Babiker traveled to Purdue after the Conference to confer with scientists and administrators Girma Tegegne traveled to Kansas State for additional laboratory training with Larry Claflin Senait Yetneberk spent a week at Texas A&M to work in Lloyd Rooney's laboratory

INTSORMIL PIs also traveled to the HOA region for various collaborative activities John Sanders, Purdue, worked with economists at IAR/Ethiopia to evaluate the potential for future collaboration within the national sorghum program Gebisa Ejeta and John Yohe traveled to Kenya, Uganda, and Eritrea to establish MOAs with the national research institutes, and conducted discussions with IAR, DARE, KARI NARO, ASARECA and REDSO/East

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 David 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 the 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 With or without additional funding, INTSORMIL activities in the Horn by necessity, will be based on regional networking among, at a minimum, NARS with which we already have signed a Memoranda of Understanding The details of how such a small regional network would function will be further developed in cooperation with scientists from participating NARS at a travelling workshop to be held in Ethiopia in September 1997

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 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 annual basis, INTSORMIL and ARC scientists have held round table discussions on assessing and reevaluating production and utilization constraints in sorghum and millet 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

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, 56 students from 21 different countries were enrolled in an INTSORMIL advanced degree program Approximately 80% 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 1997, 16% of all INTSORMIL graduate participants were female Eighteen of the total 56 students received full INTSORMIL scholarships An additional 21 students received partial INTSORMIL funding and the remaining 17 students were funded from other sources as shown in Figure 3

All 57 students worked directly with INTSORMIL principal investigators on INTSORMIL projects These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding, pathology, entomology, food quality, and economics

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 1996-1997 this had 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 Four post doctoral scientists and one visiting host country scientist were provided the opportunity to upgrade their skills in this fashion during 1996-1997

The following table is a compilation of all INTSORMIL training activities for the period July 1 1996 through June 30, 1997

