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INTSORMIL 2004 ANNUAL REPORT

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2004 Annual Report

INTSORMIL

Sorghum/Millet International Research

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Sorghum/Millet Collaborative Research Support Program (CRSP)

Fighting Hunger and Poverty with Research ... a team effort

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Research Support Program (CRSP)

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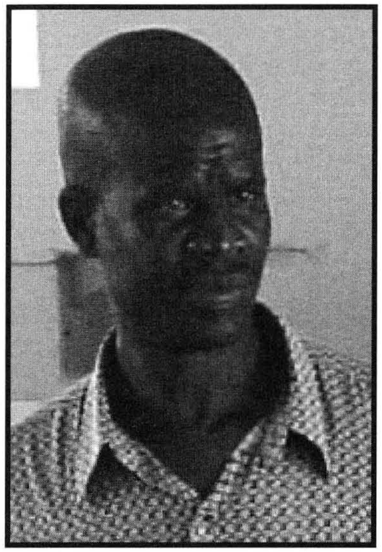

Michael Mogorosi

The 2004 INTSORMIL annual report is dedicated to Mr. Michael Mogorosi in remembrance of his contributions to INTSORMIL and pearl millet and sorghum research and extension.

Michael Mogorosi, Senior Research Officer in the Cereal Improvement Program of the Department of Agricultural Research (DAR) in Botswana died after a brief illness in October 2004. Michael joined the Cereal Improvement Program, DAR in 1979. He was awarded a number of educational opportunities starting with a diploma in agriculture from the Botswana College of Agriculture in 1984. He completed a six-month course in sorghum and pearl millet improvement at ICRISAT in 1985. Michael earned a B.Sc. in agronomy at the University of Nebraska in 1989 and subsequently took courses in G X E interaction effects and the use of GIS in agriculture. In 1999 he returned to the University of Nebraska on a visiting scholar grant from INTSORMIL for the application of recent breeding techniques in pearl millet.

Due to his experience and expertise Michael often represented DAR and Botswana in regional and international workshops, and was an invited participant in a review of INTSORMIL's activities in the SADC region. His career was a productive synthesis of academic achievements and relevant specialist training. Less well known, however, was his detailed knowledge and understanding, obtained over many years, of family farming systems in Botswana. Michael's desire to develop practical applications from research at the farmer level was a constant goal in his professional career, and earned him respect and appreciation from farmers, extension workers and researchers alike.

While in charge of cereal research in northern Botswana, Michael's research, both on experimental sites, and on-farm plots led to the release of two new pearl millet varieties. Michael of course also ensured that a good local seed multiplication system was in place.

Michael's sincerity and knowledge earned the respect of farmers and professional colleagues. His passing is a sad loss to the small cadre of experienced pearl millet and sorghum research in the SADC region, and INTSORMIL will miss his contributions to collaborative research.

Contributed by Dr. David Andrews, Professor Emeritus, University of Nebraska, Lincoln

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Introduction and Program Review

The 2004 INTSORMIL Annual Report presents the progress and notable achievements by the Sorghum/Millet CRSP during the period of July 1, 2003 - June 30, 2004. These results are an outcome of partnerships between scientists at six U.S. Land Grant Universities (Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University) and scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia and National Agricultural Research Systems (NARS) and National Universities in nineteen countries in Central America, West Africa, East Africa and Southern Africa.

Agricultural research provides benefits not only to producers of agricultural products but also to processors and consumers of agricultural products. Agricultural research has proven itself continuously as providing improvements which yield products of greater quantity and quality, as well as improved health to consumers and broad-based economic growth which goes beyond producers and consumers.

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between 18 U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. ***The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production and utilization for the mutual benefit of the U.S. and Less Developed Countries (LDCs).*** Collaborating scientists in NARS developing countries and the U.S. jointly plan and execute research that mutually benefits all participating countries, including the United States.

INTSORMIL takes a regional approach to sorghum and millet research in western, eastern, and southern Africa, and in Central America. INTSORMIL focuses resources in the four regions supporting the general goals of building NARS institutional capabilities, creating human and technological capital to solve problems constraining sorghum and millet production and utilization. INTSORMIL's activities are aimed at achieving sustainable, global impact, promoting economic growth, enhancing food security, and encouraging entrepreneurial activities.

INTSORMIL continues to contribute to the transformation of sorghum and pearl millet from subsistence crops to value-added, cash crops. Because sorghum and millet are important food crops in moisture-stressed regions of the world, they are staple crops for millions in Africa and Asia, and, in their area of adaptation, sorghum and millet have a distinctly competitive advantage to yield more grain than other cereals. As wheat and rice products have been introduced to urban populations in developing countries, traditional types of sorghum, because of some quality characteristics, have not been able to effectively compete with wheat and rice products. However, as a result of research by INTSORMIL researchers and others, improved, food-quality sorghums produce grain that can be used for special ethnic and dietary products as well as for traditional food products. Special white sorghums developed by INTSORMIL collaborative research in Mali have improved characteristics which allow preparation of high-value food products made of as much as 100% sorghum which can compete successfully with wheat and rice products in village and urban markets. Couscous made from food-quality, hybrid sorghum developed with INTSORMIL support has been market tested in Niger. The development of both open-pollinated and hybrid sorghums for food and feed with improved properties such as increased digestibility and reduced tannin content is contributing to sorghum becoming a major feed grain in the U.S., Africa and in Cental and South America. Pearl millet is also becoming an important feed source in poultry feeds in the southeastern United States. Improved varieties and hybrids of pearl millet, like improved lines of sorghum, can be grown in developing countries, as well as the United States, and have great potential for processing into high-value food products which can be sold in villages and urban markets, competing successfully with imported wheat and rice products. In the U.S. pearl millet is also finding a place in niche markets, i.e., heads of pearl millet for birdfood and for floral arrangements. These emerging markets for sorghum and pearl millet are results of the training and collaborative, international scientific research that INTSORMIL has supported both in the United States and collaborating countries.

Although significant advances have been made in improvement and production of sorghum and millet in the developing countries of regions in which INTSORMIL serves, population growth rates continue to exceed rates of increase of cereal production capacity. There remains an urgent need to continue the momentum of our successes in crop improvement, improved processing and marketing of sorghum and millet, and strengthening the capabilities of NARS scientists to do research on constraints to production, utilization and marketing of sorghum and millet.

INTSORMIL maintains 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 provides needed support for education of agricultural scientists in both developing countries and the United States. The results of this support include strengthening the capabilities of institutions to do research on sorghum and millet, development of international, collaborative research networks, promoting and linking to technology transfer and dissemination of technologies developed by research, and enhancing national, regional, and global communication linkages. *INTSORMIL provides essential support to bridge gaps between developing countries and the United States.* A major innovative aspect of the INTSORMIL program is to maintain continuing relationships with scientists of collaborating countries 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 their national agricultural research systems and regional networks in which they collaborate.

Conserving biodiversity and natural resources: Results of the collaborative research supported by INTSORMIL include development and release of enhanced germplasm, development and improvement of sustainable production systems, development of sustainable technologies to conserve biodiversity and natural resources. The knowledge and technologies generated by INTSORMIL research also enhance society's quality of life and enlarge the range of agricultural and environmental choices available both in developing countries and the United States. Thus, INTSORMIL promotes conserving millet and sorghum germplasm, conserving natural control of arthropod pests and diseases of sorghum and millet, developing resource-efficient cropping systems, developing integrated pest management strategies, 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 regional sites in countries other than the United States has been strengthened by using multidisciplinary research teams composed of American and NARS scientists focused on unified plans to achieve common objectives. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and pearl millet. The outputs from these disciplinary areas of research are linked to immediate results. INTSORMIL uses both traditional science of proven value and newer disciplines such as molecular biology in an integrated approach to provide products of research with economic potential. These research products which alleviate constraints to production and utilization of sorghum and pearl millet are key elements in fighting hunger and poverty by providing means for economic growth, generation of wealth, and improved health. New technologies developed by INTSORMIL collaborative research are extended to farmers' fields and to processors and marketers of sorghum and millet products in developing countries and the United States through partnerships with NGOs, research networks, extension services and the private sector. In addition, economic analysis by INTSORMIL researchers plays a crucial role by enabling economic policymakers too more intelligently consider policy options to help increase the benefits and competitiveness of sorghum and pearl millet as basic food staples and as components of value-added products.

Supporting information networking: INTSORMIL research emphasizes working with both national agricultural research systems and sorghum and millet networks to promote effective technology transfer from research sites within the region to local and regional institutions. Technology transfer is strengthened by continued links with regional networks, International Agricultural Research Centers, and local and regional institutions. Emphasis is placed on strong linkages with extension services, agricultural production schemes, private and public seed programs, agricultural product supply businesses, and nonprofit 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, with the ultimate goal being economic and physical well-being to those involved in production and utilization of these two important cereals both in developing countries and the United States.

Promoting demand-driven processes: INTSORMIL economic analyses are all driven by the need for stable markets for the LDC farmer and processor, so these analyses focus on prioritization of research, farm-level industry evaluation, development of sustainable food technology, processing and marketing systems. INTSORMIL seeks alternate food uses and new processing technologies to save labor and time required in preparation of sorghum millet for food and feed and add value to the grain and fodder of the two crops. Research products transferred to the farm, to the livestock industry and to processors and marketers of sorghum and millet are aimed at spurring rural and urban economic growth and providing direct economic benefits to producers and consumers. INTSORMIL assesses consumption shifts and socioeconomic policies to reduce effects of price collapses, and conducts research to improve processing for improved products of sorghum and millet which are attractive and useful to the consumer. Research by INTSORMIL agricultural economists and food scientists seeks to reduce effects of price collapse in high yield years, and to create new income opportunities through diversification of markets for sorghum and pearl millet. INTSORMIL socioeconomic projects measure impact and diffusion and evaluate constraints to rapid distribution and adoption of introduced, new technologies.

The INTSORMIL program addresses the continuing need for development of technologies for agricultural production, processing and utilization of sorghum and pearl millet for both the developing world, especially in the semiarid tropics, and the United States. There is international recognition by the world donor community that national agricultural research systems (NARS) in developing countries must assume ownership of their development problems and move toward achieving resolution of them. The INTSORMIL program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits to the U.S. agricultural sector. These aspects of INTSORMIL present a win-win situation for international agricultural development, strengthening developing countries' abilities to solve their problems in the agricultural sector while providing benefits to the United States.

Administration and Management

The University of Nebraska (UNL) hosts 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 and USDA/ARS for the research projects between U.S. scientists and their collaborating country counterparts. A portion of the project funds, managed by the ME and U.S. participating institutions, supports regional research activities. 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 country coordination, budget management, and review.

Education

During Year 25, 2003-2004, there were 49 students from 19 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 71% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2003-2004 totaled 10. An additional 35 students received partial funding from INTSORMIL and the remaining four students were funded from other sources.

Another important category of education which INTSORMIL supports is non-degree research activities, namely postdoctoral research and research of visiting scientists with INTSORMIL PIs in the United States. During Year 25, twenty scientists improved their education as either postdoctoral scientists (6) or visiting scientists (14). Their research activities were in the disciplines of plant breeding, economics, entomology and pathology research. These scientists came to the United States as postdoctoral scientists or visiting scientists from Egypt, Ethiopia, India, Indonesia, Malawi, Mali, Niger, Senegal, South Africa, and the United States.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as 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 (ASARECA, ECARSAM, SADC/SMINET, SADC/SMIP and others) private industry and government extension programs to coordinate research and technology transfer efforts.

- Supports INTSORMIL 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 in India, Mali, Niger, Central America and Zimbabwe, SAFGRAD, WCASRN/ROCARS, WCAMRN/ROCAFREMI, ASARECA, ECARSAM and SMIP/SMINET in Africa, CLAIS and CIAT of Central and South America and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditures of research dollars. There also has been efficient 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 Africa, West Africa and with SMIP/SMINET in Southern Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with WCAMRN/ROCAFREMI and WCASRN/ROCARS in West Africa had much potential in allowing INTSORMIL utilization scientists to collaborate regionally. ROCAFREMI was a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last four years, INTSORMIL, the Bean/Cowpea CRSP and World Vision International had been working with NARS researchers and farmers in five countries under the West Africa Natural Resource Management Project, creating and using a technology-transfer network in West Africa. That project was terminated in 2003. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Regional Activities and Benefits

West Africa (Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal)

The activities in the Western Region of West Africa proceeded well in 2003-2004. A planning workshop was held in Ouagadougou in April 2004 for merger of the INTSORMIL West African regional programs (Eastern and Western) into one six-country region. The new regional program will start in July 2004. In Niger, a project was begun with Rockefeller funding to introgress *Striga* resistance into a high quality local variety, El Mota. Further work showed that a midge resistant sorghum line identified by INRAN scientists holds promise. In the Niger couscous project, the CIRAD-designed agglomerator in the INRAN cereal processing unit was successfully fabricated locally and put in an entrepreneur's processing facility (funded through IFAD Sorghum-Millet Initiative). Good progress was made in development of millet hybrids with downy millet resistance at Lake Chad Research Institute, Maiduguri, Nigeria. At the University of Maiduguri, good progress was shown in using new hybrids/varieties of millets in high quality foods, and a move towards commercial processing of millet couscous was initiated. A project in Burkina Faso was initiated to improve production practices for sorghums optimum for *dodo* (traditional beer) making. A combination of microdose fertilizer application and Zai (water management) substantially improved yields of cv.Framida – a superior red sorghum for the brewing process. This is an interdisciplinary project developed and implemented by the Burkanabi scientists. Another positive outcome was the third year of INTSORMIL collaborative activities in Ghana and Senegal with activities in breeding, pathology, entomology, agronomy, and *Striga*. The strong Mali research program in IER continues to show leadership in the region by enhancing germplasm exchange, scientist to scientist cooperation, and collaborative research activities among scientists in several West African countries.

One concern regards the best way to organize, coordinate, etc., research activities among the various countries in West Africa. Bringing the countries of Mali, Niger, Ghana, Senegal, Burkina Faso, and Nigeria together into a single regional program strengthens the research effort across the region, but the limited funding for these new countries is still a problem. Also, the time and funding required for U.S. PIs to travel to more countries in West Africa is a concern. The addition of new INTSORMIL projects has been a positive development and should strengthen the West Africa regional program in the future. Positive moves in that area include John Leslie's travel and efforts on behalf of pathology. However, pathology needs assistance beyond grain toxin studies. The work of Dr. Jeff Wilson, USDA/ARS will strengthen the millet breeding and millet pathology area. Dr. Clint Magill, Texas A&M University has become involved in biotechnology collaborative research in the region. Dr. Bonnie Pendleton, West Texas A&M has shown a strong effort in strengthening collaboration in entomology. Dr. Mitch Tuinstra, Kansas State University has initiated collaboration in sorghum breeding and has established collaboration in 2003. Dr. Joe Hancock, Kansas State University brings poultry and livestock feeding experience to the program. The PI Conference in November 2002 and the regional workshop in April 2004 were excellent opportunities for scientific exchange and collaborative research development.

The loss of both the sorghum and millet networks in West Africa has been a major concern, and this loss has resulted in less funding, communication and cooperation among scientists doing research on production, utilization, and marketing of sorghum and pearl millet in West and Central Africa. INTSORMIL will work with and encourage NARS to develop a new framework to restore some of the important network functions such as scientific meetings, workshops, etc.

Horn of Africa (Ethiopia, Eritrea, Kenya, Tanzania, Uganda)

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya and Uganda. In this report, we document progress of some work in Tanzania and Eritrea. Host country PIs in each country has taken keen interest in collaborating with U.S. PIs where partnership has been developed. Because of expanded collaborative involvement in several countries, more U.S. PIs are needed to provide collaborative linkages with host country scientists. New PIs joining INTSORMIL are expected to take advantage of the opportunities for collaboration in the Horn of Africa region, where host country scientists and programs continue to appreciate and welcome technical support provided by INTSORMIL.

Work on integrated *Striga* management that started in Ethiopia has been extended to Eritrea and Tanzania. Field performance of the technology package of *Striga* resistant cultivars, fertilization, and water conservation practice has produced good results in both countries. Farmer response to the package has been, not surprisingly, excellent as well. Opportunities for advancing the program by putting in place an organized and functional seed production and a delivery mechanism as well as viable market outlets for both seed and grain in Tanzania look very promising. Availability of grain market outlets via cottage industries such as Power Foods and large-scale factories (brewery, feed processors) provides excellent opportunities to tie in research, extension and processing, so that investments in both research and on-farm could show profitable results.

We look forward to finding an appropriate forum for sharing these experiences with stakeholders from all over the region.

Southern Africa (Botswana, Mozambique, Namibia, South Africa, Zambia)

Activities described in individual work plans were carried out as planned and described. Unpredictable weather affected the condition of field nurseries and data collection at some locations. The results reported in the report are a summary of results from the collaborators. All collaborators develop and submit work plans prior to each growing season. All collaborators also submit a summary of the research conducted for inclusion in the annual report. The program is evolving to place more responsibility on collaborators for the activity and quality in their research program. Budgets will eventually be adjusted to reward the most productive collaborators while attempting to maintain a broad-based, multi-country, multi-institution, multidisciplinary program.

There are two major constraints to development of the South Africa regional program at this time. First is the lack of scientific expertise for sorghum and pearl millet in the region. Although INTSORMIL has trained many Southern Africa students over the last 20-years few returned to their home institutions to conduct research in either sorghum or pearl millet. Within each institution and discipline there is basically one scientist available for collaboration. This is contributing to the increasing emphasis of regional scientists collaborating across national boundaries. As capable students are identified and matched with available advisors additional graduate education will occur. The students need assurance of positions in sorghum and pearl millet research upon returning from their degree programs. The second constraint is the continued decline in the number of hectares devoted to sorghum (and pearl millet) production. As in most semi-arid regions the decline can be attributed to government policy, lack of a marketing system to handle either traditional grain or grain with enhanced end-use traits, and consumer preference for other grains. These problems can also work to the benefit of sorghum and pearl millet if a production and marketing system can be developed for the crops. With the right varieties or hybrids and the right marketing system the natural stress resistance of sorghum and pearl millet can help provide a consistent supply of high quality grain for processors and consumers.

Most INTSORMIL activities in Southern Africa were carried out as planned. The collaborative research has produced results that are important to increasing the production and quality of end-products of sorghum and pearl millet in the Southern Africa region. Hybrid parents have been bred for sorghum and are nearing completion for pearl millet. A large amount of sorghum breeding material and varieties in use have been characterized for resistance to major diseases and sugarcane aphids. Multi-location testing of sets of such lines provides strategic geographic information on distribution and severity of diseases. Factors influencing the incidence and control of sorghum ergot are now better understood, leading to better control of the disease, especially in hybrid production fields. Food quality research can lead to increased use of sorghum in various products. Linking variety qualities to specific end uses is being shown to be very important.

Active, interdisciplinary collaboration exists in sorghum breeding, plant pathology, grain quality, and entomology. Regional pearl millet breeders continue interaction with INTSORMIL at a reduced level due to retirements of U.S. principal investigators. Efforts are underway to establish and strengthen collaboration with regional pearl millet breeders but progress is very slow. Efforts are on-going to continually refocus activity for increased relevance and generation of useful technology. Collaboration can be improved and increased in all research areas. Additional collaboration is needed in all disciplines for all research objectives. Unfortunately, there are more collaborators and opportunities in Southern Africa than there are INTSORMIL principal investigators in the United States.

The regional budget has been reallocated to contribute additional funds to collaborators and to improve accountability for the funds. Funds are passed to the host country research organizations and joined to specific work plan objectives. This enables scientists to have funds available on a more timely basis and increases accountability of the scientists for the funds and in providing research results. This brings collaborators more directly into INTSORMIL and provides a forum for dissemination of research results.

Central America (El Salvador, Nicaragua, Honduras)

Since 1999 the Central America program has increased activity in El Salvador and Nicaragua. A Memorandum of Understanding was signed with DICTA to allow future collaborative research in Honduras. Program implementation the past four years has leveraged new or increased research on grain sorghum by more than 25 scientists in national programs in the region. The research activities developed for 2003-2004 were successfully completed, and administrative procedures for reporting research results and financial expenditures are proceeding satisfactorily. A regional graduate education and short-term training plan have been developed with the regional research directors. Three students are currently in graduate degree programs, and three more scheduled to start in 2004-2005. Short-term training in experimental design and data analysis was given to 30 collaborators in the region. A conference was held to report research results and plan collaborative research priorities for 2002-2006, and 11 of the research reports were published in La Calera. Present efforts are to implement these research priorities while expanding activity into Honduras and Guatemala. Communication with and coordination of the many groups participating in the program remains a challenge. On the whole, the present collaborative model being used by the Central America Regional Program is functioning well, due to the commitment of scientists in the region, and has resulted in transfer of improved cultivars with increased yield and nitrogen use efficiency. The improved photoperiod sensitive variety 85-SCP-805 with high yield potential and nitrogen use efficiency was validated on 40 farms. The new variety with 47 kg ha^{-1} N fertilizer application increased grain yield by 800 kg ha^{-1} (about 25%) over the local variety without N fertilizer. Major progress was made in developing forage and grain hybrids, including line identification, testing and in seed production. Grain utilization issues are increasing in importance in the program. Increased awareness of the desirable livestock feeding value of sorghum grain was created through workshops, and a keynote presentation on this topic was presented at the PCCMCA Annual Meeting. Equipment for efficient milling of sorghum grain was identified in El Salvador. Researchers participating in the INTSORMIL Central America Regional Program have also developed management strategies for fall armyworm and sorghum midge, identified priority disease problems, developed sorghum flour substitution technology, and implemented research on nitrogen rates and nitrogen use efficiency of sorghum germplasm adapted to the region. Improved germplasm, production practices and pest management methods are being moved to producers through validation and demonstration trials, collaboration with extension services and NGOs, and through workshops with producers.

Regional Benefits by Technical Thrust

Germplasm Enhancement and Conservation

The goals of pearl millet breeding research supported by project ARS-206 are to improve the productivity, yield stability, and pest resistance of pearl millet cultivars. Achieving these goals requires 1) identifying constraints limiting production or utilization within and across environments, 2) acquiring and evaluating new germplasm for desirable characteristics, 3) crossing selected germplasm with regionally adapted breeding lines or cultivars, 4) selecting and evaluating improved progeny as potential new cultivars.

Project collaborators at multiple locations have been identified. These individuals have contributed cultivars and experimental germplasm for evaluating genotype x environment interactions in grain yield, quality, and disease and pest resistance. Collaborators have reached a consensus on project objectives, methods and timetable to achieve these objectives. In Niger two research collaborators were identified and contributed to the 2003 workplan. Although seed for trials were sent to these individuals, no data have been received. Dr. Issoufou Kapran, INRAN sorghum program leader, has identified Issaka Ahmadou as a new collaborator for 2004 trials. A replicated set of selected pearl millet germplasm was distributed among collaborators. Multi-location experiments have been established in Ghana, Mali, Niger, Nigeria, and Senegal. The germplasm is being assessed for characteristics that contribute directly or indirectly to stability of grain yield and quality.

In an effort to expand the diversity in the breeding populations being selected at collaborating locations, crosses have been made between several African cultivars and U.S. breeding lines to develop new germplasm in the A1 and A4 male sterile cytoplasms, and also with corresponding genes for fertility restoration. The introduced accessions are being evaluated for pests and diseases of importance to growers in the U.S. and in Africa. Sources of resistance to leaf blight, rust, and root knot nematode have been identified in the African pearl millets.

Research and germplasm development in INTSORMIL sorghum breeding project PRF-207 addresses the objectives of proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing of breeding sorghum varieties and hybrids for use in developing countries requires. 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. 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 (drought, cold, grain mold, and other diseases). Research and germplasm development in PRF-207 attempts to address these essential requirements.

Over the years significant progress has been made in some of these areas. Superior raw germplasm has been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed. In this report, PRF-207 has included observations relative to identification and characterization of sorghum genetic variants in glycinebetaine accumulation and their role in tolerance to drought and salinity stresses. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed in a number of African countries.

The principal objectives of INTSORMIL project TAM-222 are to identify and develop disease resistant and drought resistant sorghum germplasms 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 programs continued to develop and evaluate new germplasm for use in the U.S. and host countries. Forty-nine new fully converted exotic lines and 71 partially converted lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released. Sixty diverse breeding germplasm lines ranging from advanced generation to early generation with Pathotype three downy mildew resistance were selected for release. Numerous advanced generation B and R lines developed in TAM-222 were identified as potential releases for distribution to private companies and U.S. and host country public programs as the project moves to closure of the TAM-222 sorghum breeding project with the retirement of the project leader. More than 750 items were distributed to private seed companies with MOA's upon their request based on observation of a 500-entry B/R-line Observation Nursery in 2003.

Several very unique and promising new Durra and Durra-Bicolor and Durra-Dochna type cultivars from the dry northern part of Mali were identified in the Mali Sorghum Collection, and hold promise in sorghum improvement in the drought prone areas of Africa and the U.S. The B/R-line reaction and hybrid vigor of selected Malian and Sudanese cultivars continued. Twenty-five sorghums from the Mali Collection were selected for entry into the Sorghum Conversion Program. The Conversion Program, however, is in a temporary holding status since the USDA-ARS program in Puerto Rico dropped their portion of the Conversion Program in early 2004.

Breeding progeny developed in TAM-222 which had showed excellent potential in Zambia, South Africa, Nicaragua, El Salvador, and in south and west Texas with various combinations of high yield, drought resistance, grain quality, and disease resistance were again distributed to several host country scientists. They offer good potential for use as varieties directly where appropriate and also as parental lines for use in hybrids. Macia (an improved cultivar from Mozambique) derivative lines appeared especially promising and also offer potential to develop some improved white-seeded, tan-plant parental lines for U.S. use.

Sterilization and evaluation continued on a large number of new B-line breeding genotypes to assist decisions on which ones to release. These lines contain various combinations of stay green drought resistance, lodging resistance, improved grain quality, and head smut resistance. Several are white-seeded, tan-plant A-B pairs that could be useful in food-type hybrids.

The acceptance of white-seeded, tan-plant improved Guinea type sorghum cultivars, developed in the INTSORMIL/IER collaborative breeding program in Mali, by both farmers and in the marketplace has been excellent. The successful use of N'Tenimissa flour by a private bakery in Mali to commercially produce and market a cookie using some sorghum flour has demonstrated that new improved food quality cultivars can stimulate new commercialization of sorghum-based products. Another encouraging activity is the interest of farmers involved in the flawed 2002 identity preserved grain increase with N'Tenimissa in doing a similar thing with a different grain/market entrepreneur. It shows that new cultivars with improved grain quality traits can stimulate the development and commercialization of new sorghum-based products. Some of the new N'Tenimissa breeding progenies in Mali promise to be superior to N'Tenimissa in production and grain quality. Several (N'Tenimissa*Tiemarfing (local Guinea)) derivative breeding lines have been given cultivar names and released, including 97-SB-F5DT-63 as Wassa, 97-SB-F5DT-64 as KénikédiP, 99-BE-F4P-128-1 as Darrellken, 97-SB-F5DT-74-2 as Niéta, 96-CZ-F4P-98 as Zarra-blP, and 96-CZ-F4P-99 as Zarra-djé, along with one intermediate caudatum-guinea type 97-SB-F5DT-150 as Niétichama.

Collaborative INTSORMIL activities recently initiated in Senegal and Ghana continue in the areas of sorghum breeding, disease resistance, and *Striga*, as well as in entomology and agronomy research. The consolidation of all the West African INTSORMIL collaborative programs in six countries into one overall regional program was initiated in early 2004.

Progress was made in all research areas in INTSORMIL's project TAM-223 aimed at enhancing sorghum germplasm for resistance to insects and improving efficiency for sustainable agricultural systems. Germplasm was obtained and evaluated for resistance to economically important insect pests. Selections were made to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield and widely adapted hybrids. A study to apply the results of previous molecular mapping studies on greenbug resistance and stay-green to compare the effectiveness of molecular versus conventional selection was completed. Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny was identified that combines several favorable traits into a single genotype. As research continues to generate new technology, the importance of testing on-farm and soliciting producer input on research activities will increase.

During the life of this project significant research progress has been achieved. Technology (seed containing improved germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Impact assessment studies show a high rate of return on investment from research conducted by this project.

Excellent progress was made in initiating nutrition research and germplasm characterization studies. Good progress also was made in initiating research plans with international collaborators in Africa and Central America. Several students from Central America and Africa were identified and selected for graduate training.

The emphasis of project KSU-220 is on developing high yielding sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics for use as human food and in animal feed. Recent nutritional studies indicated that certain large-seeded hybrid sorghums were equivalent in feeding value to hybrid maize and were significantly better than conventional sorghum varieties. Breeding efforts have been initiated to transfer these enhanced feed quality characteristics into high-yielding sorghum varieties adapted for production in Africa, Central America, and the United States. This will be accomplished through conventional breeding strategies and by adapting marker-assisted selection technologies as appropriate. Several new large-seeded lines have been identified through applied plant breeding efforts.

Other research efforts have focused on the characterization and utilization of genes to improve resistance to grain mold and tolerance to weathering. Recent studies evaluating the efficacy of marker assisted selection for improvement of grain mold resistance indicated that QTL were only effective in the original mapping population. This fact limits their potential usefulness in an applied breeding program. Greater success has been observed through applied plant breeding efforts. These results suggest that more emphasis may be needed on applied plant breeding activities to ensure success of the project.

More than 80 disease resistant (R) genes have been identified and cloned based on database searches of sorghum expressed sequence tags and by PCR amplification using primers derived from motifs conserved in resistance genes cloned from other species. More than one-half of these have been placed on the genetic map of sorghum. Reports from other species suggest that these genes may confer disease resistance to fungal, bacterial, and viral pathogens and even to insects.

Technology transfer activities, particularly in the area of poultry nutrition and production, have been initiated in several countries. In Central America, technical assistance and technology transfer are being pursued through interactions with Dr. Carlos Campabadahl, one of the leading nutritionists in Central America. In West Africa, poultry feeding demonstrations have been initiated with great interest by producers. It is important that these demonstrations evolve into training programs directed toward key poultry producers and feed millers.

Sustainable Production Systems

INTSORMIL's project, PRF 205, has successfully completed its second principal year of the Marketing-Processing project which has indicated the importance of combining inorganic fertilizers with the new cultivars and of inventory credit even in a good rainfall year. In other fieldwork the same techniques of combining new technology introduction with marketing innovations were shown to be critical to introducing new maize technologies into central Mozambique.

The project has had a successful year in graduate student training. Besides the new marketing activity, economists in PRF-205 continue to do impact analysis. Graduate students in PRF-205, as in other INTSORMIL projects, develop their skills as researchers by actually doing research under the guidance of their major professor, an INTSORMIL principal investigator. The project PI supported four graduate students from INTSORMIL priority countries, two Ethiopians, a Mozambican, and a Nicaraguan. The two Ethiopians, Nega Wubenah and Yigezu Yigezu were directly supported by the INTSORMIL funding except when Yigezu was doing his fieldwork and then working full time on the impact of the *Striga* resistant cultivars. Both Ethiopian students have benefitted from the supplemental INTSORMIL funding for evaluating the impact of new technologies. Both have done fieldwork in different regions of Ethiopia on the impacts of *Striga* resistant cultivars and associated technologies. Mr. Nega finished his M.S. thesis on the diffusion of new technologies in Tigray and returned for more fieldwork there during the summer of 2003. This work will be supplemented by Mr. Yigezu's fieldwork and future thesis from the Ethiopia Amhara region on the same topic.

Mr. Rafael Uaiene (Mozambique) has been directly supported by another USAID training grant to INTSORMIL from the Mozambican USAID Mission. Felix Baquedano (Nicaragua) has conducted follow-up to the research of Tahirou Abdoulaye in western Niger. He has interviewed the same sample of farmers that Dr. Tahirou interviewed in 2000 and has evaluated their continuing use of inorganic fertilizer and their subsequent adoption of inventory credit. He has been supported by our PRF-205 project Impact-USAID funding in that field activity.

The PRF-205 project has been involved in the development of a Marketing-Processing Project for West Africa. During the first one and one half years the project was financed first by ROCAFRAMI (the previous 14 country millet network operating in West and Central Africa) and then by the USAID-Washington through the Impact Project with partial funding from INTSORMIL for Dr. Botorou Ouendeba's travel. During the past six months INTSORMIL set aside funding for the support of the Project coordinator and the six weeks of fieldwork in the summer of 2004 to evaluate the second year impact and to extend project operations to feed processors. WARP, the USAID regional mission in West Africa has indicated their intention of supporting this work for the next fiscal year. The project scientists will be extending this work from the four Sahelian countries presently involved (Senegal, Mali, Niger, and Burkina Faso) to include Nigeria in 2004.

With other funding from USAID/Africa the Principal Investigator of PRF-205 and his graduate students have continued studying the potential impact of biotechnology, focusing their attention on the costs to West Africa of not introducing Bt cotton. Another project has been an analysis of the effects of technology and policy on farm income and technology introduction in cacao production in Cameroon and Ghana. Both projects broaden the scope of PRF-205 and give the PI ideas for the projects INTSORMIL researches.

INTSORMIL's project UNL-213 which focuses on cropping systems to optimize yield, water and nutrient use efficiency of pearl millet has been extremely productive in graduate education of West African collaborating scientists, agronomic research which has led to publication in scientific journals, the publication of extension bulletins, the transfer of improved practices to pearl millet producers, and strengthening the activities of the West and Central Africa Pearl Millet Research Network. In the U.S. the project has documented the potential for pearl millet as a new grain crop in the Great Plains, and developed production practice recommendations for planting date, row spacing, and nitrogen fertilizer application. Research activities expanded from West Africa to Central America in 2001.

The major managerial issues facing Project UNL-213 is balancing INTSORMIL efforts with other responsibilities in National Research Systems and/or in U.S. universities. Although electronic communication has improved the situation, communication remains problematic both in planning and reporting research activities. There is continuing difficulty in identification of potential graduate students from West African and Central American countries largely due to the need for English language skills. Funding of graduate student studies is becoming increasing difficult with flat budgets along with increased costs (especially overhead and stipend), and due to fewer supplemental funding opportunities from other sources. Although effective programs have been established, the future is somewhat uncertain due to the weak institutional strength of national programs. The collapse of the West and Central Africa Pearl Millet and Grain Sorghum Networks has reduced opportunity for meeting to share research results and plan research activities. Nebraska research on pearl millet is severely constrained by the lack of a pearl millet breeding program in the Great Plains, and the lack of private sector investment in developing pearl millet as an alternate grain crop.

During the 2003-2004 program year project output included the identification of the improved photoperiod sensitive (maicillo criollo) sorghum variety 85SCP805 with increased grain yield, improved NUE, and high % N fertilizer recovery for production in relay intercropping systems with maize in El Salvador. The variety produced higher yield in validation (40 farms) and transfer (260 farms) plots than local varieties, and showed greater response to N fertilizer application.

In West Africa, research confirmed that microdose fertilizer application increases grain and stover yields of pearl millet (and grain sorghum) although the response varies greatly across location and year. Estimated nutrient removal indicated that this system mines nutrients from the soil at approximately the same rate as with no fertilizer application.

In eastern Nebraska, pearl millet grain yield is optimized with application of 90 kg ha^{-1} N fertilizer, while the response is minimal in western Nebraska due to the low rainfall conditions.

The UNL-219 project implementation has progressed as planned. Tie-ridge tillage and an implement for tie-ridging are proving to be agronomically sound and feasible for farmer use in some sorghum production areas of Ethiopia. However, communication with the project partners in Ethiopia is still a constraint to the progress and quality of implementation in Ethiopia.

Participatory research on soil and water management issues in Uganda is in its third season and is progressing well. Data have been collected for sorghum production areas in Ethiopia, Kenya and Uganda and are being compiled in GIS referenced databases. Arrangements have been made for collaborative work in Mozambique.

Use of starter fertilizer for no-till sorghum production infrequently resulted in a yield increase and in less grain moisture at harvest. The least expensive starter fertilizer option appears to be as good as other options. However, with typical planting dates, little or no economic benefit was found for starter fertilizer use for no-till sorghum production.

The INTSORMIL sponsored graduate student, Soares Xerinda, is scheduled to complete his M.S. degree in August 2004 and a work plan has been developed for collaborative work in Mozambique. Two graduate students supported by INTSORMIL, including Mr. Soares Xerinda, received their M.S. degrees in July 2004 and another expects to graduate in August 2004. Two EARO researchers completed their M.S. degrees at Alemaya University in July 2004; their study and research were partly supported by INTSORMIL with advisory support from UNL-219. The graduate research of three additional students at UNL is partly supported by INTSORMIL.

Sustainable Plant Protection Systems

INTSORMIL project KSU-211 is working on identifying the correct causal agent(s) for grain mold requires that at the least the major species being recovered be correctly identified, thus formal taxonomic descriptions of these new species needs to continue. Molecular diagnostic tools are being developed for these species, but validating them requires a sufficient sample to determine their validity. Studies of mycotoxin production under field conditions are needed, and the mycotoxigenic profiles of newly described species continue to need to be developed. As before, species identification appears to be critical in estimating the risks posed by mycotoxins, and many of the *Fusarium* species common on sorghum do not make high levels of many of the common mycotoxins (but are toxic). The KSU-211 project has identified an interspecific hybrid *Fusarium* strain that could be part of the explanation for the development of isolates that cause Pokkah boeng disease.

The Scientific Writing and *Fusarium* Laboratory workshops have become successful, visible outreach efforts and included more than one thousand participants in the 2003-2004 reporting period in Asia and Africa. A *Fusarium* Laboratory Workshop held at KSU in Manhattan had 43 participants from 17 countries in attendance. The 2004 workshop is scheduled for Pretoria, South Africa; the 2006 location will be in Bari, Italy. These workshops serve as interdisciplinary venues for scientists in developed and developing countries that work on various crops to exchange information and to interact with one another in an informal setting. Iowa State Press (now Blackwell Professional Publishing) is interested in publishing books to go with each of these courses. A contract has been signed by Brett Summerell (Australia) and the KSU-211 PI to prepare a manual to accompany the Fusarium Laboratory Workshop, and the manuscript in camera-ready form should be delivered to the publisher in the 3rd or 4th quarter of 2004.

Work with the *Fusarium* collections is progressing. A visiting scientist, Dr. Giuseppe Mulé, from Italy did collaborative research in the laboratory of the PI of KSU-211. Upon her return to Italy, Dr. Giuseppe Mulé and her colleagues have been sequencing extensively several phylogenetically informative loci from *Fusarium* strains from finger millet. The sequencing efforts have identified a large number of species, at least 20, with much higher levels of variation than is reported from crops that are more widely cultivated. It is possible that finger millet may be serving as a center of diversity for *Fusarium* pathogens of a number of crops that originated in Africa. As such, sampling this crop as it is found in fields of indigenous farmers may be of particular importance in determining the intra and inter-specific variation within these fungal pathogens. Work with the Tanzanian strain set has progressed to the point that the analysis of the identified species is essentially complete, and has led to the identification of a series of strains that represent a number of previously undescribed and uncharacterized species. Work with the strain set from Mali is continuing in collaboration with Prof. W. Marasas in South Africa. The toxicology work needs a collaborator who can test the effects of toxins in commercial animal feeds, and who can model their effects in laboratory systems by using human and animal cell lines as models.

The KSU-211 project has begun working with Dr. Ranajit Bandyopadhyay of IITA (Ibadan, Nigeria) and his network of pathology collaborators in West Africa, including Dr. Stephen Nutsugah (Ghana), Dr. Adama Neya (Burkina Faso) and Dr. Zachee Ngoko (Cameroon) to identify causal agents of grain mold and head blight in sorghum in West Africa. Dr. Bandyopadhyay also will play a role in collecting samples to be analyzed by Prof. Marasas to evaluate mycotoxin levels in maize and sorghum planted side-by-side in West Africa.

The extension of MSU-205 into Nicaragua and El Salvador during the past four years has provided this project the opportunity to investigate entomological constraints to sorghum production on large farms compared with the small field, low input, subsistence farming systems in which, MSU-205 was involved during the previous 20 years in Honduras. The economic threshold (ET) level for a fall armyworm on sorghum was confirmed to be one larva per plant on plant growth stage two (five leaves), but was determined to be too low for subsequent stage plants, thus allowing farmers greater latitude in the use of the ET concept for application of insecticide on older plants and reducing the cost to manage this pest. Research collaboration with scientists in INTA, UNA and ANPROSOR in Nicaragua and CENTA in El Salvador has proved to be extremely beneficial in developing research plans and coordinating, implementing and conducting scientific investigations in these countries. Investigations of the specific insect pest problems identified in the respective countries have yielded the basic biological information needed for developing and recommending effective insect pest management programs. Recommendations to manage the complex of lepidopterous caterpillars on intercropped sorghum and corn in Honduras, sorghum midge in Nicaragua and fall armyworm in El Salvador represent some research successes of MSU-205. Recently, the multidisciplinary (entomology and plant pathology) on-farm crop production demonstration activities in both Nicaragua and El Salvador have been effective in the development of collaboration between scientists and farmers. The transfer of new crop production technology, particularly related to the integration of insect pest and disease management programs, will be achieved using this approach to working with sorghum producers in this region of Central America. In the United States, research continues on the occurrence, behavior and management of the principal insect pests of sorghum in Mississippi. This includes fall armyworm on whorl stage plants and sorghum midge, fall armyworm, sorghum webworm and corn earworm on the panicles. Effective insecticide use practices for control of sorghum midge on sorghum panicles and redefined economic threshold levels for fall armyworm on whorl stage sorghum plants will assist farmers in decision-making regarding the application and effective use of insecticides to manage these pests.

The emphasis of project KSU-220 is on developing high-yielding sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics for use as human food and in animal feed. Recent nutritional studies indicated that certain large-seeded hybrid sorghums were equivalent in feeding value to hybrid maize and were significantly better than conventional sorghum varieties. Breeding efforts have been initiated to transfer these enhanced feed quality characteristics into high-yielding sorghum varieties adapted for production in Africa, Central America, and the United States. This will be accomplished through conventional breeding strategies and by adapting marker-assisted selection technologies, as appropriate.

Other research efforts have focused on the characterization and utilization of genes to improve resistance to grain mold and tolerance to weathering. Studies evaluating the role of known defense response pathways have shown that factors other than the activation of defense genes account for differences among sorghum genotypes with contrasting host-plant resistance characteristics. Marker-assisted selection studies indicated that a subset of grain mold resistance genes tagged in the variety SureZo are expressed across environments and in diverse genetic backgrounds. These genes represent excellent candidates for utilization in crop improvement programs via marker-assisted selection.

A training program is being developed to transfer the technology and knowledge needed to effectively utilize improved sorghum and millet cultivars for animal feeding and human food. Technical assistance and technology transfer are being pursued through interactions with Dr. Carlos Campabadahl, one of the leading nutritionists in Central America, and Mr. Salissou Isa, Head of the Animal Husbandry Unit at INRAN in Niger. These efforts include the development of training programs directed towards key poultry producers and feed millers in West Africa and Central America, including demonstration experiments and workshops.

The efforts of the investigators in KSU-220 to improve and protect sorghum grain quality include integrated research projects involving pathology, breeding, and poultry nutrition within the framework of a "mega-project" involving the four principal investigators and collaborating scientists in developing countries. Although good progress has been made to initiate interdisciplinary research projects and collaborations to address this objective, the group has not yet coalesced into a fully integrated team. Some interdisciplinary components of the project have been very effective and productive, but these synergies are less evident in other areas. In these areas, the amount of collaboration among principal investigators within this project is comparable to interactions with principal investigators of other INTSORMIL-CRSP projects. Thus, the KSU-220 team continues working toward fully integrated collaboration.

The project, PRF-213, supports research and training of scientists combating a widespread parasitic weed in Africa which can severely decrease yields of sorghum and millet. 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. The project's goal is to exploit the unique life cycle and parasitic traits of *Striga* especially the chemical signals required for germination, differentiation, and establishment.

Recent activities in screening wild sorghum accessions for their potential as sources of powerful *Striga* resistance genes for sorghum breeding have identified unique sources of *Striga* resistance in wild sorghum accessions (PQ-434). The new genes inhibit haustorial formation and disrupt parasitic association with host plants. A small collection of wild sorghums screened for potential *Striga* resistance mechanisms allowed the project to identify some unique reactions that prevent the parasitic invasion. The bioassays used were designed to take a quick look at the earliest steps in parasitic establishment. Among the germplasm studied were sorghums around which *Striga* did not germinate. Accessions were also identified that had reduced capacity to elicit haustorial induction of *Striga asiatica*. To the project scientists this is the first report of low haustorial initiation activity. Up too now, this potentially useful trait has not been found among any of the *Striga* resistant sorghums. Thus, low haustorial initiation capacity may be a good trait to transfer from wild to cultivated sorghums. None of these wild sorghum accessions has yet been field tested in *Striga* sick plots so at this point the project cannot correlate these phenomena observed in the laboratory with actual *Striga* resistance. Chemical and genetic characterization of the traits reported here for PQ-434 are currently underway.

INTSORMIL project WTU 200 has achieved significant research output in 2003-2004. The PI of INTSORMIL's project for sustainable management of insect pests (WTU-200), traveled to West and Southern Africa to review INTSORMIL activities and discuss collaborative research in entomology. Research was done as planned with scientists in Africa. An African Sorghum and Millet Entomology Workshop to discuss current and future research was held in Burkina Faso in April 2004. Resistance of sorghum lines developed by project TAM-223 and a commercial seed company were evaluated for resistance to greenbug biotypes. Fitness of greenbugs on sorghum was assessed in relation to host and soil water and nitrogen. Tritrophic effects of resistant sorghum on beneficials were assessed. Resistance of genotypes of sorghum and cowpeas was evaluated in 230,000 observations. Thesis programs of five graduate students were directed; two M.S. degree students graduated in August 2003, two will graduate in August 2004, and one Malian student learned English and began graduate studies in 2004 and an Ethiopian student will begin a Ph.D. degree in 2004. As planned, research results were presented by the PI and graduate students at entomology and other scientific meetings.

Crosses of Malisor84-7 and improved sorghums were evaluated and found resistant to panicle bugs and grain mold in Mali. Sorghum sprayed with extracts from local plants were less damaged by sorghum midge than the nontreated check in Mali. Twenty times more stalk borers infested millet in a field, especially when sorghum residue was left after harvest in Mali. More borers infested millet than maize or sorghum. Nineteen sorghums from SADC were evaluated and found susceptible to sugarcane aphids and stalk borers, but 13 were resistant to termites in Botswana. Two hundred sorghum lines were evaluated for resistance to greenbug biotypes C, E, and I, and one line developed by Pioneer Hi-Bred International, Inc. was very resistant to biotype I. Resistant sorghum did not affect the number of biotype I greenbugs consumed by convergent lady beetles but negatively affected numbers of eggs laid and hatched, especially at 30°C. Greenbug fecundity and longevity were 4.4 and 2 times less on barnyardgrass than sorghum. Soil water potential, but not nitrogen, affected greenbugs, with twice as many nymphs and 6.4 more days of life per greenbug on sorghum in soil with -33 versus -300 kPa of water. Stored grain of resistant SureZo, Sima, and Macia sorghum retained 94.6-99.2% of original weight at 105 days after infestation by maize weevils.

Utilization and Marketing

INTSORMIL project PRF-212 has made progress in better understanding the mechanism causing the comparably low starch digestibility characteristic of cooked sorghum foods. Novel web-and sheet-like protein structures that form during the cooking process were shown to directly relate to starch digestion properties. This knowledge can form the basis for manipulation of starch digestion rate either up or down to provide greater energy availability in sorghum foods or slowly digestible starch for health benefit. They now know how to improve starch digestibility in cooked sorghum foods – by using a high protein digestibility sorghum or addition of reducing compounds – and have gained knowledge on how to moderate starch digestion rate of sorghum and other starchy foods. This has important implications in areas of obesity, diabetes and pre-diabetes, and cardiovascular disease that is not only important in the U.S., but is becoming a large problem in urban areas of developing countries.