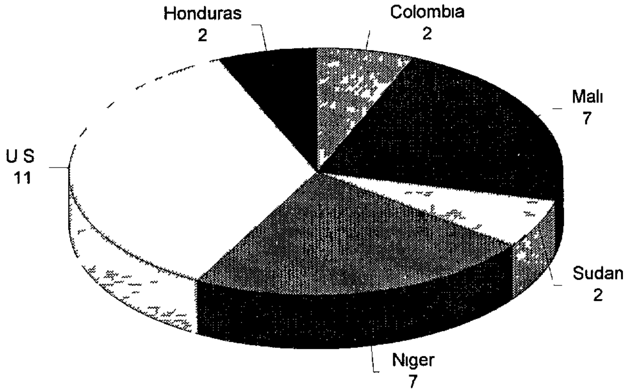

Figure 1 Participants by Country

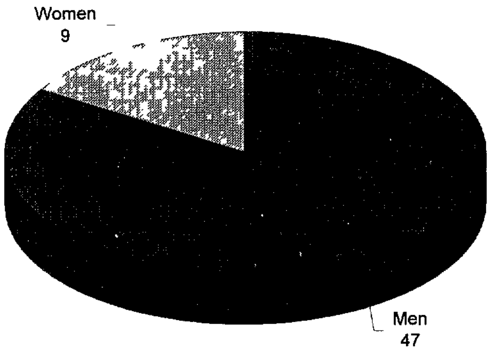

Figure 2 Participants by gender

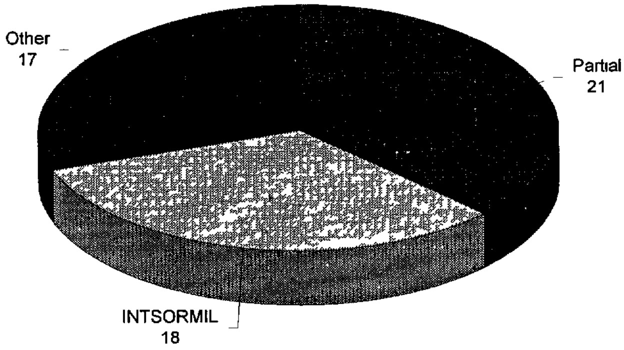

Figure 3 Source of Funding

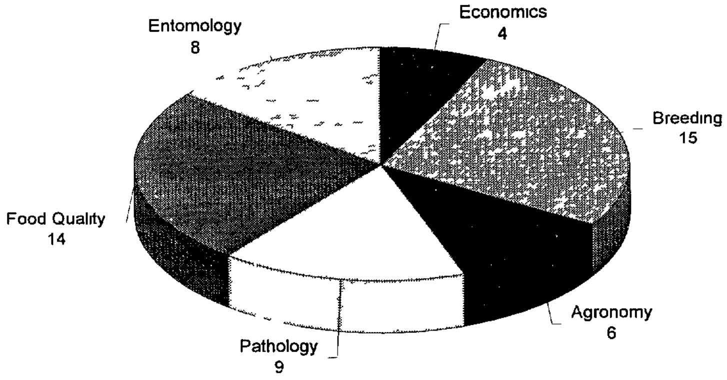

Figure 4 Discipline Breakdown

Year 18 INTSORMIL Training Participants

Name	Country	Univ	Discipline	Advisor	Degree	Gender	Funding*
Gutierrez Patricio F	Ecuador	UNL	Agronomy	Clegg	PHD	M	I
Masi Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M	O
Traore Abdoulaye	Mali	UNL	Agronomy	Maranville	PHD	M	I
Maman Nouri	Niger	UNL	Agronomy	Mason	MSC	M	I
Stockton Roger	U S	UNL	Agronomy	Mason	PHD	M	P
Traore Samba	Mali	UNL	Agronomy	Mason	PHD	M	O
Carvalho Carlos H S	Brazil	PRF	Breeding	Axtell	PHD	M	P
Kapran Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	I
Ndulu Lexingtons	Kenya	PRF	Breeding	Axtell	PHD	M	I
Ibrahim Yahia	Sudan	PRF	Breeding	Ejeta	PHD	M	I
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
Tuinstra Mitchell	U S	PRF	Breeding	Ejeta	PD[2]	M	I
Katsar Catherine Susan	U S	TAM	Breeding	Peterson/Teetes	PHD	F	P
Rodriguez Raul	Mexico	TAM	Breeding	Rosenow/Rooney	PHD	M	P
Teme Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Wiltse Curtis	U S	TAM	Breeding	Rosenow/Rooney	MSC	M	P
Jeutong Fabien	Cameroon	UNL	Breeding	Andrews	PHD	M	O
Setimela, Peter	Botswana	UNL	Breeding	Andrews	PHD	M	O
Tiryaki Iskender	Turkey	UNL	Breeding	Andrews	MSC	M	O
Coulibaly Bakary	Mali	PRF	Economics	Sanders	MSC	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
Vergara, Oscar	Ecuador	MSU	Entomology	Pitre	MSC	M	I
Diarisso Yaro Niamoye	Mali	TAM	Entomology	Teetes/Peterson	PHD	F	P
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
Buckner Becky	U S	PRF	Food Quality/Util	Hamaker	PHD	F	P
Itapu Suresh	India	PRF	Food Quality/Util	Hamaker	PD[2]	M	O
Mamadou Lewamy	Niger	PRF	Food Quality/Util	Hamaker	MSC	M	P
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
Bueso Francisco Javier	Honduras	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	I
Floyd Cherie	U S	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Kunetz Christine	U S	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Quintero Fuentes Ximena	Mexico	TAM	Food Quality/Util	Rooney	MSC	F	P
Seetharaman Koushik	India	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Suhendro Elly	Indonesia	TAM	Food Quality/Util	Rooney	PHD	F	P
Zhao Haiyan	China	TAM	Food Quality/Util	Rooney/Waniska	VS[1]	M	O
Diourte Mamourou	Mali	KSU	Pathology	Claflin	PHD	M	O
Lu Ming	China	KSU	Pathology	Claflin	PHD	M	P
Murithi Linus M	Kenya	KSU	Pathology	Claflin	PHD	M	O
Narvaez Dario	Colombia	KSU	Pathology	Claflin	MSC	M	P
Nzioki Henry S	Kenya	KSU	Pathology	Claflin	MSC	M	O
Arjula, Vaishali	India	KSU	Pathology	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