The project also made headway in finding ways to improve starch digestibility of raw sorghum grain for animal feed use. Starch granule morphologies were identified that show promise as more easily digested. In the area of sorghum porridges, starch structural properties were shown to affect storability and staling characteristics of sorghum-based foods. Such information is important in putting together a strategy to fundamentally change sorghum grain for better food and feed use.

Work continues toward commercialization of sorghum and millet products in West Africa as this effort takes on a more regional approach. The project PI will work with the team formed in the integrated, regional crop utilization project that will culminate in a proposal for funding a larger processing effort for the region.

INTSORMIL project TAM-226 continues to work on the importance of grain supply chain management in being recognized as a vital part of crop improvement programs and utilization of grains. They have publicized the need for this approach to provide for sustainable utilization of sorghum and millets in food products.

New markets for value-enhanced white food sorghums are being promoted by the U.S. Grains Council from their research on food sorghum processing and prototype products. In Japan, value-enhanced white food sorghums are processed into several commercial snack foods. Sorghum flour was demonstrated to be effective in nearly 20 traditional Japanese foods by Japanese chefs and food processors.

Several mills are producing sorghum flour for niche markets in the U.S.A. Total use is still very low but new products for celiac patients and ethnic foods exist.

In Central America, white sorghums are used in bakery products as a substitute for wheat or maize. Some vertically integrated farmers market special white sorghums as value-added baked products in local villages.

The antioxidant level in certain bran fractions of special sorghums is higher than that of blueberries. These brans and their extracts are useful as food ingredients in a number of applications. Extrusion processing of sorghum reduced the tannins into smaller polymers with improved health promoting effects.

Several parental sorghum lines released from the Texas A&M program are used in commercial hybrids grown in Mexico and United States. ATx635 hybrids have outstanding milling properties. The protein content of food sorghums is higher than that of other commercial sorghums.

A method was developed to effectively evaluate milling properties of sorghums when light colored meals were desirable.

Antifungal proteins (AFP) are related to grain mold resistance in sorghum. However, the measurement of AFP levels must be accomplished when the sorghums are exposed to molding conditions. Thus, it may be easier for breeders to evaluate mold resistance by subjective methods. The AFP levels remain high in resistant cultivars that are exposed to high levels of mold infection.

Activities in Honduras, El Salvador and Southern Africa are top priority. The hiring of Dr. Javier Bueso at EAP in Honduras was encouraging. The opportunity to develop a more comprehensive program in El Salvador and Honduras is challenging because there is a lack of effective personnel with the knowledge required to do value-added processing research. The TAM 226 PI will try to develop a relationship with Dr. Saldivar at ITESM in Mexico to help with the program in El Salvador. The chance to interact with a good cadre of Southern and East African students at University of Pretoria is a unique opportunity.

The uncertainty of funding from year to year inhibits commitments to graduate training. Inflation has eroded away much of our graduate training capabilities. The project utilizes significant research funded by other sources for the mold and breeding research support that is necessary for this project. Their ability to attract additional financial support for the work has allowed continued productivity. The funds from INTSORMIL have relatively little buying power since they have about the same number of total dollars they had 20 years ago. The addition of new PIs working on breeding and molds at TAMU will help. Also, the project on animal feeding and breeding at KSU will provide useful interaction.

Millet research has been minimized as funds from INTSORMIL decrease in actual buying power. Millet is not a crop in Texas and leveraged funds from other sources are all for sorghum research which makes it difficult to significant work on pearl millet. Overall, TAM 226 is quite productive, but cannot do everything that is required.

Biotechnology

Biotechnology encompasses a number of concepts and techniques based on recent knowledge of genetics, biochemistry, and computer science. INTSORMIL scientists employ techniques of biotechnology, such as marker-assisted selection to accelerate plant breeding and laboratory assays to accelerate selection of *Striga*-resistant germplasm. INTSORMIL scientists see biotechnology as a means, not an end. INTSORMIL's ends to which the tools of biotechnology may be applied are summarized in its four main objectives, namely 1) promote economic growth, 2) improve nutrition, 3) increase yield, and 4) improve institutional capability to do research on sorghum and millet.

Future Directions

During the past 25 years, INTSORMIL has educated more than one thousand scientists by degree programs, visiting scientist experiences, postdoctoral training, workshops, conferences, and scientific publications. About one-third of those trained are Americans and two-thirds are from developing countries. The bridges built by this training are crucial to maintain scientific and peaceful linkages between the United States and developing countries. The collaborative research supported by INTSORMIL continues to produce benefits for both developing countries and the United States. Food production, utilization and marketing in both developing countries and the United States are strengthened by INTSORMIL. The health benefits of the two nutritious cereals, sorghum and millet, are enjoyed by millions of people, since 500 million people directly consume sorghum, 300 million people directly consume pearl millet, and sorghum is a key element in the food chain of the United States, being a key feed for livestock. What, then is the future for collaborative, international sorghum and millet research supported by INTSORMIL? The future is bright.

There continues to be a need for highly qualified researchers for these two crops both in developing countries and the United States. INTSORMIL fulfills a unique role in providing postgraduate training (M.S. and Ph.D. level) to meet this need. As the demand for water in cities continues to put greater pressure on the use of water for irrigated crop production, sorghum and millet which are, for the most part, rainfed will gain increased importance in meeting the caloric needs of developing countries, particularly in the semi-arid tropics, and of the livestock feed industry in the United States. Recent INTSORMIL research on the nutritional benefits of sorghum and millet form a strong base for future research to enable the commercialization of nutritionally superior sorghum Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raising incomes. With its increasing strength of scientific expertise in developing countries, INTSORMIL is now able to more effectively reduce constraints to production and utilization of sorghum and millet to the mutual benefit of developing countries and the United States. Advances in sorghum and millet research over INTSORMIL's first 25 years and the training of sorghum and millet scientists by INTSORMIL in the United States, Africa and Central America now enable scientists from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are keys to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are 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 have a sustainable and global impact.

Future strategies of INTSORMIL will maintain INTSORMIL's current, highly productive momentum, build on its record of success, and accomplish a new set of goals. INTSORMIL's global strategy for 2001-2006 is intended to contribute to the shift of sorghum and pearl millet from subsistence crops to value-added, cash crops, and proposes to produce scientific knowledge and technologies to: contribute to economic growth, improve nutrition, increase yield, and improve institutional capability to meet global, regional and national needs.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU 210
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Summary

The origin of pathogenic *Fusarium* strains in formerly fallowed fields was examined by evaluating native grasses from the Konza Prairie, a native tallgrass prairie that has never been plowed. Fifty-three of 241 *Fusarium* isolates recovered were potential sorghum pathogens. *Fusarium proliferatum*, a common sorghum pathogen that can cause the pokkah boeng disease, was the single most common species. In general, the species found in the prairie grasses paralleled those typically recovered from the maize or from sorghum crops grown in the adjacent area. The only species that we collected that has not been typically reported from either of these two crops was *G. konza*, and the only species commonly recovered from either maize or sorghum that we did not recover from the Konza Prairie was *F. andiyazi*. Toxin production by the Konza Prairie isolates was neither qualitatively nor quantitatively different from isolates of those same species from agricultural settings. Isolates of *F. verticillioides* generally produced fumonisins, but neither beauvericin nor fusaproliferin. The isolates of *F. proliferatum* usually produced as much or more fumonisins as did the isolates of *F. verticillioides*. One of the strains identified from the Konza Prairie survey, X-10626, is of particular interest as its molecular markers are consistent with it being a hybrid between *F. fujikuroi* (usually a rice pathogen) and *F. proliferatum*. This strain could be part of a hybrid swarm between these two species that could help explain how these pathogens evolve and adapt to new agroecosystems. For example, such a hybrid could be the source of the capability of some strains of *F. proliferatum* to cause pokkah boeng disease, since *F. fujikuroi* strains are capable of producing various plant growth promoters, most notably gibberellic acid. The number, pathogenicity and relatedness of such putative hybrid swarms remain important questions for further study and analysis in terms of sustainable and durable resistance to these ubiquitous fungal pathogens.

Objectives, Production and Utilization Constraints

Objectives

- Determine the presence of viable fungi and related mycotoxins in sorghum and millet grain.
- Use genetic and molecular traits to assessing genetic variability in populations of *Fusarium* from Mali, Tanzania, India, Uganda, South Africa, and the United States.
- 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.
- Conduct Scientific Writing and *Fusarium* identification training workshops.
- Prepare text for *The* Fusarium *Laboratory Manual*.

Constraints

- 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.
- *Fusarium* spp. associated with sorghum and millet do obvious damage as stalk rot, grain mold and pokkah boeng. All of these diseases can cause intermittently heavy losses in the United States and in developing countries. Breeding for resistance to *Fusarium*-associated diseases often is limited because resistant germplasm is either unavailable or has undesirable characters from which the resistance trait must be separated. The source of the pathogens in fields that have been fallow for some time has never been clearly defined.

Research Approach and Project Output

Research Methods

Recovery and culture of *Fusarium* isolates. Several species of perennial warm-season grasses, *e.g.*, *Andropogon gerardii* Vitman, *Andropogon scoparius* Michx. and *Sorghastrum nuttans* (L.) Nash, dominate vegetation on the Konza Prairie, while sub-dominant species include a diverse mixture of other warm and cool season grasses, composites, legumes, and other forbs. In October 1997, we sampled *A. gerardii*, *S. nuttans*, and *A. scoparius* from the Konza Prairie Biological Station and LTER (Long Term Ecological Research) site. We arbitrarily selected 15 plants each of *A. gerardii* and *A. scoparius*, and 14 plants of *S. nuttans* across three different experimental watersheds of the Konza Prairie that differ in the frequency in which they are burned. Flowering tillers of each plant were cut at ground level, bagged individually, and cataloged on site. Fungal isolations were made from these materials within three days of collection.

For isolation of fungi, each plant was cut into small sections (2-5 cm length) and surface sterilized in 95% ethanol for 2 minutes. Sterilized sections were rinsed briefly in sterile H_2O, and placed on a peptone-PCNB medium semi-selective for *Fusarium* spp. Cultures were incubated under fluorescent lights at 25°C for 4-7 days to allow fungal colonies to grow out onto the media. Two to five morphologically distinct *Fusarium* colonies were isolated from each plant and then transferred to complete media (CM) slants. From these colonies, cultures were started from microconidia separated by micromanipulation, and a subculture frozen for long-term storage at -70°C in 15:85 (v:v) glycerol: water. Vegetative cultures were grown on minimal medium solidified with 2% agar in slants or Petri dishes, or as liquid cultures in 125 ml Erlenmeyer flasks. Incubations on solid media were at 25°C under a 12 h light-12 h darkness diurnal cycle. Sexual crosses were made on carrot agar with standard tester strains from the Fungal Genetics Stock Center (University of Kansas Medical School, Kansas City, Kansas) serving as the female parents. Cultures for toxin production were grown on cracked corn. Harvested corn culture material was dried in a forced draft oven at 60°C for 48 h, finely ground, and stored at 4°C until used.

We extracted soluble proteins, and used the isozyme profiles to identify putative mating populations within the *Gibberella fujikuroi* species complex. Specifically, malate dehydrogenase, isocitrate dehydrogenase, fumarase, and triose phosphate isomerase profiles were evaluated for each strain. Mating population identifications were confirmed and mating type specificity (*MAT-1* or *MAT-2*) identified in crosses in which the field isolates served as males and the standard tester strains for these mating populations as the female parents. Isolates with variant isozyme profiles were crossed with testers from the mating population or set of mating populations with profiles that most closely resembled those of the field isolates. Isolates that were cross fertile with a mating-type tester strain were tested for female fertility by using the field isolate as a female in a cross with the mating type tester as the male parent. Mating type idiomorphs of isolates that were not cross fertile with any of the tester strains for the known mating populations were identified by allele-specific PCR amplification.

AFLP analyses and comparisons. Isolates for DNA extraction were cultured by inoculating approximately 1 ml of a spore suspension (typically 10^6-10^7 conidia) into 40 ml of liquid CM. Isolates were grown on a rotary shaker (150 rpm) for 2 days at room temperature (23-26°C) and harvested by filtration through milk filters. Mycelia were blotted dry between paper towels and the dried mycelia stored at -20°C until DNA extraction. DNA was extracted with a cetyltrimethylammonium bromide (CTAB) protocol as described and AFLPs generated by standard methods. *Eco*RI primers used in the final specific PCR amplifications were labeled with ^{33}ãP-ATP.

The presence or absence of polymorphic AFLP bands ranging in size from 100-800 bp in each gel was scored manually and the data recorded in a binary format. All polymorphic markers in this size range were scored, even those that were unique to a single individual. Bands appearing at the same mobility in different individuals were assumed to represent the same allele. Each band of differing mobility was treated as a single independent locus with two alleles (present or absent), and unresolved bands or missing data were scored as ambiguous.

Initially, a single AFLP primer pair was used to group isolates that could not be identified to a specific mating population on the basis of either isozyme profile or cross fertility. Results for each group were compared to profiles from isolates of previously identified *Fusarium* species. The resulting binary data set was analyzed with the UPGMA clustering option of PAUP (v 4.10b*) to suggest possible species associations for the unidentified isolates. UPGMA similarities were calculated based on these AFLP gels. Final UPGMA genetic distances within and between sets of species were calculated with the Dice coefficient and the CLUSTER option of SAS.

Beauvericin and fusaproliferin recovery and measurement. For beauvericin and fusaproliferin extractions, 5 g of each sample were ground and homogenized at room temperature with 50 ml of methanol and clarified by centrifugation. Samples were filtered through Whatman No. 4 filter paper and 30 ml of filtrate collected (corresponding to 3 g of sample) and then evaporated at 35-40°C under reduced pressure. The raw organic extract was resuspended in 3 ml of methanol and loaded onto a C18 column. The pre-purification column was washed with 2 ml of methanol and the eluted sample dried under vacuum. Finally, the collected residue was resuspended in 1 ml of methanol and filtered through an Acrodisk filter (0.22 mm pore diameter) before injection of 20 µl into the high performance liquid chromatograph (HPLC). Fusaproliferin was detected at 261 nm and beauvericin at 205 nm. Mycotoxins were identified by comparing retention times and UV spectra of samples with those of authentic standards and quantified by comparing peak areas from samples with a calibration curve of standards. The recovery efficiency of this extraction method was 94% and 71% for beauvericin and fusaproliferin, respectively. The detection limit was 100 ng/g for beauvericin and 25 ng/g for fusaproliferin. All analyses were run in triplicate.

Recovery and measurement of fumonisins. A 5-g sample of each fungal culture was ground and added to 50 ml of a 75:25 methanol:water solution. The samples were homogenized and then clarified by centrifugation. Thirty ml of the supernatant (corresponding to 3 g of sample) were evaporated at 35/40°C under reduced pressure, and the residue resuspended in 5 ml of methanol and dried in a centrifugal evaporator at 35-40°C. The recovery efficiency of this extraction method was 90% and 68% for FB_1 and FB_2, respectively. Fumonisins were detected by liquid chromatography-mass spectrometry (LC-MS) with resolution of 0.5 amu. The detection limit for the fumonisin standards, determined by using the protonated signal at m/z 722, was equivalent to 0.5 ng/g and the limit of quantification was equivalent to 1.2 ng/g. Measurements were made in quadruplicate within an experiment, and the data are based on the average of two experiments.

Brine shrimp assays. Toxicity to brine shrimp (*Artemia salina*) larvae was determined by exposing larvae to fungal culture extracts in 24-well cell culture plates [30 to 40 larvae per well in 500 ml of 3.3% (wt/vol) marine salt in H_2O]. The number of dead larvae was recorded after incubation at 27°C for 24 hr. The total number of larvae in each cell was counted after killing the surviving larvae by freezing at -20°C for 12 hr. Water-soluble extracts, containing fumonisins, in general had little or no toxicity towards the brine shrimp larvae. Tests in each experimental run were performed in quadruplicate. Data are based on the averages of two independent experiments. We examined correlations between toxin production by individual *Fusarium* species and mortality to *A. salina* by comparing observed toxin concentrations (ppm) to percent mortality observed with the CORR procedure of SAS.

Research Findings

Experimental rationale. *Fusarium* species are important pathogens of sorghum and millets, where they usually persist as endophytes until the end of the season when they can become serious pests causing stalk rot, head blight and grain mold. Even when these crops are planted into areas where they have not previously been cultivated, these fungi can appear on crops almost immediately. One possibility is that the pathogens are being brought in on seed and farming implements, and the other is that the pathogens are present, perhaps as pathogens or symbionts, of the native grasses in fields that have been fallowed or never planted.

We tested these hypotheses by analyzing strains from the Konza Prairie Biological Station, just south of Manhattan. The Konza Prairie is one of the largest remaining contiguous pieces of tallgrass prairie remaining in North America. This area has been grazed but has never been tilled. The present study had two objectives: (i) to determine the species composition and genetic diversity of isolates from the *Gibberella fujikuroi* species complex found on the Konza Prairie, and (ii) to examine the types and quantity of secondary metabolites produced by strains recovered from non-agricultural hosts. There has been considerable study of *Fusarium* species diversity and toxin production among isolates collected from major grain crops such as rice, maize, or sorghum. However, this study represents the first population-level characterization of a non-agricultural, grasslands *Fusarium* community to determine whether such a community differs qualitatively or quantitatively from populations associated with the agricultural crops to which these fungi are economically important pathogens on a worldwide basis.

Survey results. We examined 72 isolates that produced microconidia from a total of 241 *Fusarium* isolates recovered. Of the 52 grass stems sampled, 45 produced at least one isolate that made microconidia and that grouped morphologically within *Fusarium* sections *Liseola* or *Elegans*. More than one species from the *Gibberella fujikuroi* species complex was recovered from 16/45 plants, and members of more than two species from the *Gibberella fujikuroi* species complex were recovered from 5/45 plants indicating that multiple infections of native grasses with more than one species of *Fusarium* is common. Of the 72 *Fusarium* isolates examined, 12 belonged to *F. verticillioides*, one to *F. thapsinun*, three to *F. subglutinans*, nine to *F. konzum*, 40 to either *F. fujikuroi* or *F. proliferatum*, and seven could not be assigned readily to any of the described species in the *Gibberella fujikuroi* species complex. Isolates were characterized (Table 1) with isozymes, AFLP fingerprint profile, sexual cross-fertility, and mating type. Collectively, these characterizations did not always yield the same answer.

Table 1. Species identification for and secondary metabolite production by strains of the *Gibberella fujikuroi* species complex recovered from grasses growing on the Konza Prairie.

KSU no.	ITEM no.	Plant Host[a]	Isozyme Pattern[b]	AFLP Pattern[b]	Mating Type	FB_1 (µg/g)	FB_2 (µg/g)	FUP (µg/g)	BEA (µg/g)	% *A. salina* Mortality
A-10548	3117	*Ag*	*Fv*	*Fv*	*MAT-2*	590	420	n.d.	n.d.	93
A-10560	3122	*Ag*	*Fv*	*Fv*	*MAT-2*	1200	710	n.d.	9	97
A-10568	3126	*Ag*	*Fv*	*Fv*	*MAT-2*	760	780	n.d.	n.d.	97
A-10577	3131	*Ag*	*Fv*	*Fv*	*MAT-2*	750	670	n.d.	n.d.	68
A-10584	3136	*Ag*	*Fv*	*Fv*	*MAT-1*[c]	1000	700	n.d.	n.d.	39
A-10594	3140	*Ag*	*Fv*	*Fv*	*MAT-2*[c]	110	130	n.d.	n.d.	78
A-10605	3147	*As*	*Fv*	*Fv*	*MAT-1*	280	64	n.d.	4	100
A-10621	3152	*As*	*Fv*	*Fv*	*MAT-1*[c]	480	150	n.d.	2	100
A-10631	3158	*As*	*Fv*	*Fv*	*MAT-1*[c]	890	200	n.d.	5	48
A-10636	3161	*As*	*Fv*	*Fv*	*MAT-2*	280	97	n.d.	n.d.	100
A-10685	3181	*Sn*	*Fv*	*Fv*	*MAT-2*[c]	500	130	n.d.	n.d.	76
A-10691	3184	*Sn*	*Fv*	*Fv*	*MAT-1*	18	4	n.d.	n.d.	100
X-10626	3155	*As*	*Ff*	*Ff*-var	*MAT-1*	900	170	n.d.	180	71
X-10677	3178	*Sn*	*Fp*-var	*Ff*-var	*MAT-1*	n.d.	n.d.	n.d.	30	11
D-08384	3110	*Sn*	*Fp*	*Fp*	*MAT-1*	430	350	840	310	100
D-08387	3111	*Sn*	*Fp*	*Fp*	*MAT-2*	37	36	49	110	97
D-08392	3112	*Sn*	*Fp*	*Fp*	*MAT-1*	780	360	540	230	100
D-08403	3114	*Sn*	*Fp*	*Fp*	*MAT-1*	3600	4200	590	170	100
D-08411	3108	*Ag*	*Fp*	*Fp*	*MAT-2*	400	110	560	120	48
D-08420	3109	*Ag*	*Fp*	*Fp*	*MAT-1*	500	570	830	180	100
D-10550	3118	*Ag*	*Fp*	*Fp*	*MAT-1*	160	230	2000	450	100
D-10552	3120	*Ag*	*Fp*	*Fp*	*MAT-1*	6300	4000	260	n.d.	100
D-10557	3121	*Ag*	*Fp*	*Fp*	*MAT-2*	640	210	500	210	99
D-10563	3124	*Ag*	*Fp*	*Fp*	*MAT-1*	1300	530	490	430	100
D-10565	3125	*Ag*	*Fp*	*Fp*	*MAT-1*	610	700	150	830	100
D-10580	3133	*Ag*	*Fp*	*Fp*	*MAT-1*	280	78	390	310	100
D-10582	3134	*Ag*	*Fp*	*Fp*	*MAT-2*	620	760	550	1400	100
D-10583	3135	*Ag*	*Fp*	*Fp*	*MAT-1*	1200	830	200	1200	100
D-10587	3137	*Ag*	*Fp*	*Fp*	*MAT-1*[c]	1500	840	110	450	100
D-10590	3138	*Ag*	*Fp*	*Fp*	*MAT-2*	250	120	270	530	100
D-10591	3139	*Ag*	*Fp*	*Fp*	*MAT-2*[c]	1000	620	570	580	100
D-10599	3145	*As*	*Fp*	*Fp*	*MAT-1*	1400	360	200	1300	100
D-10609	3148	*As*	*Fp*	*Fp*	*MAT-2*[c]	1100	370	430	66	72
D-10614	3149	*As*	*Fp*	*Fp*	*MAT-2*[c]	1300	170	510	660	100
D-10616	3150	*As*	*Fp*	*Fp*	*MAT-2*[c]	3	1	200	7	28
D-10617	3151	*As*	*Fp*	*Fp*	*MAT-2*	710	190	280	1000	100
D-10625	3154	*As*	*Fp*	*Fp*	*MAT-2*	450	93	180	700	100
D-10627	3156	*As*	*Fp*	*Fp*	*MAT-1*	150	29	n.d.	66	12
D-10630	3157	*As*	*Fp*	*Fp*	*MAT-2*	520	120	51	12	3
D-10647	3165	*As*	*Fp*	*Fp*	*MAT-2*[d]	210	67	320	570	100
D-10649	3166	*Sn*	*Fp*	*Fp*	*MAT-1*	240	74	210	1200	100
D-10657	3170	*Sn*	*Fp*	*Fp*	*MAT-2*[d]	86	27	130	140	26
D-10659	3171	*Sn*	*Fp*	*Fp*	*MAT-1*[c]	n.d.	n.d.	86	270	77
D-10668	3174	*Sn*	*Ff*/*Gi*	*Fp*	*MAT-2*	810	230	560	780	100
D-10670	3175	*Sn*	*Fp*	*Fp*	*MAT-1*	170	29	170	350	89
D-10675	3176	*Sn*	*Fp*	*Fp*	*MAT-2*	340	51	630	820	100
D-10694	3185	*Sn*	*Fp*	*Fp*	*MAT-1*	860	58	45	4	35
D-08374	3107	*Ag*	*Fp* -var	*Fp*	*MAT-2*	1500	1000	450	480	100
D-10544	3115	*Ag*	*Fp* -var	*Fp*	*MAT-1*	10	23	n.d.	n.d.	5
D-10545	3116	*Ag*	*Fp* -var	*Fp*	*MAT-1*	60	820	150	n.d.	3
D-10571	3127	*Ag*	*Fp* -var	*Fp*	*MAT-2*	1500	360	200	1000	99
D-10572	3128	*Ag*	*Fp* -var	*Fp*	*MAT-2*	1700	1400	32	170	92
E-10562	3123	*Ag*	*Fs*	*Fs*	*MAT-2*[c]	trace	n.d.	300	n.d.	98

Table 1. Cont'd - Species identification for and secondary metabolite production by strains of the *Gibberella fujikuroi* species complex recovered from grasses growing on the Konza Prairie.