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* 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 - 1997

	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	Global Conference on Ergot of Sorghum	Sete Lagoas MG Brazil	6/97

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 Agronomico Tropical de Investigacion y Enseñanza Costa Rica
CEDA	Centro de Enseñanza y Adiestramiento SRN Honduras
CEDIA	Agricultural Document and Information Center Honduras
CENTA	Centro de Technologia de Agricola El Salvador
CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands Mexico
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigacion 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
CRSP	Collaborative Research Support Program

CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization Australia
DAR	Department of Agricultural Research Botswana
DR	Dominican Republic
DRI Yoro	Integrated Rural Development Project Honduras Switzerland
EAP	Escuela Agricola Panamericana Honduras
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
ECHO	Educational Concerns for Hunger Organization
EEC	European Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria Brazil
EMBRAPA CNPMS	EMBRAPA Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture Honduras
EPIC	Erosion Productivity Impact Calculator
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
DRA	Division de la Recherche Agronomique IER Mali
FAO	Food and Agriculture Organization of the United States
FEDEARROZ	Federacion Nacional de Arroceros de Colombia
FENALCE	Federacion Nacional de Cultivadores de Cereales
FHIA	Fundacion Hondurena de Investigacion Agricola Honduras
FPX	Federation of Agricultural and Agro Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
HIAH	Honduran Institute of Anthropology and History
IAN	Institute Agronomia Nacional Paraguay
IANR	Institute of Agriculture and Natural Resources University of Nebraska Lincoln
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas

ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas Guatemala
IDIAP	Agricultural Research Institute of Panama
IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy Mali
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IHAH	Instituto Hondureno de Antropologia e Historia
IICA	Instituto Interamericano de 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
INTSORMIL	International Sorghum/Millet Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronomicas Brazil
IPIA	International Programs in Agriculture Purdue University
IPM	Integrated Pest Management
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Research Institute Philippines
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISRA	Institute of Agricultural Research Senegal
ISVN	International Sorghum Virus Nursery
ITA	Institut de Technologie Alimentaire Senegal
ITAT	International Tropical Adaptation Trials
ITESM	Monterrey Institute of Technology Mexico
ITVAN	International Tall Variety Adaptation Nursery
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LASIP	Latin American Sorghum Improvement Project Mexico

LDC	Less Developed Country
LIDA	Low Input Dryland Agriculture
LIFE	League for International Food Education
LUPE	Land Use and Productivity Enhancement
LWMP	Land and Water Management Project
MAFES	Mississippi Agricultural and Forestry Experiment Station
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation Sudan
MIAC	MidAmerica International Agricultural Consortium
MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture Botswana
MOALD	Ministry of Agriculture and Livestock Development Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales Honduras
MSU	Mississippi State University
NAARP	Niger Applied Agricultural Research Project
NARP	National Agricultural Research Project
NARS	National Agricultural Research System
NCRP	Niger Cereals Research Project
NGO	Non Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory Fort Collins CO
NU	University of Nebraska
OAS	Organization of American States
OAU	Organization of African Unity
OICD	Office of International Cooperation and Development
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios
PI	Principal Investigator
PL480	Public Law No 480
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains in Central America
PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis South 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
SAT	Semi Arid Tropics
SDM	Sorghum Downy Mildew
SDMVN	Sorghum Downy Mildew Virulent Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMIP	Sorghum and Millet Improvement Program
SPARC	Strengthening Research Planning and Research on Commodities Project Mali
SRCVO	Section of Food Crops Research Mali
SRN	Secretaria de Recursos Naturales Honduras
TAES	Texas Agricultural Experiment Station
TAMU	Texas A&M University
TARS	Tropical Agriculture Research Station
TC	Technical Committee
TropSoils	Tropical Soils Collaborative Research Program CRSP
UANL	Universidad Autonoma de Nuevo Leon Mexico
UHSN	Uniform Head Smut Nursery
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska Lincoln
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDA/TARS	United States Department of Agriculture/Tropical Agriculture Research Station
VCG	Vegetative Compatibility Group
WASAT	West African Semi Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WSARP	Western Sudan Agricultural Research Project