KSU no.	ITEM no.	Plant Host[a]	Isozyme Pattern[b]	AFLP Pattern[b]	Mating Type	FB_1 (μg/g)	FB_2 (μg/g)	FUP (μg/g)	BEA (μg/g)	% *A. salina* Mortality
E-10646	3164	*As*	*Fs*	*Fs*	*MAT-1*	n.d.	n.d.	190	5	24
E-10688	3182	*Sn*	*Fs*	*Fs*	*MAT-1*	n.d.	n.d.	1300	10	100
F-10597	3142	*Ag*	*Ft*	*Ft*	*MAT-1*	6	9	n.d.	n.d.	6
I-08373	3106	*Ag*	*Fs*-var	*Fk*	*MAT-1*	10	12	540	120	79
I-10595	3141	*Ag*	*Fs*-var	*Fk*	*MAT-2*	17	12	210	160	80
I-10638	3162	*As*	U	*Fk*	*MAT-2*	120	24	ND	5	2
I-10653	3168	*Sn*	*Fs*-var	*Fk*	*MAT-1*[c]	n.d.	n.d.	250	91	28
I-10663	3173	*Sn*	*Fs*	*Fk*	*MAT-1*	n.d.	n.d.	310	4	17
I-10676	3177	*Sn*	*Fs*	*Fk*	*MAT-1*	n.d.	n.d.	210	230	80
I-10678	3179	*Sn*	*Fs*-var	*Fk*	*MAT-2*	n.d.	n.d.	50	59	32
I-10689	3183	*Sn*	*Fs*	*Fk*	*MAT-2*	ND	ND	140	89	43
I-10681	3180	*Sn*	U	*Fk*	*MAT-2*	ND	ND	78	320	78
I-10578	3132	*Ag*	*Fs*-var	*Fk*-like	*MAT-2*[d]	trace	trace	160	650	99
X-10622	3153	*As*	U	Type-α	ND	18	5	ND	80	100
X-10635	3160	*As*	U	Type-α	ND	ND	ND	ND	32	100
X-10661	3172	*Sn*	U	Type-α	ND	ND	ND	ND	190	57
X-10576	3130	*Ag*	*Fv*	Type-β	ND	9	12	ND	ND	0
X-10634	3159	*As*	*Fv*	Type-β	ND	ND	ND	ND	10	1
X-10551	3119	*Ag*	U	Type-γ	*MAT-1*[d]	13	13	ND	32	13

ND – not detected.
[a]Species abbreviations: *Ag – Andropogon gerardii*, *As – Andropogon scoparius*, and *Sn - Scoparius nuttans*
[b]Species abbreviations: *Ff – F. fujikuroi*, *Fk – F. konzum*, *Fp – F.proliferatum*, *Fs – F. subglutinans*, *Ft – F. thapsinum*, *Fv – F. verticillioides*, and U – unique. Patterns that are substantially the same as one species but differ at one or a few bands (usually new) are designated as "var" for variant. Strains with a "var" designation need not have the same banding pattern.
[c]Female fertile.
[d]Mating type determined via mating-type allele specific PCR.

At least 53 of the 72 isolates are potentially pathogenic to sorghum, which is consistent with the hypothesis that native grasslands can serve as refuges for *Fusarium* strains pathogenic on agriculturally important crops. The three isolates of *F. subglutinans* are unlikely to be sorghum pathogens, and the pathogenic potential of the remaining 16 isolates of *F. konzum* and unidentified *Fusarium* spp. towards sorghum is unknown. In general, the range of species found in the prairie grasses paralleled that recovered from the maize or from sorghum crops grown in the adjacent area. The only species that collected that had not been typically reported from either of these two crops is *G. konza*, and the only species commonly recovered from either maize or sorghum that we did not recover from the Konza Prairie was *F. andiyazi*. The *Fusarium* species most commonly reported from maize and from sorghum are *F. verticillioides* and *F. thapsinum*, respectively. Although both *F. verticillioides* and *F. thapsinum* were present on the Konza Prairie, 17% and 2% of the isolates, respectively, neither was found at the high levels (often > 70%) frequencies at which they can be recovered from agricultural fields of maize or sorghum. *F. proliferatum* often is viewed as a "generalist", as it has been recovered from a broad range of agricultural hosts, including asparagus, banana, maize, mangos, millet, pine, rice, sorghum, and tobacco. When *F. proliferatum* is recovered it often is relatively infrequent (5-15% of the total population), especially in the Great Plains region in the United States. This species also is not considered generally to show any significant host preference or specialization, although in commercial sorghum in Egypt, *F. proliferatum* often is the most commonly recovered fungus. The dominance of *F. proliferatum* on the Konza Prairie is consistent with a hypothesis in which a generalist species is expected to be at an advantage in a native ecosystem, even if this species can survive and persist in a more specialized agricultural ecosystem.

Mycotoxin production and toxicity to *Artemia salina*. Toxin production by the Konza Prairie isolates was neither qualitatively, nor quantitatively different from isolates of those same species drawn from agricultural settings. Isolates of *F. verticillioides* generally produced fumonisins, but neither beauvericin nor fusaproliferin. In general the isolates of *F. proliferatum* produced as much or more fumonisins as did the isolates of *F. verticillioides*. Six of the isolates of *F. proliferatum* produced > 2000 μg/g total fumonisins, including D-08403 which produces ~8000 µg/g total fumonisins and D-10552 which produces > 10,000 µg/g, and is one of the highest producers of these toxins ever reported.

In general, the toxicity, *i.e.*, LD_{50}, of strains from species in the *G. fujikuroi* species complex to *A. salina* is correlated with the concentrations of beauvericin and/or fusaproliferin in the corresponding organic extracts. For the isolates of *F. proliferatum* examined, toxicity was positively correlated with both fusaproliferin ($p = 0.02$) and beauvericin ($p < 0.001$), but was not correlated with fumonisin production. The toxin production pattern by *F. proliferatum* strain D-08411 suggests that additional toxigenic compounds are synthesized by this species and remain to be identified.

Evolution of new pathogenic species. One way of creating new pathogens is analogous to the manner in which new traits are imported into agricultural crops, *i.e.,* through wide crosses with related species. We found evidence that such wide crosses may be occurring under natural conditions on the Konza Prairie. Native areas are a more likely place for such wide crosses to occur as they usually contain more species than those found in a comparable agroecosystem. Selection pressure in a native system, which has more and usually fragmented ecological niches, often is different from that in an agroecosystem, which usually is relatively uniform and may contain only a single ecological niche, making it more likely for the progeny of a wide cross to be able to survive and become a significant component of the native system.

One of the strains identified from the Konza Prairie survey, X-10626, is of particular interest as its molecular markers are consistent with it being a hybrid between *F. fujikuroi* (usually a rice pathogen) and *F. proliferatum.* Such a hybrid could be the origin of the capability of some strains of *F. proliferatum* to cause pokkah boeng disease, since *F. fujikuroi* strains are capable of producing various plant growth promoters, most notably gibberellic acid. Genes for the production of the plant growth promoters could be transferred between species in such a cross.

Results of interspecific *Fusarium* crosses. Thirty-two progeny were collected from a cross between X-10626 and FGSC 7614 (*F. proliferatum* standard) and scored for 70 segregating AFLP markers. Approximately 19% of the AFLP markers did not segregate in a 1:1 manner, and the mean frequency of the allele derived from the *F. proliferatum* parent amongst the progeny was 54%. Eighteen progeny were collected from the cross between X-10626 and FGSC 8932 (*F. fujikuroi* standard) and scored for 24 segregating AFLP markers. Approximately 17% of the AFLP markers were not segregating in a 1:1 manner, and the mean frequency of the allele derived from the *F. fujikuroi* parent amongst the progeny was 56%. A cross also was made between the *F. fujikuroi* and *F. proliferatum* tester strains. Forty-seven progeny were collected from this interspecific cross and scored for 80 segregating AFLP markers. Approximately 66% of the AFLP markers were not segregating in a 1:1 manner, and the mean frequency of the allele derived from the *F. proliferatum* parent amongst the progeny was 61%. Only ~75% of the progeny of this cross were fertile in a backcross to the standard *F. proliferatum* tester strains.

The existence of X-10626 under field conditions suggests that crosses between isolates of different *Fusarium* species can occur in nature and are not just laboratory artifacts. If the proportion of loci at which segregation is not 1:1 is used as a measure of the genetic distance between the parental strains, then the testers for *F. fujikuroi* and *F. proliferatum*, in whose intercross approximately two thirds of the loci do not segregate 1:1, are more distant from each other than either of these testers is from KSU X-10626, for which < 20% of the loci are not segregating in a 1:1 manner. One interpretation of these results is that the standard testers for *F. fujikuroi* and *F. proliferatum* represent distinct species, but that one, or more, hybrid swarms, perhaps separated geographically or specialized to a particular host, exist between these species. As *F. fujikuroi* normally is associated with rice and is easily confused with *F. proliferatum* on the basis of morphology, the hybrid nature of many field strains might easily be missed unless relatively extensive crossing and/or molecular analyses were conducted. Indeed the entity currently identified as *F. proliferatum*, which is known to have a broad host range and geographic distribution, could be a series of hybrid swarms that share taxonomically important morphological characters. The number, pathogenicity and relatedness of such putative hybrid swarms remain important questions for further study and analysis.

Networking Activities

Editorial and Committee Service (2003)

- Editor of *Applied and Environmental Microbiology*
- Member of the International Society for Plant Pathology

Fusarium Committee

- Senior Fulbright Scholar Review Panel (U.S. – Australia – New Zealand)

Research Investigator Exchanges

Dr. Leslie made the following international scientific exchange visits (2003):

Australia – January 20 – February 1
Malaysia – February 1-4
South Korea – February 4-9
Nigeria – April 25 – May 4
Egypt – September 12-18
Italy – September 18-26
Nigeria/Burkina Faso/Ghana – October 9-25
South Africa – October 31 – November 21

Seminar, Workshop & Invited Meeting Presentations (2003)

Organized in *Fusarium* Laboratory Workshop at KSU – Manhattan from June 22-27; 43 participants and five instructors from 17 countries.

Editor for Proceedings of Sorghum/Millet pathology conference in Guanjuato, Mexico.

9th International Fusarium Workshop, Sydney, Australia.
School of Biological Sciences, Science University of Malaysia, Penang, Malaysia.

School of Agricultural Biotechnology, Seoul National Univ., Suwon, South Korea.

Department of Plant Pathology, University of California-Davis – 02/03.

22nd Fungal Genetics Conference, Asilomar, California – 03/03.

International Institute for Tropical Agriculture, Ibadan, Nigeria – 04/03.

Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt.

Institute of the Science of Food Production, CNR, Bari, Italy.

FABI, University of Pretoria, Pretoria, South Africa.
Institute of Wine Biotechnology, Stellenbosch University, Stellenbosch, South Africa.

Workshop on Technologies to Produce Mycotoxin-Free Agricultural Commodities in Developing Countries, St. Louis, Missouri.

During 2003 Fusarium *cultures were provided to:*

Dr. Ranajit Bandyopadhyay, IITA, Ibadan, Nigeria
Drs. Robert L. Bowden, Larry E. Claflin, & Mitch Tuinstra, Kansas State University, Manhattan, Kansas.
Dr. Elhamy M. El-Assiuty, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt.
Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, Kansas.
Dr. D. Geiser, Department of Plant Pathology, Pennsylvania State University, University Park, Pennsylvania.
Prof. Dr. Laszlo Hornok, Agricultural Biotechnology Center, Institute for Plant Sciences, Godollo, Hungary.
Prof. Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea.
Dr. Antonio Logrieco, Istituto Tossine e Micotossine da Parassiti Vegetali, Bari, Italy.
Prof. Dr. W. F. O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa.
Dr. J. Scott Smith, Department of Animal Sciences & Industry, Kansas State University, Manhattan, Kansas.
Dr. Brett Summerell, Royal Botanic Gardens-Sydney, Sydney, Australia.
Dr. Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.
Drs. Mike Wingfield & Brenda Wingfield, Forestry & Agricultural Biotechnology Institute, University of Pretoria, Pretoria, South Africa.
Dr. Baharuddin bin Salleh, School of Biological Sciences, Science University of Malaysia, Penang, Malaysia.
Dr. Kerry O'Donnell, National Center for Agricultural Utilization Research, USDA-ARS, Peoria, Illinois.

Other collaborating scientists (Host country)

Dr. Sofia Chulze, Department of Microbiology, National University of Rio Cuarto, Rio Cuarto, Argentina.
Drs. M. Flieger & S. Pazoutova, Institute of Microbiology, Czech Academy of Sciences, Prague, Czech Republic
Dr. Laszlo Hornok, Agricultural Biotechnology Center, Godollo, Hungary
Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea
Drs. Antonio Logrieco, Antonio Moretti & Giuseppe Mulé, Institute of the Science of Food Production, CNR, Bari, Italy
Dr. Anaclet S. B. Mansuetus, Department of Biological Sciences, University of Swaziland, Kwaluseni, Swaziland
Dr. Neal McLaren, Agricultural Research Council, Potchefstroom, South Africa
Prof. Baharuddin Salleh, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia
Dr. Brett A. Summerell, Royal Botanic Gardens, Sydney, Australia
Drs. Michael and Brenda Wingfield, FABI, University of Pretoria, Pretoria, South Africa

Other collaborating scientists (U.S.)

Dr. G. N. Odvody, Texas Agricultural Experiment Station, Corpus Christi, Texas

Publications and Presentations

Journal Articles.

Saleh, A. A., K. A. Zeller, E. M. El-Assiuty, A.-S. M. Ismael, Z. M. Fahmy & J. F. Leslie. 2003. Amplified fragment length polymorphism (AFLP) diversity in *Cephalosporium maydis* from Egypt. *Phytopathology* **93:** 853-859.
Seifert, K. A., T. Aoki, R. P. Baayen, D. Brayford, L. W. Burgess, S. Chulze, W. Gams, D. Geiser, J. de Gruyter, J. F. Leslie, A. Logrieco, W. F. O. Marasas, H. I. Nirenberg, K.

O'Donnell, J. P. Rheeder, G. J. Samuels, B. A. Summerell, U. Thrane & C. Waalwijk. 2003. The name *Fusarium moniliforme* should no longer be used. *Mycological Research* **107:** 643-644.

Summerell, B. A., B. Salleh & J. F. Leslie. 2003. A utilitarian approach to *Fusarium* identification. *Plant Disease* **87:** 117-128.

Wu, X., J. F. Leslie, R. A. Thakur & J. S. Smith. 2003. Preparation of a fusaproliferin standard from the culture of *Fusarium subglutinans* E-1583 by high performance liquid chromatography. *Journal of Food and Agricultural Chemistry* **51:** 383-388.

Zeller, K. A., R. L. Bowden & J. F. Leslie. 2003. Diversity of epidemic populations of *Gibberella zeae* from small quadrats in Kansas and North Dakota. *Phytopathology* **93:** 874-880.

Zeller, K. A., B. A. Summerell, S. Bullock & J. F. Leslie. 2003. *Gibberella konza* (*Fusarium konzum*) sp. nov., a new biological species within the *Gibberella fujikuroi* species complex from prairie grass. *Mycologia* **95:** 943-954.

Abstracts

Bowden, R. L., J. E. Jurgenson, J.-K. Lee, Y.-W. Lee, S. H. Yun, K. A. Zeller, & J. F. Leslie. 2003. A second generation genetic map of *Gibberella zeae*. *Fungal Genetics Newsletter* **50**(Suppl.): 102.

Cumagun, C. J. R., R. L. Bowden, J. E. Jurgenson, J. F. Leslie & T. Miedaner. 2003. Mapping of quantitative trait loci associated with pathogenicity and aggressiveness of *Gibberella zeae* (*Fusarium graminearum*) causing head blight of wheat. *Phytopathology* **93**:S19.

Jeon, J.-J., H. Kim, H.-S. Kim, K. A. Zeller, T. Lee, S.-H. Yun, R. L. Bowden, J. F. Leslie & Y.-W. Lee. 2003. Genetic diversity of *Fusarium graminearum* from maize in Korea. *Fungal Genetics Newsletter* **50**(Suppl.): 142.

Saleh, A. A. & J. F. Leslie. 2003. Molecular phylogenetic analysis indicates *Cephalosporium maydis* is a distinct taxon in the *Gaeumannomyces-Phialophora* species complex. *Fungal Genetics Newsletter* **50**(Suppl.): 142.

Saleh, A. A. & J. F. Leslie. 2003. Biological species in the *Gibberella fujikuroi* species complex (*Fusarium* section *Liseola*) recovered from maize and sorghum in Egypt. *Fungal Genetics Newsletter* **50**(Suppl.): 142.

Zeller, K. A. & J. F. Leslie. 2003. When species concepts collide. *Phytopathology* **93**:S93.

Zeller, K. A., J. I. Vargas, G. Valdovinos-Ponce, J. F. Leslie & R. L. Bowden. 2003. Population genetic differentiation and lineage composition among *Gibberella zeae* in North and South America. *Fungal Genetics Newsletter* **50**(Suppl.): 143.

Zeller, K. A., M. A. Wohler, L. V. Gunn, S. Bullock, B. A. Summerell & J. F. Leslie. 2003. Interfertility and marker segregation in hybrid crosses of *Gibberella fujikuroi* and *Gibberella intermedia*. *Fungal Genetics Newsletter* **50**(Suppl.): 144.

Agroecology and Biotechnology of Fungal Pathogens of Sorghum and Millet

Project KSU 211
Larry E. Claflin
Kansas State University

Principal Investigator

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Dr. John Leslie, Dept. of Plant Pathology, Kansas State University, Manhattan, KS 66506
Dr. Stephen Mason, Dept. of Agronomy, University of Nebraska, Lincoln 68583-0915
Mr. Henry Nzioki, National Dryland Farming Research Center-Katumani, P. O. Box 340, Machakos, Kenya
Ing. Sergio Pichardo, UNA, Apartado Postal 453, Managua, Nicaragua (Now a graduate student in entomology & plant pathology, Mississippi State University)
Dr. Henry Pitre, Mississippi State University, Mississippi State, MS 39762
M.C. Jesus Narro Sanchez, INIFAP, Apdo. Postal 112., C.P. 38010, Celaya, Guanajuato, Mexico
Dr. Mitch Tuinstra, Department of Agronomy, Kansas State University, Manhattan, KS 66506

Objectives, Production and Utilization Constraints

Objectives

- U.S./Mexico/Nicaragua/El Salvador: Determine the prokaryotic plant pathogenic organisms responsible for unique and unusual diseases of sorghum that may pose yield constraints. These causal agents are primarily insect disseminated and a joint collaborative project was established with MSU-205.
- U.S./Mexico/Nicaragua/El Salvador: Ascertain disease incidence through surveys coupled with utilization of the ADIN nursery from Texas A & M University at various locations. Genetic variability of accessions within the ADIN will be determined if disease severity occurs.
- U.S./Nicaragua: Determine the number of races/pathotypes of *Colletotrichum graminicola*: (*C. sublineolum* and *C. falcatum*) that occur in Nicaragua with DNA fingerprinting techniques. This is a portion of the Ph.D. thesis project of Sergio Pichardo at Mississippi State University.
- U.S./El Salvador: Continue to evaluate germplasm for genetic variability to rust and evaluate fungicides for control of various sorghum diseases.
- U.S./Central America/Africa: Develop a rapid and reliable protocol to detect Claviceps africana (causal agent of ergot) spores and hyphal propagules in sorghum seed and feed grains.
- U.S./Africa: Continue to evaluate germplasm and screening protocols for ascertaining genetic germplasm tolerant/ resistant to Fusarium stalkrot.

Constraints

Grain sorghum received limited attention in Central America in previous years, as corn was the crop favored by commercial and subsistent growers. A 10-fold increase in less than 10 years in the poultry industry has provided an impetus for sorghum production. Sorghum diseases were poorly characterized and the incidence and severity were unknown. Surveys were conducted and the use of genotypes in the ADIN has shed valuable information on sorghum diseases in El Salvador and Nicaragua. Interestingly, the major diseases, anthracnose and gray leaf spot are of the highest incidence with one or the other predominating in a particular year. For example, anthracnose was predominant in 2002 and gray leaf spot in 2001.

Anthracnose is a significant constraint to yields of grain sorghum in numerous LDC's. The disease may be partially controlled by chemicals but they are either unavailable or the cost may be prohibitive for farmers. Incorporation of resistant or tolerant germplasm into acceptable cultivars would partially alleviate losses due to anthracnose. The correct species identification of the causal agent of anthracnose remains in flux.

Fusarium stalk rot is one of the most prevalent diseases of sorghum wherever the crop is grown. The causal organism is found in living plant tissues, crop debris, and soils in different geographical regions. At least 12 different *Fusarium* species have been reported as pathogens of sorghum although for nearly 100 years, *F. moniliforme* was widely reported as the specific epithet. *F. moniliforme* consists of numerous species, strains, and isolates that are important pathogens on a wide range of economically important plants. Recently, this fungal complex was classified into eight mating populations and a large number of asexual phylogenetic species. Reducing losses due to stalk rot have been through breeding efforts to develop resistant cultivars. The complex nature of the disease coupled with the environment and lack of reliable inoculation protocols that mimic natural infection have limited the potential for screening large numbers of genotypes. Previously, *Fusarium* sp. infested toothpicks were inserted in the basal stalk to evaluated limited numbers of genotypes.

A need exists for a rapid and reliable diagnostic procedure to detect *Claviceps africana* in sorghum seeds and feed grains due to strict and rigid quarantine regulations of numerous countries. A PCR-fingerprint of this fungus was evaluated for use in detecting spores and hyphal fragments in sorghum seeds.

Networking Activities

Research Investigator Exchanges

L. E. Claflin traveled to Leon (Celaya) Mexico September 16-19, 2004 to evaluate sorghum germplasm at the INIFAP station with Jesus Narro. Considerable time was devoted to bacterial disease diagnosis and detection. The Baheel area of Mexico is often plagued with bacterial streak disease. Several compendia, specialty chemicals and antisera (for bacterial disease diagnoses) were given to Mr. Narro.

L. E. Claflin surveyed sorghum fields and discussed mutual research in El Salvador and Nicaragua from November 15 - 22.

L. E. Claflin visited Mississippi State University July 8 - 10 to assist in planning the Ph.D. program for Sergio Pichardo.

L. E. Claflin was granted an adjunct Professorship and appointed to the graduate faculty in the Department of Entomology and Plant Pathology at Mississippi State University for the purpose of serving on the committee of Sergio Pichardo.

L. E. Claflin attended the 50th annual PCCMCA meeting (4/18 - 4/23) in El Salvador and discussed future research projects with collaborators in El Salvador and Nicaragua. Cooperative on-farm projects in Nicaragua were finalized with Octavio Menocal (INTA).

Research Information Exchange

The All Disease and Insect Nursery (ADIN) was planted in three locations in El Salvador including an area in Northern El Salvador that has incurred losses due to white flies. This is the first report of white flies colonizing sorghum. Three locations were also planted in Nicaragua including an area plagued with downy mildew to determine disease incidence and severity and possibly, determine the pathotype.

Numerous extension publications, compendia, and textbooks were furnished to Reina Guzman and Ing. Sergio Pichardo. In addition, specialty equipment and supplies were purchased with funds from KSU-211 and distributed to the laboratories.

Publications and Presentations

de Serrano, R. S., Claflin, L. E., Jaco, M. P., and A. Moran. 2004. Evauacion del Dano Ocasionado por Roya (*Puccinia* sp) en sorgos comerciales y criollos en El Salvador. LaCalera 3:23-27.

de Serrano, Morales, C. A. B., and L. E. Claflin. 2004. Evaluacion de tolerancia a enfermedades e insectos en viveros ADIN (All Disease and Insect Nursery) en El Salvador. PCCMCA 218 (abstract).

Melara, C. B., de Serrano, R. F., and L. E. Claflin. 2004. Respuesta de variedades criolla & jejoaradas de sorgo (Sorghum bicolor) a la aplicacion de fungicidas 2003. PCCMCA:219 (abstract).

Gao, Z., Jayaraj, J., Muthukrishnan, S., Claflin, L. E., and G. H. Liang. 2004. Efficient genetic transformation of sorghum using a visual screening marker. Genome (accepted)

Ramundo, B. A., and L. E. Claflin. 2004. Identification of *Burkholderia andropogonis* with a Repetitive Sequence BOX element and PCR. Current Microbiology (In Press).

Tesso, T. T., Tuinstra, M. R., and L. E. Claflin. 2004. Analysis of stalk rot resistance and genetic diversity among drought tolerant sorghum genotypes. Crop Science (in press).

Tesso, T. T., Tuinstra, M. R., and L. E. Claflin. 2004. Estimation of combining ability for resistance to Fusarium stalk rot in grain sorghum. Crop Science 44:1195-1199.

Zhou, B., Ardales, E., Brasset, E., Claflin, L. E., Leach, J. E., and S. H. Hulbert. 2004. The Rxo1/Rba1 locus of maize controls resistance reaction to pathogenic and non-host bacteria. Theor Appl Genet (In Press).

Presentations

Nicaragua (12/1/02-12/4/02). Delivered supplies and evaluated ADIN nurseries for disease incidence and severity as part of the INTSORMIL program.

El Salvador (12/4/02-12/8/02). Delivered equipment, books, supplies, evaluated ADIN nurseries, and research plots under the auspices of INTSORMIL.

Miscellaneous Publications

Claflin, L. E. 2003. Agroecology and biotechnology of fungal pathogens of sorghum and millet. Pp. 9-13 in INTSORMIL Ann. Repts., A Technical Res. Rept. of the Grain Sorghum/ Pearl Millet Collaborative Res. Support Prog. (CRSP), University of Nebraska, Lincoln.

Enhancing the Utilization of Grain Sorghum and Pearl Millet through the Improvement of Grain Quality via Genetic and Nutrition Research

Project KSU 220

Mitchell Tuinstra and Joe Hancock, Kansas State University
William Rooney and Clint Magill, Texas A&M University

Principle Investigators

Dr. Mitch Tuinstra, Kansas State University, Dept. of Agronomy, Manhattan, KS 66506
Dr. Joe Hancock, Kansas State University, Dept. of Animal Sciences and Industry, Manhattan, KS 66506
Dr. William Rooney, Texas A&M University, Dept. of Soil & Crop Sciences, College Station, TX 77843
Dr. Clint Magill, Texas A&M University, Dept. of Plant Pathology & Molecular Biology, College Station, TX 77843

Collaborating Scientists

Dr. Carlos Campabadahl, Centro de Investigaciones en Nutricion Animal, Universidad de Costa Rica, San Jose, Costa Rica
Dr. Medson Chisi, Private Bag 7, Mt. Makulu Research Station, Chilanga, Zambia
Ing. René Clará, Centro Nacional de Technologia, Agricola de El Salvador, San Salvador, El Salvador
Dr. Salissou Issa, INRAN Rainfed Crops Program, INRAN, BP 429, Niamey, Niger
Dr. Issoufou Kapran, INRAN Rainfed Crops Program, INRAN, BP 429, Niamey, Niger
Dr. Chris Little, Dept. of Biology, UT-Pan American University, Edinburgh, TX 78541
Dr. Paul Marley, Natl Ag Res Project Office, Inst Ag Research, Ahmadu Bello Univ, PMB 1044, Samaru, Zaria, Nigeria
Dr. Paco Sereme, Director General, INERA, 01 B.P. 476, Ouagadougou, Burkina Faso
Dr. Aboubacar Touré, IER/Sotuba Research Station, BP 262, Bamako Mali
Dr. Eva Weltzien Rattunde, ICRISAT, P.B. 320 Bamako, Mali
Mr. Adama Neya, INERA, Station de Farako-Ba, BP 910, Bobo Dioulolasso, Burkina Faso
Mamourou Diourte, IER/Sotuba Research Station, BP 262, Bamako, Mali

Summary

The marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value compared to other cereals. This research project attempts to address this weakness through plant breeding to develop elite varieties and hybrids with improved nutritional and grain quality traits and through development and transfer of animal feed and production technologies to developing countries. Breeding efforts continue with the exchange and testing of new germplasm and improved varieties through collaboration of scientists around the world. Animal feed workshops and seminars as well as poultry feeding demonstrations are being conducted with collaborators in numerous countries in Africa and Central America.

The major emphasis of this project is to develop sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics. Large-seeded sorghum genotypes with enhanced feed-value and grain-quality characteristics have been identified and these genes are being incorporated into improved genetic backgrounds for deployment in regions of Africa, Central America, and the United States. We also are cooperating with TAM 224 to determine if high protein digestibility and grain mold resistance can be combined. Currently, small populations have been developed to test this relationship and we have begun to create larger populations in order to completely characterize this relationship.

Natural tolerance to heat and drought permit sorghum to be grown in areas unsuited for production of other cereal crops. Past breeding efforts have significantly enhanced yield potential in semi-arid regions of the world, but little attention has been focused on feed value and grain quality in these production environments. Tan-plant sorghum hybrids with improved drought tolerance are being developed to address this problem. In the United States, food-grade hybrids are now commercially available in all maturity groups. These hybrids are high yielding and well adapted to dryland and limited-irrigation environments.

Our training program focuses on the transfer of technology and knowledge to allow development and utilization of improved sorghum and pearl millet cultivars for animal feeding and human food. A key component of technical assistance and technology transfer in Central America is the RAPCO Short Course for animal nutrition. This week-long short courses in

animal feeding and nutrition is held each year and includes participants from Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, the Dominican Republic, Columbia, Venezuela, Peru, and Ecuador. Additionally, for the 2003-2004 budget year, short courses were held in Managua and San Salvador from January 11-17, 2004. These short courses were designed specifically to address issues (real and perceived) that limit the expanded use of sorghum as a feedstuff for poultry farming in Nicaragua and El Salvador. Technology transfer efforts in West Africa were initiated in 2003 through interaction with Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in NIGER. Farm visits were accomplished in the Niamey area during August of 2003 and animal feeding trials (accomplished in Niger) were evaluated during a second visit to Niger in April of 2004. Additional feeding trials are currently being conducted in Niamey to demonstrate the relative feed value of local and improved sorghum varieties in comparison to traditional corn-based feed rations.

In addition to providing new cultivars and the technology to utilize them effectively, graduate students and visiting scientists with interest in crop improvement, crop utilization, and molecular biology are being hosted for short-term and graduate training at Kansas State University and Texas A&M University. Student projects are strongly multidisciplinary and provide opportunities for collaboration with investigators from different departments and universities. The focus of this training is to enhance the human and institutional capacity of research institutions in developing countries.

Objectives, Production and Utilization Constraints.

Objectives

Research

- Identify and map genes related to grain quality, including but not limited to grain mold resistance, seed size, protein content, anthracnose resistance, and grain quality parameters per se. Strategies will be developed to use these tools and this information to improve the efficiency of crop improvement efforts.

Germplasm Development

- High-yielding, locally-adapted sorghum varieties and hybrids with improved grain quality, grain mold resistance, and resistance to other disease (such as anthracnose) will be developed using conventional breeding techniques and marker-assisted selection strategies.

Training and Institutional Development

- Short-term and graduate education programs will be conducted to train U.S. and international scientists in plant breeding and genetics as well as animal nutrition.
- Technical assistance will be provided to promote the use of improved sorghum and millet grains in poultry feeding in the developing regions of West and Southern Africa and Central America.

Constraints

Poultry and egg production is increasing in many developing countries as economies grow and demand for higher-protein diets increase. This change in diet provides an opportunity for farmers to market grain as a cash crop to feed millers instead of the traditional view of cereal grains as a subsistence crop for human consumption. The grain of choice in poultry feed in many countries is corn. This decision makes sense when local and inexpensive stockpiles are available for use in feed manufacturing. However, many sorghum-producing countries are using more expensive, imported corn in formulating poultry rations. This decision is often based on the belief that sorghum and millet are not suitable for poultry production even though considerable information is available showing good feed-value of sorghum and millet. Furthermore, it is known that variety selection and adoption of appropriate milling technologies can enhance the value of sorghum so that it is nearly equal to the feed value of corn.

Genetic resources to enhance grain quality and host-plant resistance have been identified for use in crop improvement but the inheritance of these traits is complex and screening under field conditions is environmentally dependent and often unreliable. Genes for improved grain quality and host-plant resistance can be identified and cloned to facilitate crop improvement. Breeding projects to assemble these genes into improved cultivars should proceed rapidly with the aid of marker-assisted selection complemented by performance tests made in multiple environments.

Research and technology transfer efforts are needed to address food quality and feed efficiency traits in sorghum and millet. Our research efforts will address this weakness in sorghum and millet through the integration of laboratory assays for feeding quality, traditional plant breeding, and biotechnology to develop elite hybrids and cultivars with improved nutritional and grain quality traits. Technology transfer efforts are underway to train and inform poultry producers, nutritionists, and feed mill operators as to the feed value of sorghum and millet and the best-management practices required to maximize the profitability and efficiency of poultry production in developing countries. The recognition of the true nutritional value of grain sorghum by animal producers will lead to greater health and productivity in livestock and humans in regions of the world where hunger and poverty are commonplace.

Research Approach and Project Output

The KSU 220 research project is multidisciplinary in nature. Principle investigators at Texas A&M University and Kansas State University coordinate this research project. These institutions are located in two of the largest sorghum producing states in the United States. Research efforts involve interdisciplinary collaborations on each campus as well as regional collaboration among institutions. Research efforts at Kansas State University focus heavily on development of sorghum varieties and hybrids with improved agronomic performance and nutritional value and technology transfer efforts to improve the utilization of sorghum and millet in poultry rations. Research at Texas A&M University focuses heavily on development of sorghum varieties and hybrids with improved grain mold and weathering resistance for use as human food and animal feed.

Our crop improvement efforts in the United States are focused on the development of improved parent lines for hybrid seed production. This involves both applied plant breeding activities as well as germplasm characterization and enhancement for improved agronomic performance and enhanced food and feed value. These research activities are coordinated through extensive nursery and field-testing programs in Texas and Kansas. The programs in each state use a rich and diverse pool of sorghum and millet germplasm assembled from crop improvement programs in the United States and internationally. Crosses and populations derived from elite lines or germplasm sources are evaluated in multi-location nurseries and regional yield trials. Crop improvement efforts to develop cultivars adapted to environments in West and Southern Africa and Central America utilize elite varieties and cultivars that are adapted to each of the regions. The lines used to create these populations are selected through evaluations of elite U.S. and host country germplasm in the target region. This material is evaluated in the target region in conference with collaborating plant breeders. Improvement efforts in Western and Southern Africa focus on the development of early-maturing, drought-tolerant cultivars and hybrids while efforts in Central America are on improved food-type and Macio Criollos cultivars. These efforts are focused on the development of photoperiod sensitive hybrids using Ma5 and Ma6.

More basic research efforts are focused on the identification and utilization of genes that contribute to improved grain quality. Combining various grain quality attributes into one genotype is a challenge that could be facilitated by the use of molecular technology. Results from these studies will provide a better understanding of the genetic control of important quality traits and will provide genetic markers that can be used by sorghum improvement programs in the near future. One aspect of this research focuses on disease resistance (R) genes isolated from a variety of plant species to identify similar genes in sorghum. Many of these genes are likely to control variation in host-plant resistance to important sorghum diseases. Development of these technologies should enhance the efficiency of combining grain quality factors including feed quality characteristics and grain mold resistance into varieties with high yield potential. Mapping populations are being developed and characterized in cooperation with collaborators at domestic and international sites. These populations are being genotyped in laboratories in the U.S. using various types of genetic markers.

Collaborative research efforts in Africa and Central America are supported through short and long-term training programs, germplasm exchange and evaluation, and complementary basic research support activities. These research efforts are conducted in three regional programs including West Africa, Southern Africa, and Central America. Current training activities include graduate student education, information exchange workshops and meetings, short-term training visits to the United States for collaborating researchers, and workshop activities in animal production and nutrition. Technical assistance and technology transfer efforts in poultry production and nutrition are currently focused on workshop and short course activities. In 2003 and 2004, Dr. Hancock contributed to the RAPCO Short Course, a weeklong short course in animal nutrition. The participants included industry leaders in animal feeding/nutrition with representatives from Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, the Dominican Republic, Columbia, Venezuela, Peru, and Ecuador. Additionally, Dr. Hancock collaborated with Dr. Lloyd Rooney and René Clará to present short courses in Managua and San Salvador from January 11-17, 2004. Those short courses were designed specifically to address issues (real and perceived) about expanding the use of sorghum as a feedstuff for poultry farming in Nicaragua and El Salvador. Technology transfer efforts in West Africa were initiated in 2003 through collaborative interaction with Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in NIGER. Farm visits were accomplished in the Niamey area during August of 2003 and animal feeding trials (accomplished in Niger) were given "on-site" evaluation in April of 2004. Additional feeding trials are currently being conducted near Niamey to demonstrate the relative feed value of local and improved sorghum varieties in comparison to corn-based feed rations. Finally, plans are being made to expand these technical assistance activities to key poultry producers and feed millers as in Southern Africa and West Africa this fall and/or next spring in collaboration with John Taylor and Salissou Issa, respectively.

Research Findings

Grain Mold Resistance

This focus of this research is to develop a better understanding of the genetic control of disease resistance, particularly grain mold, in sorghum. One aspect of this research focuses on disease resistance (R) genes isolated from a variety of plant species to identify similar genes in sorghum. The great majority of known R-genes possess a putative nucleotide-binding site (NBS), a domain that spans approximately 300 amino acids at the N-terminus end of the encoded protein. All NBSs are composed of distinctive, highly conserved, short amino-acid motifs. Two approaches were used to identify analogs of known resistance genes (RGAs) present in the sorghum genome. One strategy focused on the development and use of degenerate primers matching conserved regions (P-loop and GLPL region) of NBS genes was to amplify sorghum genomic DNA via the polymerase chain reaction (PCR). Any bands of the appropriate size were cloned and sequenced for comparison to known resistance gene NBS sequences. In a different approach, the NBS sequences from 18 previously cloned R-genes were used to search for sequence homology among all available sorghum DNA sequences using the programs BLAST or "TBLASTN". The NBS sequences from 18 cloned disease-resistance genes (6-Arabidopsis, 3-flax, 3-tomato, 1-potato, 3-rice, 1-maize, 1-barley) were used to search for homology with all available sorghum DNA and protein sequences. Each sorghum sequence in the NCBI GenBank and TIGR databases was examined for homology to each NBS. Likewise, all the sequences in a large set of expressed sequence tags (sequences derived from mRNA present in control or treated tissues) available from the University of Georgia were compared to each NBS sequence. More that 80 resistance gene analogs have been identified and cloned based on database searches of sorghum expressed sequence tags and by PCR amplification using primers derived from motifs conserved in resistance genes cloned from other species (Table 1). All of the matching EST clones and PCR-generated fragments have been used as probes versus the sorghum-mapping parents (BTx623 X IS3620C) to identify restriction endonucleases that generate polymorphisms. Those with clear-cut banding patterns will be used to locate the position of the RGA on the sorghum map. Forty-two restriction fragment length polymorphism markers have been placed on the sorghum genetic map to date. Because resistance genes are often clustered in plant genomes, the ability to identify prospective R-genes may greatly speed the search for gene tags for use in marker assisted selection, one of the goals of this INTSORMIL project. Based on reports from other species, it is likely that at least a portion of the RGAs will be genes that confer disease resistance to fungal, bacterial, and viral pathogens and even to insects.

Table 1. Source and number of sorghum resistance gene analogs identified based on homology to nucleotide binding site (NBS) sequences.

Database	Tissue source	Library code	Number of clones
Sorghum EST	Pathogen-induced:incompatible	PI	14
	Pathogen-induced:compatible	PIC	12
	Immature pannicles	IP	9
	Light-grown seedlings	LG	7
	Heat-shocked seedlings	HS	3
	Dark-grown seedlings	DG1	2
	Embryos	EM	2
	Iron-deficient seedlings	FE	2
	Oxidatively-stressed leaves and roots	OX	2
	Drought-stressed	WS	2
	Drought-stressed after flowering	DSAF	1
	Drought-stressed before flowering	DSBF	1
	Ethlene-treated seedlings	ETH	1
	Ovaries	OV1 2	1
	Phosphorus-deficient seedlings	PH	1
	Acid- and alkaline-treated roots	RHOH	1
	Abscisic acid-treated seedlings	ABA1	0
	Callus culture/cell suspension	CCC1	0
	Nitrogen-deficient seedlings	NIT1	0
	Pollen	POL1	0
	Salicylic acid-treated seedlings	SA1	0
	Salt stressed seedlings	SS1	0
	Wounded leaves	WOUND 1	0
Sorghum Genomic Sequences	GSS (Genome Survey Sequences)		43
	NR (Non-redundant)		14

Primers and probes for quantification of chalcone synthase and chitinase mRNA have also been developed and are being used to compare responses to inoculation with spores of *F. thapsinum* and *C. lunata*. Four inbred cultivars, RTx2911, Sureño, SC170 and RTx430, that range from highly resistant to susceptible are being evaluated for differences in reaction. The real-time PCR protocol is sensitive enough for use on specific floral tissues, so will permit testing the hypothesis that differences in resistance result from differential levels or timing of expression of these defense-response genes.

Applied plant breeding efforts to enhance grain mold resistance focused on five breeding populations that were created by crossing elite U.S. sorghum parental lines (RTx430, RTx436, BTx631, BTx635, and Tx2903) with 'Sureño', a dual-purpose grain mold resistant sorghum cultivar. Molecular markers associated with five previously reported quantitative trait loci (QTL) for grain mold resistance originating in 'Sureño' were used to determine if their presence enhanced selection for grain mold resistance in these populations. The allelic status of 87 F4 lines, with respect to these QTL, was determined using both simple sequence repeats (SSR) and amplified fragment length polymorphism (AFLP) markers. All 87 F4:5 lines and their parental lines were evaluated for grain mold resistance in replicated trials in eight diverse environments in south and central Texas during the summer of 2002. The effects of each allele from the grain mold resistant parent 'Sureño' were determined across and within all five populations, within individual environments, and in each population x environment combination. With a few exceptions, the QTL were effective in reducing grain mold susceptibility only within the RTx430/Sureño progeny. These studies indicate that while these alleles do confer additional grain mold resistance, they are only selectable in the original mapping population. This fact limits their potential usefulness in an applied breeding program.

Anthracnose Resistance

Breeding for stable host plant resistance to anthracnose has been difficult because of the variable nature of the pathogen and an incomplete understanding of host/pathogen interaction. To develop new lines with possibly more durable forms of resistance, different sources of genetic resistance must be identified and characterized. The objectives of this study were (1) to determine if different sources with anthracnose resistance possess different genes for resistance, (2) to determine the inheritance of anthracnose resistance in the groups identified in objective 1, and (3) to identify which sources provide resistance across environments. Populations created from hybridizing resistant by resistant lines were evaluated to determine if segregation for resistance occurred within a family. The presence of segregation (susceptible plants) within a population indicated that the parents have different resistance genes. In the eleven germplasms evaluated, six different sources of resistance were identified. Segregation ratios in resistant × susceptible F2 populations were consistent with the expectations of simply inherited traits and resistance was dominant in some lines and recessive in others. Evaluation of the sources of resistance across environment indicated that one source, SC748-5, provided resistance in all evaluation environments. Efforts are currently underway to map the resistance in SC748-5.

Breeding for Improved Feed- and Food-grade Characteristics in Sorghum

Genetic sources that contribute to improved seed size have been publicly released and currently are being used in crop improvement to increase seed size and yield potential. Recent genetic studies indicated that these seed characteristics appear to be beneficial to sorghum-based poultry diets, resulting in increased animal performance that was comparable to that of birds fed maize-based diets. Although these large seeded sorghum hybrids produce grain with enhanced nutritional value, genetic improvement in grain mold resistance and agronomic adaptation are still needed. Five inbred lines with improved seed size and acceptable grain mold resistance characteristics were identified in 2004 (Table 2). These lines combine large seed size with improved agronomic characteristics. Early generation materials also are being evaluated and several F4 lines were identified that integrate large seed with improved grain mold resistance. Three large mapping populations currently are being developed to determine the genetic bases for variation in seed size. We also are cooperating with TAM224 to determine if high protein digestibility and grain mold resistance can be combined. Several small populations have been developed to test this relationship and we have begun to create larger populations in order to completely characterize this relationship.

Table 2. Sorghum lines with improved seed size and agronomic characteristics.

Entry	Plant color	Grain color	Seed weight *g seed^{-1}*
KS115 – Large-seeded Check	Purple	Yellow	0.055
02MN5035T	Tan	Yellow	0.054
02MN5035P	Purple	Yellow	0.054
02MN5398	Tan	Yellow	0.044
02MN5453	Tan	Yellow	0.043
Tx430 – U.S. Check	Purple	Yellow	0.027
90SN7 – Niger Check	Tan	White	0.033

Crop improvement efforts to further improve the yield potential and grain quality of tan-plant sorghum hybrids are continuing. Elite tan-plant parent lines and hybrids are evaluated across the Central Great Plains to determine specific zones of adaptation and grain quality attributes. The regional tan-plant hybrid test has been conducted in Texas, Kansas, and Nebraska during the past three years. The number of commercial entries continues to rise and hybrids are now available in all maturity groups. Several full-season, tan-plant hybrids have been identified with high yield potential and acceptable grain quality in limited irrigation environments. Certain regions of Texas, especially the Winter Garden and High Plains areas, are optimally suited for production of food-grade hybrids. Many of these hybrids also are adapted to areas of Kansas and Nebraska, where small premiums have been received for the improved grain quality. Of the 40 entries in the 2003 test, most were experimental hybrids from private and public sorghum breeding programs. The majority of the entries were white-grain, tan-plant hybrids, but two red-grain, tan-plant hybrids also were included. A comparison of entries indicated that tan-plant hybrids tended to be later in maturity but similar in yield and plant height (Table 3). Several full-season, tan-plant hybrids were identified that combined high yield potential and good grain quality; however, only a few early- and mid-season tan-plant hybrids were identified with similar characteristics (Table 4). Our crop improvement efforts will continue to be focused on development of early- and medium-maturity hybrids. The grain quality of most tan-plant hybrids was good and could be used in processing for food, animal feed, or industrial applications. Several of the experimental hybrids evaluated in 2003 had lower grain quality, but these entries will not be commercially released. Red-grain, tan-plant hybrids will continue to be emphasized because of improved grain weathering resistance in these materials.

Sorghum hybrids with waxy endosperm (either homozygous or heterozygous waxy) generally have better processing and/or nutritional value but lower grain yield potential compared to non-waxy endosperm hybrids. The cause of this yield reduction is not known. From a genetic perspective, the yield reduction could be caused by pleiotrophy or genetic linkage between the *wx* locus and other loci that influence grain yield. The specific cause of this relationship is important because an effective breeding program can alleviate the problem if it is because of linkage. The objective of this study was to determine whether linkage or pleiotrophy is causing the negative relationship between grain yield and waxy endosperm. From each of two F_2 breeding populations segregating for waxy endosperm, between 40 and 50 inbred lines were derived, with equal numbers of waxy and non-waxy endosperm lines. No selection for yield was practiced during the development of these lines. The lines from these two populations and a set of testcross hybrids (derived from one population) were evaluated in four environments in Texas from 1998 to 2000. Across all tests and environments, the combined yield of the waxy genotypes was 17% lower than non-waxy genotypes. While yields were lower in waxy genotypes, analysis of the individual in-

Table 3. Comparison of tan-plant and pigmented-plant hybrids in the 2003 regional tan-plant sorghum trials in Texas.

Location	Hybrid type	Plant color	Plant height *inch*	Panicle exsertion *inch*	Anthesis *days*	Desirability rating *1 to 10*	Grain yield *lbs/acre*
College Station	Conventional	Purple	52	3	74	5.1	5,036
	Food-type	Tan	52	2	77	4.7	4,622
	LSD (P<0.05)		ns	ns	***	ns	ns
Gregory	Conventional	Purple	48	5	69	4.5	3,279
	Food-type	Tan	45	4	73	4.8	2,303
	LSD (P<0.05)		ns	ns	***	ns	*
Hondo	Conventional	Purple	55	4	67	4.3	5,868
	Food-type	Tan	52	4	70	3.9	5,275
	LSD (P<0.05)		ns	ns	***	*	ns
Halfway	Conventional	Purple	46	3	73	4.3	7,024
	Food-type	Tan	47	4	74	3.6	6,643
	LSD (P<0.05)		*	ns	*	**	ns
Perryton	Conventional	Purple	53	4	78	4.5	7,123
	Food-type	Tan	53	5	79	3.9	7,073
	LSD (P<0.05)		ns	*	**	**	ns
Combined	Conventional	Purple	51	4	72	4.5	5,666
	Food-type	Tan	50	4	75	4.2	5,183
	LSD (P<0.05)		*	ns	***	**	ns

Table 4. Agronomic characteristics and average grain yields of hybrids evaluated in the regional tan-plant sorghum trials in Kansas in 2002-2003.

Hybrid Entry	Plant color	Maturity class	Harvey County	Republic County	Thomas County	Finney County	Average
			---------------	bu/acre	---------------		bu/acre
MMR Genetics Jowar 1	Tan	Full	51	168	176	116	128
Tx2752*Tx2783	Purple	Full	54	155	193	104	127
Tx635*Tx436	Tan	Full	47	175	185	98	126
Warner 902W	Tan	Full	47	172	172	111	126
NC+ 7W92	Tan	Full	47	169	162	107	121
Wheatland*Tx430	Purple	Medium	56	135	176	115	121
Tx631*Tx436	Tan	Full	51	163	169	98	120
Tx631*Tx437	Tan	Medium	48	166	165	89	117
Sorghum Partn. NK8828	Tan	Full	40	152	169	104	116
Dekalb DKS44-41	Tan	Early	48	160	158	96	116
TxArg1*Tx436	Tan	Full	33	146	143	115	109
Tx623*Tx430	Purple	Medium	42	146	166	83	109
Asgrow Eclipse	Tan	Early	47	134	155	90	107
Sorghum Partn. 1486	Tan	Full	39	93	135	88	89

bred lines and hybrids revealed that several waxy inbred lines were not statistically different from the best non-waxy inbreds. These results imply that selection of high yielding waxy genotypes is possible, but a significant breeding emphasis on their development is required to effectively identify those genotypes.

Sorghum germplasm characterization efforts also continue in an effort to identify new germplasm sources to enhance the elite sorghum germplasm pool. In cooperation with Drs. Medson Chisi and Neal McClaren, sorghum cultivars and breeding lines from Southern African are being used as pollinators to create a set of hybrids to determine the level of heterosis present in this germplasm. This trial was conducted in Zambia during 2003-04 and it currently is under evaluation in Texas.

Networking Activities

Workshops and Meetings

Dr. Mitch Tuinstra participated in the KSU Fall Cereal Conference, Manhattan, KS, July 31, 2003.

Dr. Joe Hancock lectured about feedstuffs and feed manufacturing to nutritionists, veterinarians, and feed manufacturers (30 to 35 people representing 12 to 14 Central/South American and Caribbean countries) at the week-long RAPCO (Cursos Regionales en Produccion Animal) Short Course in Atenas, Costa Rica, August, 2003.

Dr. Mitch Tuinstra participated in the INTSORMIL Regional Program Review, West Africa (Niger and Mali), Oct 10-18, 2003.

Drs. Tuinstra and Rooney participated in the American Seed Trade Association Meetings, Chicago, IL, Dec 10 – 12, 2003.

Drs. Tuinstra and Rooney participated in the ARS Sorghum Germplasm Committee, Chicago, IL, Dec 10, 2003.

Dr. Mitch Tuinstra participated in the Plant and Animal Genome Meeting, San Diego, CA, January 11-14, 2004.

Dr. Joe Hancock gave lectures to research scientists from INTA/CINA and academics from the University of Nicaragua (total of 45 people) to share sorghum grain data from his lab concerning the effects of particle size, extrusion, expansion, UPC, steam flaking, white seed/tan plant, kernel hardness and size, waxy endosperm, ergot, tannins, distillers grains, etc., in diets for poultry and swine, Managua, Nicaragua, January 12, 2004.

Dr. Joe Hancock collaborated with Dr. Lloyd Rooney and Ing. René Clará to present a seminar on myths about sorghum feeding value, processing properties, chemical composition, and tannins to 35 members of the El Salvador Poultry Producers Association in San Salvador, January 14, 2004.

Drs. Tuinstra, Hancock, and Magill participated in the West Africa Regional Planning Meeting, Ouagadougou, Burkina Faso, April 18-21, 2004.

Dr. Mitch Tuinstra participated in the Annual INTSORMIL Technical Committee Meeting, Kansas City, MO, May 6-7, 2004.

Research Investigator Exchanges

Dr. Joe Hancock traveled to Niger to evaluate research facilities and develop plans for poultry feeding studies in August of 2003.

Dr. D. Booyens, Pannar Seed Company, South Africa was hosted for a two day visit to Kansas State University.

Dr. Darrell Rosenow was hosted at KSU to evaluate cooperative nursery plots and review research activities, Aug 28, 2003.

Rooney traveled to El Salvador and Nicaragua in November to plan activities and evaluate germplasm in cooperative trials with Ing. René Clará and Rafael Obando.

Dr. William Rooney traveled to Zambia and South Africa to participate in the External Review of the Southern Africa program in March 2004.

Dr. William Rooney traveled to El Salvador in April 2004 to participate in the PCCMCA meeting and to make selections in breeding populations being grown in Santa Cruz Porilla, El Salvador.

Dr. Farid Waliyah, ICRISAT, was hosted for a visit to KSU to discuss potential for collaborative research activities regarding mycotoxins in feed rations, particularly for poultry, in West Africa.

Dr. Joe Hancock traveled to Niger to set up poultry feeding demonstrations in April of 2004.

Germplasm and Research Information Exchange

Coordinated the 2003 Tan Plant Hybrid Trial. This trial is designed to evaluate commercially available tan plant (improved grain quality) sorghum hybrids for agronomic adaptation and grain quality parameters. The test included 40 hybrids from nine companies that were grown in 11 locations across Kansas and Texas. Included in this trial were breeding lines from TAM220, TAM222, and TAM223.

Distributed germplasm from KSU220A for evaluation in Niger, Burkina Faso, Ghana, Mali, and Senegal.

Distributed germplasm from TAM220C for evaluation in Central America and Southern Africa.

Planted, evaluated, and increased seed for potential germplasm releases for TAM222.

Publications and Presentations

Journal Articles

Little CR, and C Magill. 2004. Elicitation of defense response genes in sorghum floral tissues infected by Fusarium thapsinum and Curvularia lunata at anthesis. Phys Mol Plant

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Ahmed Sabry. 2003. QTL mapping of resistance to Sorghum Downy Mildew in Maize. Ph.D. Dissertation Texas A&M University, College Station, TX.

Aparna Viswinathan. 2003. Phylogenetic analysis of Sclerospora graminicola using internal transcribed spacer region-2. M.S. Thesis. Texas A&M University, College Station, TX.

Travis D. Kriegshauser. 2003. Genetic analysis of large-seeded sorghum hybrids with increased grain-fill duration and effects of increased seed size on feed quality. M.S. Thesis. Kansas State University, Manhattan, KS.

Michael J. Stamm. 2003. Effects of a genetically longer grain fill duration on seed weight and composition of grain sorghum. M.S. Thesis. Kansas State University, Manhattan, KS.

Abstracts

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White PM Jr, Rice CW, and Tuinstra MR. 2003. Potential for enhanced soil carbon sequestration using lodging-resistant grain sorghum varieties. ASA-CSSA-SSSA Conf. Denver, CO, Nov. 10-12.

Pandravada A, Tuinstra MR, St Amand PC, Mullet JE, and Klein PE. 2003. A genetic map of sorghum based on 567 AFLP and SSR markers. ASA-CSSA-SSSA Conf. Denver, CO, Nov. 10-12.

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Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU 205
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Summary

Research activities in MSU 205 during the past few years has concentrated on principal insect pest problems on sorghum grown on relatively large commercial farms on the Pacific coastal plains of Nicaragua and El Salvador. These activities differed somewhat from MSU 205 research conducted in Honduras during the previous 20 years in that in Honduras almost all of the entomological research was conducted on insect situations on intercropped sorghum and corn grown on very small subsistence farms on the hillsides and on the coastal plains. Low input, inexpensive insect pest management technology was the emphasis on the subsistence farms in Honduras, whereas the commercial operations in Nicaragua and El Salvador can involve a much higher level of insect pest management technology with greater costs to the farmer. Collaborative research activities with the Instituto Nicaraguense de Technologia (INTA) the Universidad Nacional Agraria (UNA), the Nicaraguan National Sorghum Producers Association (ANPROSOR) in Nicaragua, and the Centro de Technologia de Agricola (CENTA) and the University of El Salvador in El Salvador have included investigations on insect biology, behavior, ecology and population dynamics of the sorghum midge, stalk borers and fall armyworm, the principal insect pests on sorghum in this region of Central America. With the first outbreak of whiteflies on sorghum, corn and rice in El Salvador in 2003, this pest problem was given considerable attention by entomologists at the University of El Salvador. Information from the basic investigations on the insect pests in used in developing cultural, biological and chemical control tactics for implementation in insect pest management systems for the specific pests or complex of pests. Research has been published in scientific journals and popular articles have been published for farmer utilization in the application of sorghum midge pest management in Nicaragua and fall armyworm management in El Salvador. Workshops and seminars have been organized and presented to emphasize integrated insect and disease management in sorghum. Complementary research on insect pest behavior and management, and damage to sorghum by specific insect pests is in progress in the United States for improving sorghum midge, stalk borer and fall armyworm pest management strategies. The collaborative research activities among INTSORMIL and research and farmer organizations have been fruitful in developing greater research capacity and furthering institution building activities in this ecogeographic zone. Graduate student education and professional workshops have increased agricultural capabilities of professionals in this region of Central America. The MSU 205 principal investigator will continue to support graduate student education to conduct sorghum research in Central America and the United States, to collaborate with scientists in governmental organizations and agricultural universities, and to work with non-governmental organizations to

develop improved insect pest management and integrated crop management practices for sorghum production.

Objectives, Production and Utilization Constraints

Nicaragua

- Collaboration among INTA and UNA scientists to investigate on-farm cultural and non-chemical methods for management of insect pests and plant diseases on sorghum.
- MSU 205 PI to meet with Central America collaborator scientists and NGO personnel in INTA, UNA and ANPROSOR to develop collaborative sorghum production research plans for 2003.
- Conduct IPM workshops for agricultural professionals and local sorghum producers.

El Salvador

- Evaluate the efficacy of insecticide programs on sorghum varieties for control of stem borers.
- Evaluate the efficacy of insecticide programs on sorghum varieties for control of sorghum webworm.
- Establish research relationships with entomologist at the University of El Salvador to collaboratively investigate the serious whitefly problem encountered in El Salvador in 2003.

United States

- Continue experiments to refine the economic thresholds for fall armyworm on sorghum.
- Investigate the influence of sorghum-soybean rotational cropping systems on insect pest occurrence and population densities, and damage to the crops. Work collaboratively with plant pathologist in describing these relationships for plant diseases on both crops.
- Complete research and academic programs for MSU 205 Ph.D. student.

Research Approach and Project Output

Nicaragua

Investigations were conducted on commercial farms at 2 locations (Chanandega and Tisma) in Nicaragua where replicated sorghum plots were planted to examine the effects of chemical (diazinon spray), non-chemical (Neem spray and the fungus biological agent *Beauveria bassiana*), and a cultural planting system (pigeon pea barrier) on the incidence and severity of insect pests and diseases. The MSU 205 PI traveled to Nicaragua in November 2003 with Dr. Larry Claflin, plant pathologist, INTSORMIL KSU 211, to observe progress in the on-farm research and demonstration interdisciplinary IPM program. Plots were maintained and sampled by the investigators during the period from August through December. The insect pests included in a sampling program were fall armyworm, *Mocis* (a looper), sorghum midge and leaf-footed bug. Natural enemies, plant diseases, plant damage, and yield were recorded. The results obtained for cumulative fall armyworm and *Mocis* infestations during the different plant growth stages indicated that there were no differences in numbers of larvae in the different treatments. No other insect pests infested the crop in damaging levels. Treatment plots were too small and Neem and *B. bassiana* were not effective on sorghum midge, and the pigeon pea barrier planting was not used in these small plots in a manner that might be practical in having any influence on insects that fly some distances. Plant diseases were investigated in this interdisciplinary on-farm investigation and are reported by the collaborating plant pathologists. These investigations (on-farm demonstrations) are important in the effective transfer of improved crop production technology. The on-farm IPM demonstrations will be conducted again in 2004 with modifications in methodology to improve scientific design of the work plan.

Two professional and farmer educational workshops emphasizing sorghum production problems were conducted in two regions in Nicaragua with contributions from scientists and administrators at UNA, INTA and ANPROSOR. Participants participated in the exchange of information and particularly by identifying and discussing specific agronomic, insect, and disease problems encountered in crop production situations. Particular attention was given to insect and disease identification, crop fertilization, weed control, alternative pest control methods, aflatoxins, post harvest technology and technical training assistance. Technical training workshops are planned and will be conducted in Nicaragua in 2004 and in the future.

A plant pathologist (M.S. degree) with UNA began his PhD program in MSU 205 in the Entomology and Plant Pathology Department at Mississippi State University in August 2003.

El Salvador

Entomological research in CENTA consisted of investigations to apply insect pest control tactics on sorghum for management of stalk borers in stalks and sorghum webworm on panicles in intercropped sorghum and corn in two locations in El Salvador. Insecticide applications were made on two sorghum hybrids at appropriate times to control the larvae of these insect pests. Similar results were obtained for each pest in that the control tactics had little influence on crop yield, primarily because the insect infestations were too low to obtain significant damage to the crops. However, sorghum was infested with fewer stalk borer larvae than corn in this intercropped system, suggesting that stalk borers may not reduce yield of sorghum when sorghum is intercropped with corn. The application of insecticide may have significantly influenced the stalk borer populations if the pest was at greater infestation levels. Sorghum webworms infested one variety (Soberano) in greater numbers than the other variety (RCV), with some reduced yield for Soberano. This may suggest some resistance to this pest in RCV. Insecticide had little effect on the sorghum webworm infestation. Because these insects have been identified by farmers to contribute to apparent sorghum yield losses, similar investigations will be conducted in 2004 in areas experiencing significant stalk borer and sorghum webworm problems in 2003.

The All Disease and Insect Nursery (ADIN) was established as in the past years with CENTA plant pathologists observing and recording technical information. The ADIN will be established in 2004 with entomologist participation.

An entomologist (M.S. degree) with CENTA began his Ph.D. program in the Entomology and Plant Pathology Department at Mississippi State University in May 2004.

United States

The goals of entomological research activities in the United States have been and continue to emphasize the refinement of IPM tactics and strategies for management of the principal whorl (fall armyworm) and panicle (sorghum midge, sorghum webworm, fall armyworm and corn earworm) pests of sorghum. Research to redefine the economic threshold (ET) for fall armyworm on whorl stage sorghum is considered necessary to elucidate pest infestation levels required to warrant the practical use of insecticide. The generally recommended ET of 1 larvae per plant was confirmed for whorl stage 2 (5 leaves) sorghum. This ET was determined to be too low for subsequent whorl stages.

The influence of sorghum-soybean rotational cropping systems on insect pests populations and incidence of plant diseases is under investigation (2003-2004). Insect pest (root and vegetable feeders) diversity and density, seasonal infestation levels, and incidence of root, stem and foliage diseases on sorghum and soybeans (6 rotational cropping systems) are being investigated. The influence of the cropping systems on mycotoxin-forming fungi in both crops will be determined.

A student from Nicaragua has completed the Ph.D. degree in entomology. A second student (with M.S. degree in plant pathology) from Nicaragua is conducting the rotational cropping (sorghum-soybean systems) multidisciplinary research in Mississippi with co-advisory by the MSU 205 PI and a plant pathologist in the Entomology and Plant Pathology Department at Mississippi State University.

The MSU 205 PI will continue to advise graduate students, travel to host countries, provide advice for research activities, participate in collaborative research and technology transfers in host countries and the United States, and publish in scientific journals, as well as prepare popular crop production articles for distribution into farm communities.

Networking Activities

This sorghum crop production workshop organized by INTSORMIL (MSU 205 and KSU 211), UNA, INTA, and ANPROSOR in Nicaragua in 2002 served as the stimulus for the further development of similar scientific meetings and workshops involving scientists, farm organizations personnel, and sorghum producers. Two workshops were conducted in 2003 and additional meetings and workshops are planned for 2004. They include farmer participation in reporting pest problems and crop production methods, as well as research needs, and aspects of integrated insect pest and plant disease management. The workshops were successful because of detail coordination by scientists and administrators at UNA, INTA and ANPROSOR.

Networking with ANPROSOR in Nicaragua provides opportunities to conduct on-farm integrated insect pest and disease management research with cooperation from many farmers associated with this National Sorghum Producers Association.

Popular articles on sorghum insect pests published during the past two years provide information for farmers to use in managing these pests on sorghum to improve yield. Publications are distributed by INTA into farm communities with assistance from local agricultural professionals.

Publications and Presentations

Journal Articles

Zeledon, J. and H.N. Pitre. 2003. Occurrence of sorghum midge (*Stenodiplosis sorghicola*) (Coq.) (Diptera: Cecidomyiidae) during the second crop growing season on the Pacific coastal plain of Nicaragua. La Calera. 3: 27-29.

Jaco, M.P. and H.N. Pitre. 2003. Insecticides evaluated for control of fall armyworm (Lepidoptera: Noctuidae) on sorghum. La Calera. 3: 8-11.

Jaco, M.P. and H.N. Pitre. 2003. Application of insecticide in various volumes of water at stages of sorghum development for control of fall armyworm (Lepidoptera: Noctuidae). La Calera. 3: 12-14.

Jaco, M.P. J.A. Moran and H.N. Pitre. 2003. Frequency of insecticide spray application for control of fall armyworm (Lepidoptera: Noctuidae) on sorghum. La Calera. 3: 20-22.

Dissertations and Theses

Zeledon, J.J. 2004. Methods of infestation, damage and economic injury level for fall armyworm, *Spodoptera frugiperda* (J.E. Smith), in Mississippi grain sorghum. PhD dissertation. Mississippi State University, Mississippi State, MS. 73pp.

Miscellaneous Publications

Zeledon, J.J. and H.N. Pitre. 2003. Evaluation of insecticides for management of fall armyworm, corn earworm and sorghum webworm on sorghum panicles, 2002. Arthropod Management Tests. 28: F-94.

Presentations

Insect pests on soybeans and sorghum. Mississippi Agronomic Professional Continuing Education Workshop. Mississippi State University (2003).

Striga Biotechnology Development and Technology Transfer

Project PRF 213
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Summary

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

In this report, we summarize our recent activities in screening wild sorghum accessions for their potential as sources of powerful *Striga* resistance genes for sorghum breeding. A small collection of wild sorghums screened for potential *Striga* resistance mechanisms allowed us to identify some unique reactions that prevent the parasitic invasion. The bioassays we used were designed to take a quick look at the earliest steps in parasitic establishment. Among the germplasm we studied were sorghums around which *Striga* did not germinate. Accessions were also identified that had reduced capacity to elicit haustorial induction of *Striga asiatica*. To our knowledge, this is the first report of low haustorial initiation activity. Up to now, this potentially useful trait has not been found among any of the *Striga* resistant sorghums. Thus, low haustorial initiation capacity may be a good trait to transfer from wild to cultivated sorghums. None of these wild sorghum accessions has yet been field tested in *Striga* sick plots so at this point we cannot correlate these phenomena observed in the laboratory with actual *Striga* resistance. Chemical and genetic characterization of the traits reported here for PQ-434 are currently underway.

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 to the unique adaptation of *Striga* to its environment and the complexity of the host-parasite relationship. Suggested control measures including mechanical or chemical weeding, soil fumigation, nitrogen fertilization, have been costly and beyond the means of poor subsistence farmers. Host plant resistance is probably the most feasible and potentially durable method for the control of *Striga*. Host resistance involves both physiological and physical mechanisms. Our goal is to unravel host resistance by reducing it to components based on the signals exchanged and disrupt their interactions at each stage of the *Striga* life cycle. The specific objectives of our collaborative research project are as follows:

- To develop effective assays for resistance-conferring traits and screen breeding materials assembled in our *Striga* research program for these traits.
- To elucidate basic mechanisms for *Striga* resistance in crop plants.
- To combine genes for different mechanisms of resistance, using different biotechnological approaches, into elite widely adapted cultivars.
- To test, demonstrate, and distribute (in cooperation with various public, private, and NGOs) elite *Striga* resistant cultivars to farmers and farm communities in *Striga* endemic areas.
- To develop integrated *Striga* control strategies, with our LDC partners, to achieve a more effective control than is presently available.
- To assess (both *ex ante* and *ex post*) of the adaptation and use of these control strategies, in cooperation with collaborating agricultural economists.
- To train LDC collaborators in research methods, breeding approaches, and use of integrated *Striga* control methods and approaches.

Research Approach and Project Output

Research Methods

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

The working hypothesis is that an intricate relationship between the parasite and its hosts has evolved exchange of signals and interruption of one or more of these signals result 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 inter-crossed 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. In the last four years, we have placed significant emphasis 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 refining these assays and integrating them into our plant breeding procedures for effective transfer of genes of *Striga* resistance into new and elite sorghum cultivars.

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 has served as an effective way to network our *Striga* research with NARS that have not been actively collaborating with INTSORMIL. As we combine and confirm multiple mechanisms of resistance in selected genotypes, the efficiency and durability of these resistance mechanisms can be better understood through such a wide testing scheme.

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

Research Findings

Unique Sources of Striga Resistance in Wild Relatives of Sorghum

Witchweed (*Striga* spp.) infestation in crops is a major constraint to crop production across much of Africa and part of Asia. Crop damage is most severe where drought and low soil fertility already limit productivity. Often mechanical or chemical control options are too expensive or ineffective against witchweeds, and farmers with infested land have no other choice than to change their crop or abandon their fields. A more practical control measure for subsistence farmers to insure productivity in a *Striga* -infested field is to grow crops with resistance to *Striga*.

It is plausible that the severe devastation wrought by witchweed species may be slowed or even halted by the flow of *Striga* resistance genes from the wild to an agricultural ecology. This flow to some extent has naturally occurred in *Sorghum* but will become less likely as modern agriculture continues to separate the crop from its wild companions. The selected advantages of wild sorghum that evolved under pressure from *Striga* spp. may be exploited in their cultivated relatives by deliberate introgression. As more is learned about the interactions between *Striga* and its hosts, the search for specific opportunities to disrupt parasitic association can be narrowed. Wild relatives of cereal hosts can be screened for the phenotypes corresponding to these opportunities. Although *Striga* resistance in wild and related species has not been fully exploited, a few surveys of wild sorghums for *Striga* resistance have been reported.

In this study, we screened 55 wild sorghums and 20 improved and landrace cultivars for potential mechanisms of *Striga* resistance using in vitro procedures developed in our laboratory. Our focus was on events observed early in the process of parasitic establishment, before *Striga* attaches to sorghum. The objective of the study was to determine if new sources of preattachment *Striga* resistance can be found within the primary gene pool of sorghum.

Sorghum seed used in this study were obtained from a collection maintained at the Purdue University sorghum research program. Sorghum seed was deglumed and surfaced sterilized with 25 ml 1.3% sodium hypochlorite solution for 1 hr. Bleach was removed by several washes of sterile water. Sorghum seed was then treated overnight in 10 ml 5% w/v captan slurry (active ingredient: *N*-[trichloromethyl]thio-4-cyclohexene-1,1-dicarboimiide, 39%), a non-systemic fungicide. After washing twice with sterile water, seed was transferred to sterile petri plates containing filter paper thoroughly wetted with sterile water. Sorghum was germinated in covered plates in the dark overnight at 28°C.

Striga asiatica seed received under quarantine conditions prescribed by USDA-APHIS and the Indiana Department of Natural Resources into our parasitic weed containment facility under permit. *Striga asiatica* seed was washed upon receipt with 1% Tween-20 (polyoxyethylenesorbitan monolaurate), a surfactant, and several rinses of water to remove sand and debris. Cleaned weed seed was air dried and stored in a desiccator for at least two weeks before conditioning. Conditioning of *Striga* began 10%14 days prior to infection in 0.5 g batches. Conditioning involved washing seed with 25 ml 75% ethanol for two minutes in a sonicator. This was followed by three rinses in sterile water of one minute each with sonication. The seed was then washed in a sonicator for two minutes with 25 ml Metricide 28 (Metrex, Inc., active ingredient: glutaraldehyde, 2.5%), a disinfectant, followed by three sterile water rinses. The seed was then washed with 25 ml 0.525% sodium hypochlorite for two minutes with sonication followed by three water rinses. Finally, surface sterilized seed was incubated at 28°C in 32 ml freshly prepared 50 ppm benomyl (Dragon, Inc., active ingredient: methyl 1-[butylcarbamoyl]-2-benzimidazolecarbamate, 50%), a systemic benzimidazole fungicide. The benomyl solution was changed after 2 days and subsequently every 3%4 days during the conditioning period.

Screening the collection of sorghum germplasm with the Extended Agar Gel Assay yielded several interesting results. Several wild sorghums displayed low germination stimulation of *Striga* seed in agar. The majority of wild accessions examined, however, were high *Striga* germination stimulators. The overall range of MGD values measured in Experiment 1 was greater among the wild accessions than among the cultivars. Fourteen putative low germination stimulators were identified among the wild sorghums. Thirteen of the twenty cultivars were low germination stimulators. One accession of *S.b. drummondii* (PQ-434) from Group 1 showed no germination of *Striga* in agar before ethylene treatment. A comparison of the very low germination of *Striga* near the roots of PQ-434 was made to that near a high stimulant cultivar CK60. After three days in agar with the growing roots of PQ-434, conditioned *Striga* seed did not germinate, whereas those with CK60 showed high germination.

Roots of PQ-434, SRN39 and Shanqui Red reached an average of 15 cm, 10 cm and 12 cm, respectively, after 3 days in the agar system. Although root weight was not measured, it appears that the three were similar since SRN39 had the shortest but thickest root and the wild sorghum PQ-434 had the longest and thinnest of the three. The degree to which root branching occurred within the observation period was low for all three entries. Ethylene inhibited sorghum root elongation so the position of the apical end changed little over the two days between measurements. The mean MGD for PQ-434 was not significantly ($p<0.008$) lower than that of the low stimulant producer SRN39. When germination stimulant activity, however, was measured as the percentage of weed seed germinated along the sorghum root, PQ-434 gave the lowest values of the three sorghums assayed. The mean of the *Striga* germination percentages near the roots of PQ-434 were significantly ($p<0.008$) lower than the germination percentage near SRN39. MGD was highly correlated with the percent germination of nearby *Striga* seed measured in Experiment 3 before ethylene treatment (r=0.96), very similar to the high correlation between similar measurements (r=0.93) we had reported earlier. Germination percentages of *Striga* near the sorghum roots were measured again two days after treating plates with ethylene and compared to *Striga* in plates containing no sorghum. *Striga* in agar without sorghum did not germinate during the three days before ethylene treatment. Two days after ethylene treatment, an average of 48% of the weed seed had germinated on these plates without sorghum. *Striga* germination percentages measured from blank plates in other experiments were similar. In Experiment 1, 44±12% (mean ± one standard deviation) of the weed seed germinated two days after the ethylene treatment and 49±15% for Experiment 2. *Striga* seed within 3 mm of the roots of PQ-434 germinated to a slightly, but significantly, lower degree (36±6%) after ethylene treatment relative to the *Striga* in the blank plate. Weed seed germination near the roots of SRN39 and Shanqui Red occurred at 44±10% and 52±14%, respectively, neither significantly different than on the plate without sorghum. This suggests that PQ-434 has a slight inhibitory effect on *Striga* seed germination.

The most distinguishing attribute found in this collection of wild sorghums is the apparent low haustorial initiating activity of some accessions. In Experiment 1, twenty accessions were classified as low haustorial initiators based on mean MHD comparisons with the cultivars. The lowest MHD values were measured on those accessions put into separate groups. Only one of the cultivated sorghums, SRN39, fell into either of these groups. All other cultivars tested were classified as high haustorial initiators. Wild accessions PQ-434, IS14313, IS18803, IS14301 and IS14264 had the lowest MHD values. All of these were also low germination stimulators (Group1) with the exception of IS14264 that contained a mixture of high and low germination stimulators (Group 5). The low haustorial initiation activity of PQ-434 is apparent *Striga* seeds artificially germinated with ethylene around this accession rarely formed haustoria, defined by a lack of radicle hairs on germinated *Striga*. This contrasts with the high stimulant line CK60 that forms recognizable haustoria within two days after ethylene treatment. The percentage of germinated *Striga* with haustoria along the sorghum root was taken as an additional measure of haustorial initiation activity. PQ-434 was compared with the low stimulant cultivar SRN39 and high stimulant cultivar Shanqui Red. Although the differences between the mean values of PQ-434 and SRN39 are significant ($p<0.008$), the greater distinguishing feature of the wild sorghum from the cultivars is the very low percentage of *Striga* near its roots that form haustoria. By this measure, the *Striga* -resistant cultivar SRN39 did not significantly differ from the *Striga* susceptible Shanqui Red in haustorial initiation activity. In contrast to the high correlation ($r=0.96$, $p<0.0001$) found in this experiment between MGD and near-root percent germination before ethylene treatment, MHD was only partly correlated with percentage of germinated *Striga* that formed haustoria ($r=0.65$). It is possible that screening for low haustorial initiation activity using only MHD might miss sorghums that produce a haustorial initiation signal but inhibit haustorial formation near their roots. Such sorghums may possess a very effective *Striga* resistance mechanism.

The survey of the wild sorghum collection revealed accessions with a wide range of MHD values, such as IS18874 and HD#758 with mean MHD > 4 mm and the low haustorial initiators PQ-434, IS14301, IS14313 and IS18803 with mean MHD < 0.5 mm. None of the known *Striga* -resistant cultivars had such low MHD values as the latter group, but many exceeded the highest values measured among the wild sorghums assayed. In light of the xenognostic quinone model of haustorial initiation, both high and low types are quite interesting. The high MHD values may reflect a varied cell wall composition in these sorghums that when digested with peroxidases release a more active or diffusible xenognosic compound than DMBQ. The low MHD sorghums may possess traits that interfere with H_2O_2 production, have lower levels of peroxidases, or altered root epidermal cell wall structure such that the xenognostic quinones are not produced. Alternatively, quinones released are inhibitory of the semiquinone redox response at the *Striga* binding site in a manner similar to those compounds.

Heritability of the low haustorial initiation capacity has not been clearly established. Preliminary results from progeny of PQ-434 crossed with high germination stimulant lines indicate that the low haustorial initiation trait is simply inherited with dominant gene action. If the low MHD trait is transferable and can effectively prevent haustorial initiation in any *Striga* spp., then improved sorghums could be developed that would presumably avoid parasitic attack. More significantly, a low haustorial initiation trait could be combined with high germination stimulant production in a *Striga* resistant sorghum that would also help to rid the surrounding soil of viable *Striga* seed, eliminating the need to sacrifice a sorghum season to trap crops. MHD, or percentage of haustoria formed in the extended agar gel assay, may be useful measures of a currently unexploited *Striga* resistance mechanism of low haustorial initiation activity. The predictive value of MHD and percentage of haustorial initiation to actual *Striga* resistance remains to be tested. It is evident from the survey of the twenty cultivars that other mechanisms beyond low germination stimulation and low haustorial initiation contribute to their *Striga* resistance since some of those with high MGD and MHD values are reported to have field resistance. Potential post-attachment reactions in sorghum against *Striga* have been reported including the hypersensitive and incompatible responses. The former was identified in wild accession #47-121 from our collection. By combining genes conferring pre-attachment with post-attachment mechanisms, aided by assays for each, sorghums with durable *Striga* resistance can be developed. Wild sorghums may be sources of unique resistance traits lacking in cultivars since they have evolved under selective pressures imposed by *Striga* spp.

Networking Activities

Workshop and Program Reviews

We have been involved in a number of pilot projects associated with *Striga* research and development this past year. Three major initiatives have been underway in Ethiopia, Eritrea, and Tanzania via a pilot project directed at the promotion of an integrated *Striga* management using a mix of technologies, including *Striga* resistant sorghum cultivars, nitrogen fertilization, as well as tied-ridges as a water conservation measure. In Ethiopia, over three thousand demonstration plots have been planted in four regions of the country with very exciting and promising results. Plots planted to the IPM technology yielded consistently higher and up to four times the yield of the untreated farmer-managed plots. Project efforts in Eritrea were similar, but scaled down in number with only one hundred demonstration plots this first year. A similar project in Tanzania focused on three regions each with over fifty on-farm demonstrations. The second, but very important, objective of each of these pilot projects focuses on promoting a functional seed multiplication efforts based on sale of good quality seed for a premium price. Keen farmers were identified, trained, and encouraged to engage in seed business. While early results of the quality of seed from these organized multiplication efforts have been good, it is too early to judge if the concept of seed as a business entity has taken hold yet.

A training workshop was held in Eritrea to kick of the demonstration and seed multiplication activities. A mid-term review was conducted to assess progress in activities that have been underway in Ethiopia. In addition, presentations on the *Striga* biotechnology research were made both at the First Sorghum and Millet Improvement Workshop in Nazret, Ethiopia and at the 2002 INTSORMIL PI Conference in Addis Ababa, Ethiopia.

Research Investigator Exchange

Over the last two years, Dr. Dale Hess was associated with our program as a visiting scientist conducting *Striga* research. He left recently having moved into a teaching and research position at Goshen College. Also, Dr. Hamidou Traore, a Fulbright fellow who spent a year at Purdue conducting *Striga* research in our facility returned to his home country of Burkina Faso. His work in our laboratory focused on identification of sorghum lines with multiple mechanisms of *Striga* resistance.
Germplasm Exchange

Seed of *Striga* resistant sorghum lines have been filled on a request basis. In addition, an International *Striga* Resistant Sorghum Nursery has been organized and distributed to a number of African national programs, who have agreed to collaborate on free will. This past year, the nursery has been sent to Ethiopia, Kenya, Eritrea, Niger, Mali, and Botswana.

Publications

Refereed Papers

Mohamed, A., A. Ellicott, T. L. Housley and G. Ejeta. 2003. Hypersensitive response to *Striga* infection in sorghum. Crop Sci. 43: 1320-1324.

Rich, P.J., C. Grenier and G. Ejeta. 2003. Sources of *Striga* resistance mechanisms in wild relatives of sorghum. Crop Sci. (In Press).

Conference Proceedings

Grenier, C., Deressa, A., Z. Gutema, G. Gebeyehu, H. Shewayerga, M. Mekuria, A. Belay, T. Tadesse, N. Mengistu, O. Oumar, A. Adugna, B. Tsegaw, and G. Ejeta. 2004. Integrated *Striga* Management (ISM) in East Africa. Proc. Consultation Workshop on Millet and Sorghum Based Systems in West Africa, McKnight-ICRISAT-INRAN, Niamey, Niger.

Toure, A., B. Dembele, M. Kayentao, and G. Ejeta. 2004. Genetic Improvement of *Striga* in Sorghum. Proc. Consultation Workshop on Millet and Sorghum Based Systems in West Africa, McKnight-ICRISAT-INRAN, Niamey, Niger.

Kapran, I., C. Grenier, and G. Ejeta. 2004. Introgression of Genes for *Striga* Resistance into African Landraces of Sorghum. Proc. Consultation Workshop on Millet and Sorghum Based Systems in West Africa, McKnight-ICRISAT-INRAN, Niamey, Niger.

Abstracts

Ellicott, A. and G. Ejeta. 2003. Inheritance of hypersensitive response to *Striga* in sorghum. Agronomy Abstracts, Denver Colorado.

Ejeta, G., A. Deressa, H. Shewayerga, A. Belay, M. Mekuria, T. Hussein, A. Fanta, C. Grenier, and Z. Gutema. 2003. Integrated *Striga* Management in Sorghum. Agronomy Abstracts. Denver, Colorado.

Invited Presentations

Ejeta, G. 2003. The biology and control of *Striga*. Training Workshop on *Striga* Management and Control in Eritrea. Asmara, Eritrea.

Ejeta, G. 2003. Genetic control of *Striga*. Training Workshop on *Striga* Management and Control in Eritrea. Asmara, Eritrea.

Ejeta, G. 2003. *Striga* biology and Control. Workshop on mid-term review of the ISM pilot project in Ethiopia. Melkassa, Ethiopia

Sustainable Management of Insect Pests

Project WTU 200

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Summary

The PI traveled to Ghana and Mali in October 2003 and Botswana and South Africa in March 2004 to review collaborative research to manage insect pests and develop integrated pest management (IPM) approaches for sorghum and pearl millet. In April, the PI organized and participated in an African Sorghum and Millet Entomology Workshop for entomologists from nine countries after the West Africa INTSORMIL meeting in Burkina Faso. Sorghum from crosses of Malisor84-7 and improved lines were resistant to panicle bugs and grain mold in Mali. Sorghum sprayed with extracts from local plants were less damaged by sorghum midge than the nontreated check. More stalk borers infested millet planted after sorghum, especially when sorghum residue was left in the field after harvest in Mali. More borers infested millet than maize or sorghum. Abundance of plants infested by stalk borers or sugarcane aphids was not affected, but abundance of termites was 6-fold greater on susceptible than resistant genotypes of 19 SADC sorghums in Botswana. A graduate student evaluated resistance of sorghum and cowpeas to storage weevils and will graduate in August 2004. Another graduate student assessed tritrophic effects of resistant sorghum on coccinellids feeding on greenbugs from sorghum and will graduate in August 2004. Graduate students graduated in August 2003 who finished assessing fitness of greenbug biotype I on different grasses and effects of different amounts of soil moisture and nitrogen on the biology of greenbugs. A Malian came to West Texas A&M University to learn English and began graduate studies in 2003. Sorghums developed by INTSORMIL project TAM 223 and Pioneer Hi-Bred, International, Inc. were evaluated for resistance to different biotypes of greenbugs. The PI advised extension personnel and the National Grain Sorghum Producers on management of insect pests. The PI and graduate students presented research results at entomology and other scientific meetings.

Objectives, Production and Utilization Constraints

Objectives

West Africa

- Support scientists with collaborative research to develop and transfer strategies, especially non-chemical methods, to manage insect pests and improve yield and income from sorghum and pearl millet.
- Educate graduate students in entomology and IPM.

Southern Africa

- Support scientists from Botswana and South Africa with research to evaluate resistance and develop IPM strategies for such sorghum insect pests as sugarcane aphid, stalk borers, and termites.

United States

- Study biology, ecology, and population dynamics of insect pests so effective management strategies and longer-lasting plant resistance can be developed. Assess fitness of greenbugs on different grasses to better understand insect-plant interactions. Use standard and molecular techniques to identify biotypes of greenbugs from the field.
- Assess agronomic practices on abundance of and damage by insect pests. Evaluate effects of soil moisture and fertility on greenbugs on sorghum. Assess tritrophic effects of resistant sorghum on beneficial lady beetles feeding on greenbugs from the sorghum.
- Collaborate with breeders, commercial seed industry, and molecular biologists to develop sorghum germplasm for greater yield potential and resistance to major insect pests.
- Supervise graduate student research and education in entomology and IPM.
- Advise extension and commodity organizations on managing insect pests of sorghum.
- Participate in professional meetings to transfer insect pest management information.

Production Constraints

West Africa

The most damaging insect pests of sorghum in West Africa are panicle-infesting bugs; sorghum midge, *Stenodiplosis sorghicola*; stalk borers; and beetles in stored grain. Sorghum midges can destroy 100% of kernels. Panicle bugs and associated infection by pathogens reduce yield and quality and render grain unusable for human consumption. Stalk borers bore into sorghum and kill the central shoot or break the peduncle. Storage pests consume and contaminate grain. The worst insect pests of pearl millet are millet head miner, *Heliocheilus albipunctella*, and *Coniesta ignefusalis* stalk borer.

Southern Africa

Stalk borers; sugarcane aphid, *Melanaphis sacchari*; panicle-infesting bugs; termites; and sorghum midge infest and reduce yields of sorghum. Beetles destroy stored sorghum grain.

United States

Major insect pests include greenbug, sorghum midge, and panicle-infesting bugs and caterpillars. Ecosystem disruption caused by monoculture of sorghum increases the severity of pests and results in increased production costs and reduced yield. Insecticides prevent damage and yield loss, but overuse results in increased production costs, disruption of the ecosystem, outbreaks of secondary arthropod pests, resurgence of the targeted pest, and environmental contamination. Biology, insect-plant interactions, amounts of damage, and economic and ecological costs associated with the use of chemicals to control insect pests need to be understood. Biological and cultural management tactics such as use of resistant plants are needed to prevent damage by insect pests.

Research Approach and Project Output

This project emphasizes collaborative research and education. The IPM approach is used to develop strategies to manage insect pests economically, ecologically, and environmentally. For effective IPM, the insect pest must be identified correctly; its biology, ecology, and population dynamics understood; abundance determined in relation to crop damage and yield loss; economic threshold determined; and direct control tactics used, especially conservation of natural enemies, agronomic practices, resistant varieties, and chemicals only when necessary. Information and technology from the research is transferred to extension personnel, farmers, and others.

West Africa

Tiecoura Traore from Mali finished English training and began graduate studies at West Texas A&M University. From 8-19 October 2003, sorghum and pearl millet research was viewed and collaborative research projects planned with scientists in Ghana and Mali. In Mali, the PI participated in the External Evaluation Panel review of INTSORMIL activities. Drs. Diarisso and Doumbia evaluated crosses between Malisor 84-7 and introduced, improved sorghums for resistance to panicle bugs at Sotuba, Mali. Abundance of bugs was assessed on five panicles per genotype at hard-dough. At maturity, damage by bugs was rated 1-9, where 1 = all kernels developed with few feeding punctures, to 9 = most kernels brown and/or withered and barely visible between the glumes. Grain mold was rated 1-5. Grain hardness, weight of 200 kernels, and germination were determined. Forty-six, 29, and 17 sorghums from three preliminary nurseries were resistant to bugs and grain mold. Panicles of 99-CZ-F5P-136-2, 99-CZ-F5P-131-2, 99-CZ-F5P-97-2, 99-SB-F5DT-170-1, 99-SB-F5DT-49-2, and Malisor84-7 were infested artificially with 20 pairs of bugs to confirm resistance. Bugs were counted 20 days after infestation. All six sorghums were resistant to bugs and mold, with damage scores of 1-1.33. Abundance of bugs ranged from 0.0, to 7.3 for Malisor84-7. Weight of 200 kernels ranged from 4.0 for Malisor84-7 to 5.0 for 99-SB-F5DT-170-1 nonprotected panicles, 3.8 for Malisor84-7 to 4.9 for 99-SB-F5DT-170-1 protected by cages, and 4.2 for 99-SB-F5DT-49-2 to 5.0 for Malisor84-7 protected by pollination bags.

Efficacy of extracts from local plants was assessed against bugs, sorghum midge, and grain mold on bug-susceptible S34 sorghum in the field in Mali. Bugs were counted a day before and week after treatment. Damage by bugs and mold were rated at maturity. Panicles protected by bags were not infested by bugs, sorghum midge, or mold. Damage to and weight of protected panicles did not differ from that of panicles sprayed with Dursban. Panicles protected by bags or sprayed with Dursban were less infested with insects and mold than were panicles treated with extracts from local plants, which were better than the check. The different rates of neem seed jelly did not result in differences in damage by bugs or sorghum midge, but less mold was on panicles sprayed with the high dose than on panicles sprayed with the low dose. Weight of protected kernels was greater than that of grain from the other treatments. Kernels treated with juice of *Calotropis procera* leaves weighed least. (Table 1)

Drs. Diarisso and Mamourou Diourté evaluated crop residue management practices against stalk borers and anthracnose in sorghum at Finkolo, Mali. A randomized complete block was used with three replications of six treatments (crop residue removed from the sorghum field after harvest and before planting (check); crop residue left in the sorghum field, then chopped and buried when sorghum was planted the following year; crop residue removed from the sorghum field after harvest and before planting maize; crop residue left from sorghum then chopped and buried when maize was planted in the field; crop residue removed from the sorghum field after harvest and before planting millet; and crop residue left in the sorghum field, then chopped and buried when millet was planted). Leaves and stems from seedling to mature plants were checked for stalk borers. At maturity, 10 plants per treatment were dissected for larvae, pupae, and tunnels. Virtually no borers were found in sorghum rotated with maize, and only a few larvae and tunnels were found in sorghum when crop residues were removed after harvest and before planting (check) or when residues were left in the sorghum field and chopped and buried when the next sorghum crop was planted. Millet was more vulnerable than maize or sorghum. Approximately 10 times more larvae and three times more pupae and tunnels were found when residues were removed from sorghum after harvest and before millet was planted than were found in the check plots. More than 20 times more larvae and appoximately six times more pupae and tunnels were found when residues were left in the sorghum field and chopped and buried when millet was planted. Removal of residue from the field after harvest and before planting reduced abundance of stalk borers. *Coniesta ignefusalis* was the dominant species.

Southern Africa

From 4-14 March 2004, the PI participated in the External Evaluation Panel review of INTSORMIL activities in southern Africa, viewed sorghum research, planned collaborative projects with scientists, and met prospective graduate students in Botswana and South Africa.

In collaborative research at Botswana College of Agriculture, Dr. Munthali and Mr. Obopile evaluated for resistance to sugarcane aphid, stem borers, and termites, 19 sorghums developed by National Research Systems and SADC Regional Research Projects. Each genotype was planted in four, 7- by 7-m plots in a randomized complete block. Seeds were sown with 30 cm between plants and 50 cm between rows. Plots were examined every two weeks for pests and natural enemies. Percentages of infested plants were determined per plot. Coccinellids were counted on all plants in a plot. Adult coccinellids and ichneumonid wasps were collected for identification. Abundance of plants infested by sugarcane aphids was not affected by sorghum genotype. Infested plants per plot during 2002-3 and 2003-4 were 23.9 and 42.8% (Table 2). Abundance of predators per plot was 6.5-fold less during 2002-3 (2.8 coccinellids) than 2003-4 (18.3 predators and 8.8 coccinellid adults). Coccinellids were abundant when sugarcane aphids were abundant in 2003-4. Pests and predators were assessed only once, early in 2003-4. Natural enemies are most abundant on sorghum early in the season. The 19 sorghum genotypes were equally susceptible to stalk borers. In 2003-4 and 2002-3, 78.3 and 64.2% of plants were infested per plot. In 2003-4 and 2002-3, 17.3 and 40.4% of plants had deadhearts. Although many plants were infested, a smaller proportion had severe deadheart symptoms in 2003-4. Abundance of termites was similar and great on SDSR91039, ICR89028, Segaolane, Phofu, Tegemeo and SV2, with 92.2, 91.1, 83.8, 82.9, 79.9 and 79.0% infested plants per plot, respectively. Plants of Town, BSH1, SDSH98009, SDSH98012, LARSVYT46-48, SV1,

Table 1. Damage by sorghum midge, panicle bugs, and grain mold and kernel weight of S34 sorghum treated with extracts from local plants.

Treatments	Damage by midge/10 panicles	Damage by bugs/10 panicles	Amount of grain mold/10 panicles	Weight (g) of grain from center rows
Check without spray	3.6 a	5.1 a	2.7 ab	633.3 bc
Neem seed jelly 80 g/liter	3.2 ab	5.4 a	2.9 a	733.3 bc
Neem seed jelly 160 g/liter	2.3 bc	5.0 a	2.6 b	766.6 bc
Juice from *Calotropis procera* leaves 25 kg/30 liters	2.6 abc	5.3 a	2.7 ab	500.0 c
Dursban 80 ml/15 liters	1.8 cd	3.3 b	2.5 b	966.6 ab
Panicle protected by bag	1.0 d	1.0 b	1.0 c	1200.0 a
CV%	36.73	14.96	6.77	22.72
Probability	0.048	0.00	0.00	0.005
Significance	S	HS	HS	HS

Means followed by the same letter in a column are not significantly different (Duncan range test, $P = 0.05$).

Table 2. Effects of sorghums on sugarcane aphid, coccinellids, stalk borers, and termites in Botswana during 2003-2004.

Sorghum	% sugarcane aphid-infested plants/plot	Coccinellids		Stalk borers		Termites	
		Adults	All stages	% plants attacked	% plants with dead hearts	% plants infested	% plants severely damaged
SDSH98012	35.8[NS]	14.5[NS]	29.0[NS]	44.4[NS]	7.1[NS]	11.9b	3.8c
SDSR91014	36.5	2.5	13.8	59.3	5.9	17.2b	6.9c
SDSH98009	41.0	21.5	42.5	74.4	3.4	11.2b	3.4c
Mmabaitse	37.1	7.5	15.0	64.8	16.2	14.6b	4.1c
SDS6013	36.2	8.8	17.8	65.8	22.8	14.8b	3.3c
BSH1	48.6	21.8	43.5	91.0	5.0	9.2b	3.4c
ICSH93107	46.5	16.0	38.5	79.4	11.1	17.0b	4.7c
Town	44.6	7.0	13.2	91.3	17.9	7.9b	2.2c
SV1	45.4	0.0	0.0	84.2	27.8	13.3b	5.4c
Mahube	58.1	15.0	30.0	70.4	20.7	19.6b	7.4c
LARSVYT46-48	41.2	4.8	9.5	86.5	35.9	12.3b	7.5c
Macia	41.6	12.5	22.0	89.9	34.3	14.9b	5.9c
Marupantsi	52.1	3.5	7.0	77.5	32.0	27.1b	8.3c
Segaolane	34.9	18.5	38.5	83.8	1.7	83.8a	1.7c
ICSR89028	40.2	3.2	6.0	91.1	3.4	91.1a	3.3c
SV2	36.4	7.5	13.8	92.2	9.0	79.9a	19.3c
SDSR91039	41.7	2.0	4.2	79.9	19.3	92.2a	9.0c
Tegemeo	33.2	0.8	3.0	79.0	26.3	79.0a	26.3c
Phofu	61.8	0.2	0.8	82.9	28.8	82.9a	28.7c
Overall average	42.8	8.8	18.3	78.3	17.3	36.8	8.1
CV	33.5	166.7	169.0	28.17	99.40	39.16	150.47

[NS] Means in a column are not significantly different (ANOVA, $P < 0.05$); [a,b] Means in a column followed by the same letter are not significantly different (Tukey, $P < 0.05$).

Mmabaitse, SDS6013, Macia, ICSH93107, SDSR91014, Mahube, and Marupantsi infested by termites were 7.9, 9.2, 11.2, 11.9, 12.3, 13.3, 14.6, 14.8, 14.9, 17.0, 17.2, 19.6, and 27.1%, respectively. Abundance of infested plants was 6.2-fold greater for susceptible than resistant sorghum. Termites severely damaged 8.1% of the plants per plot.

United States

Master's student Fernando Chitio from Mozambique evaluated resistance of 20 genotypes of stored sorghum grain to maize weevil, *Sitophilus zeamais*, and 20 genotypes of cowpea to cowpea weevil, *Callosobruchus maculatus*. Three female and two male newly emerged weevils were put with five g of sorghum grain in each of 10 vials. Vials of each kind of sorghum were sequentially set up and evaluated every three weeks for 105 days. Each day, each grain in the 10 vials of one kind of sorghum was evaluated for damage, numbers of live and dead weevils were counted, and grain in each vial was weighed. A scale of 1-5 was used to score damage, where 1 = no evidence of damage, 2 = some feeding on the surface, involving 1-25% or one shallow hole in a kernel, 3 = two tunnels, causing 26-50% damage to a kernel, 4 = 51-75% damage or more than two holes in a kernel, 5 = 76-100% damage and many tunnels in a kernel. Fewest maize weevils emerged from Sima, Macia, and Sureno — 1.7, 2.8, and 3.1 per gram of grain at 105 days after infestation, respectively (Table 3). Most emerged from CE151, SRN39, SC630-11E11, and ATx631 — 14.2, 12.4, 12.1, and 12.0 per gram of grain at 105 days after infestation. Sureno, Sima, Malisor-84-7-167, and Macia were least damaged, with scores of 1.5, 1.6, 1.7, and 1.8 at 105 days after infestation. CE151, SC630-11E11, and ATx631 were most damaged, with scores of 4.0, 3.9, and 3.9 at 105 days after infestation. Of the original 5.0 g of grain per vial, grain in vials of Sureno, Sima, Macia, Malisor-84-7-167, and Tegemeo weighed most at 105 days after infestation — 5.0, 4.8, 4.7, 4.7, and 4.6 g. Percentages of weight loss of grain of Sureno, Sima, Macia, and Malisor-84-7-167 were 0.8-6.6%. Grain of SC630-11E11, CE151, and ATx631 weighed least at 105 days after infestation, with 2.7, 2.8, and 3.1 g remaining of the original 5.0 g per vial. Percentages of weight loss of grain of ATx631, CE151, and SC630-11E11 were 37.2-46.8%. Grain weight loss was correlated to the cumulative total number of maize weevils produced per gram and with the score of damage to the grain, but not to grain size, hardness, or protein content. Cowpea weevils destroyed 34-65% of grain of the 20 genotypes of cowpeas.

Master's student Murali Ayyanath assessed tritrophic effects of biotype I greenbugs from resistant PI550607 versus susceptible RTx430 sorghum on the life cycle of convergent lady beetles at 23 and 30°C. Lady beetles from the field were paired in condiment cups. Larvae produced were reared individually in condiment cups at 23 or 30°C and a photoperiod of 14:10 light:dark hours in an incubator. Each day, a known number of greenbugs from RTx430 sorghum in a greenhouse was fed to half of the larvae, and the same number of greenbugs from PI550607 sorghum was fed to the other half of the larvae. The number of greenbugs remaining was counted and discarded the next day. Adult lady beetles that emerged were paired in one of four ways depending on the sorghum source of green-

Table 3. Number of maize weevil adults per gram, score of damage, and percentage of weight loss (± SEM) at 105 days after infestation of sorghum grain

Sorghum	Total maize weevils/gram	Damage score	% weight loss
Sureno	3.1 ± 0.50g	1.5 ± 0.10i	0.8 ± 0.07j
Sima	1.7 ± 0.66g	1.6 ± 0.19i	3.8 ± 0.09ij
Macia	2.8 ± 1.17g	1.8 ± 0.26hi	5.4 ± 0.18h-j
Malisor84-7-167	3.9 ± 0.81fg	1.7 ± 0.14hi	6.6 ± 0.12hi
Tegemeo	3.5 ± 1.02fg	2.0 ± 0.20g-i	8.2 ± 0.14h
ATx635	6.4 ± 0.81ef	2.3 ± 0.15f-h	13.8 ± 0.12gh
Malisor84-7-476	7.4 ± 1.11de	2.5 ± 0.20fg	15.2 ± 0.16g
Kuyuma	7.3 ± 1.75de	2.7 ± 0.24ef	16.8 ± 0.24g
Tx2882	7.5 ± 1.35de	2.7 ± 0.21d-f	17.4 ± 0.18fg
Segaolane	8.6 ± 0.94de	2.8 ± 0.27c-f	21.8 ± 0.21f
B1	10.6 ± 1.11b-d	3.1 ± 0.18c-e	27.2 ± 0.16e-g
RTx430-5451	10.1 ± 0.81b-d	3.3 ± 0.12b-d	27.4 ± 0.17d-f
Tx2737	10.0 ± 2.08b-d	3.2 ± 0.37b-e	30.2 ± 0.31d-f
RTx430-5362	10.5 ± 1.31b-d	3.4 ± 0.24a-c	32.0 ± 0.25c-e
ATx623	10.4 ± 1.31b-d	3.2 ± 0.20b-e	32.2 ± 0.23b-e
Tx2911	9.5 ± 1.39c-e	3.4 ± 0.33a-c	33.8 ± 0.29a-d
SRN39	12.9 ± 1.49ab	3.7 ± 0.24ab	35.8 ± 0.22a-d
ATx631	12.0 ± 1.50a-c	3.9 ± 0.21a	37.2 ± 0.25a-c
CE151	14.2 ± 0.95a	4.0 ± 0.15a	43.4 ± 0.14ab
SC630-11E11	12.1 ± 1.01a-c	3.9 ± 0.21a	46.8 ± 0.21a
LSD (<0.0001)	3.351	0.615	0.547

bugs. The females were fed greenbugs from the original sorghum from which they previously were fed. Daily numbers of eggs laid and hatched per female were recorded until the beetle died or 90 days passed after emergence. Lady beetle larvae and adults consumed the same numbers of greenbugs from resistant or susceptible sorghum. But, larvae ate 1.7 and adults ate 2.0-3.1 times more greenbugs at 23 than 30°C. Each adult ate 17,124.0 and 16,324.5 greenbugs from resistant and susceptible sorghum at 23°C. Lady beetle eggs hatched in 3.0 versus 2.0 days, larvae required three times longer to develop, and the pupal stage lasted 6.0 and 3.0 days at 23 and 30°C, respectively. Almost 8.5 times more eggs were produced per lady beetle fed greenbugs from susceptible sorghum at 23°C than by beetles fed greenbugs from resistant sorghum at 30°C (Table 4). Numbers of eggs were greatest from beetles fed greenbugs from susceptible sorghum. At 23°C, 91.0% hatched of the 2,893.1 eggs produced by beetles fed greenbugs from susceptible sorghum. At 30°C, more eggs hatched, 75.4%, per female when beetles were fed greenbugs from susceptible sorghum. Only 21.8-39.4% of eggs hatched from other combinations of beetles. Greenbugs from resistant sorghum negatively affected the number and viability of eggs produced by convergent lady beetles.

Table 4. Effect of temperature and sorghum source of greenbugs on eggs laid and hatched per convergent lady beetle female.

Pair (female x male)[a]	Number of eggs laid	% of eggs hatched
23°C		
SxS	2,893.1 ± 183.0aA	91.0 ± 5.2aA
SxR	1,814.3 ± 224.1bA	64.4 ± 6.4bcA
RxS	1,242.0 ± 317.0bA	44.2 ± 9.0cA
RxR	1,586.0 ± 388.2bA	81.3 ± 11.1abA
30°C		
SxS	651.0 ± 191.3aB	75.4 ± 15.2aB
SxR	498.0 ± 135.2aB	34.8 ± 10.7bB
RxS	343.0 ± 110.4aB	39.4 ± 8.8abA
RxR	342.0 ± 156.2aA	21.8 ± 12.4bA

For each temperature, means ± SE followed by the same lower-case letter in a column are not significantly different (LSD, $P = 0.05$). Between temperatures, means ± SE followed by the same upper-case letter in a column are not significantly different (LSD, $P = 0.05$). [a]S = lady beetle fed greenbugs from RTx430 sorghum; R = greenbugs from PI550607 sorghum.

Master's student Kishan Sambaraju finished assessing fitness of biotype I greenbugs on wild grasses and resistant and susceptible sorghum and wheat. Seeds of susceptible RTx430 sorghum; resistant LG-35 sorghum; susceptible Custer wheat; resistant GRS1201 wheat; barnyardgrass, *Echinocloa crus-galli*; Johnsongrass, *Sorghum halepense*; jointed goatgrass, *Aegilops cylindricum*; and Arriba western wheatgrass, *Agropyron smithii*; were sown in a greenhouse. Eighteen to 21, 2.5-cm^3 plastic cages containing a greenbug were clipped onto leaves of each kind of grass in three replications. The greenbug was removed after it produced a nymph. The nymph was retained until it produced offspring, which were counted and removed daily. The number of days the greenbug lived was recorded. Fecundity was 13.9 nymphs per greenbug on barnyardgrass, but 62.2 and 61.5 nymphs on susceptible wheat and sorghum. Each greenbug lived 14.8 days on barnyardgrass, but longest on grasses of the genus *Sorghum* (29.4, 28.8, and 27.5 days on Johnsongrass, RTx430, and LG35, respectively). The resistance mechanism in the sorghum and wheat probably is antixenosis or tolerance, rather than antibiosis.

Master's student Suresh Veerabomma finished assessing effects of soil water potential and nitrogen on abundance and longevity of biotype I greenbugs. A greenbug enclosed in a clip cage was attached to a leaf of each of 90 sorghum plants, 10 per treatment combination. Soil water potential, but not nitrogen, affected greenbug fecundity, with almost twice as many nymphs produced per greenbug on sorghum in soil with -33 kPa (44.5 nymphs) as with -300 kPa of water potential (28.5 nymphs). Greenbug longevity was affected by soil water potential but not nitrogen. Longevity was 22.2 and 28.6 days on sorghum in soil with -300 and -33 kPa of water.

Two hundred one sorghum lines were evaluated for TAM 223 for resistance to greenbug biotypes C and E. Two hundred sorghum lines developed by Pioneer Hi-Bred International, Inc. were evaluated for resistance to greenbug biotype I, with one line being very resistant.

Networking Activities

Workshops

The PI organized and participated in an African Sorghum and Millet Entomology Workshop (21-22 April 2004, Ouagadougou, Burkina Faso) after the West Africa INTSORMIL meeting. During the Workshop, entomologists from Botswana, Burkina Faso, Eritrea, Ghana, Mali, Niger, Senegal, South Africa, and the United States prioritized insect pests by region of Africa, reported on pests from their countries, presented results of current research, planned collaborative research projects, and wrote a grant proposal on "Management of Panicle Bugs to Prevent Grain Mold and Improve Sorghum Grain Quality in Africa." The PI was program co-chair, organized a sorghum symposium, and co-authored five presentations for the 52nd Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists in conjunction with the Annual Meeting of the High Plains Association of Crop Consultants (23-26 February 2004, Lubbock, Texas). The PI gave two presentations on greenbugs at the Entomology Science Conference (11-13 November 2003, College Station, Texas).

Research Investigator Exchanges

From 8-19 October 2003, the PI traveled and discussed and reviewed research and needs with scientists and administrators from SARI in Ghana and IER in Mali. Entomological emphasis was on managing panicle-infesting bugs, sorghum midge, stalk borers, and storage beetles. From 4-14 March 2004, the PI traveled, discussed and reviewed research with scientists and administrators, and met prospective graduate students from Botswana College of Agriculture, North West University in South Africa, and ARC in South Africa.

Research Information Exchange

The PI advised extension, National Grain Sorghum Producers, and commercial seed companies on management of sorghum insect pests. Two hundred sorghums developed for resistance to biotype I greenbug were evaluated for Pioneer Hi-Bred International, Inc. The PI is assisting Dr. John Burd, USDA-ARS, Stillwater, Oklahoma, with a multi-year, multistate study of greenbugs on wild and cultivated grasses. Reference materials and/or supplies were provided for entomological research for Mr. Abdou Kadi Kadi in Niger, Dr. Mamadou Baldé and Mr. Djibril Badiane in Senegal, Dr. Diarisso in Mali, Dr. Munthali in Botswana, Drs. Hannalene du Plessis and Johnnie van den Berg in South Africa, and Dr. Paul Tanzubil in Ghana.

Publications and Presentations

Publications

Sambaraju, K.R., B.B. Pendleton, C.A. Robinson and R.C. Thomason. 2003. Fecundity and longevity of greenbug on wild and cultivated grasses. International Sorghum and Millets Newsletter 44:131-132.

Ayyanath, M., B. Pendleton and G.J. Michels, Jr. 2004. Tritrophic interactions of resistant sorghum, greenbugs, and lady beetles. Pp. 2-3. In Proceedings of the 52nd Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists. Lubbock, TX. February 23-26, 2004.

Chitio, F., B. Pendleton and G.J. Michels, Jr. 2004. Resistance of stored cowpeas to cowpea weevil (Coleoptera: Bruchidae). Pp. 9-10. In Proceedings of the 52nd Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists. Lubbock, TX. February 23-26, 2004.

Sambaraju, K. and B. Pendleton. 2004. Fitness of greenbug (Homoptera: Aphididae) on wild and cultivated grasses. Pp. 20-21. In Proceedings of the 52nd Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists. Lubbock, TX. February 23-26, 2004.

Sambaraju, K.R. 2003. Fitness of greenbug (Homoptera: Aphididae) on wild and cultivated grasses. M.S. thesis. West Texas A&M University, Canyon, TX.

Veerabomma, S. 2003. Effects of different amounts of soil water and nitrogen on the fecundity and longevity of greenbug (Homoptera: Aphididae) on sorghum. M.S. thesis. West Texas A&M University, Canyon, TX.

Presentations

Entomology Science Conference, 11-13 November 2003, College Station, TX – *Greenbug review and update – biotyping, evaluating sorghums for resistance, and new insecticides* presented by Bonnie Pendleton; and *Using AFLP to distinguish sorghum greenbug biotypes* presented by Keyan Zhu-Salzman and Bonnie Pendleton.

52nd Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists in conjunction with the Annual Meeting of the High Plains Association of Crop Consultants, 23-26 February 2004, Lubbock, TX – *Tritrophic interactions of resistant sorghum, greenbugs, and lady beetles* by Muralimohan Ayyanath, Bonnie B. Pendleton, and G. J. Michels, Jr.; *Alternatives to organophosphates and carbamates for managing aphids in wheat and sorghum* by Roxanne Bowling, Bonnie Pendleton, Jerry

Michels, and Robert Bowling; *Resistance of stored cowpeas to cowpea weevil (Coleoptera: Bruchidae)* by Fernando M. Chitio, Bonnie B. Pendleton, and G. J. Michels, Jr.; *Fitness of greenbug (Homoptera: Aphididae) on wild and cultivated grasses* by Kishan Sambaraju and Bonnie B. Pendleton; and *Distinguishing sorghum greenbug biotypes by using AFLP fingerprinting* by Keyan Zhu-Salzman, Haiwen Li, and Bonnie Pendleton.

African Sorghum and Millet Entomology Workshop, 21-22 April 2004, Ouagadougou, Burkina Faso – *Current research on sorghum midge in Niger* by Hame Abdou Kadi Kadi, Bonnie Pendleton, and Issoufou Kapran; *Life table of millet head miner (Lepidoptera: Noctuidae) reared in a lab in Niger* by Hame Abdou Kadi Kadi, Frank Gilstrap, George Teetes, Ousmane Youm, and Bonnie Pendleton; *Head bug biology* by Niamoye Diarisso, Yacouba Doumbia, Mamadou N'Diaye, and Bonnie Pendleton; and *Sorghum midge* by Bonnie Pendleton.

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

Synthesis of the lessons from the four Sahelian country, Marketing-Processing project: In the good rainfall year of 2003-04 the gains from selling later in the post harvest period with inventory credit programs are considerably lower than in the bad rainfall year (2002-03). However, there are much larger payoffs to the new technologies in these good rainfall years so that the total gains to farmers' incomes are much higher than in the bad rainfall years. The myth that farmers will not use higher input levels (inorganic fertilizers and other chemicals) on their millet was once again refuted. The big payoff initial marketing strategy innovation is the inventory credit. However, with the contracting process the project is also developing the food and feed processing sector and facilitating the availability of greater quantities of a high quality cereals.

In two zones of Ethiopia the *Striga* resistant cultivars were being introduced. Their introduction was constrained by being shorter season than most local cultivars but the *Striga* resistant cultivars were appreciated in low rainfall years. A variety of water retention techniques were being adopted in both regions. Little inorganic fertilizer was being used on these short season cultivars. There is a general agreement among farmers and extension agents of the payoff to moderate and longer season length sorghums with *Striga* resistance.

We extended our research on the link between new technology introduction and marketing strategy improvement from the Sahel to central Mozambique. Without price increase from new marketing strategies no new technologies evaluated would be introduced. With inventory credit and/or the other marketing strategies evaluated new technologies are introduced and farmers' income increased by 58 to 81%.

Objectives, Production and Utilization Constraints

In the last two years we became involved in a development program in the Sahel to operationalize many of the concepts, which we have been researching. This development project is operating in five countries (four in the Sahel and it will include Nigeria). This project facilitates the introduction of both marketing strategies and new technologies in millet and sorghum production.

We continue to evaluate the introduction of *Striga*-resistant cultivars and associated technologies in Ethiopia. Field work for the second major region of Ethiopia-the Amhara zone focusing on the north Kobo valley- was begun and a journal article written on the introduction of these technologies in the Tigray region on the border with Eritrea (Sheraro). In other work an evaluation of the combined introduction of farm level technologies and marketing innovations for maize and sorghum in Mozambique was almost finished. We are taking the same concepts we are using in the Marketing-Processing project and evaluating their potential impact in Mozambique. Finally we have begun a program to resurvey the introduction of inorganic fertilizer in western Niger. We are examining the dynamics of this introduction as well as looking at the performance of inventory credit there.

Research Approach and Project Output

Marketing-Processing Development Project in the Sahel and northern Nigeria

The six weeks of field interviewing of farmers and processors in four Sahelian countries in the spring-summer of 2004 indicated the importance of combining inorganic fertilizer with the new cultivars. It also demonstrated again the returns to inventory credit so that farmers can avoid selling their cereals during the post harvest price collapse. Figure 1 indicates the differences in prices between harvest time and six months later for both a poor rainfall year (2002-03) and a good rainfall year (2003-04).

In a good year, there will be a much larger yield effect from the use of the improved cultivar, seed treatment, and inorganic fertilizers. There have been two important myths in the Sahel. First, that there is not a response to fertilizing millet. Secondly, that, farmers would not use inorganic fertilizer on millet because they only use it on cash crops, such as cotton or maize, and not on subsistence crops, such as millet and sorghum. In this good rainfall year (2003) the substantial yield gains to inorganic fertilizer were consistently observed. In the poor rainfall year of 2002 there were also yield gains from higher input use but smaller ones.

As soils continue to be depleted and organic fertilizers are increasingly used by farmers to increase the availability of water and nutrients in the sandy soils,[1] farmers focus on the importance of getting adequate inorganic fertilizers on a timely basis. For the increased use of inputs to be profitable, farmers need to sell part of their crops after the price recovery in the post harvest period. This is especially important in good rainfall years when there is not only the annual harvest price collapse but also the between year price collapse resulting from good weather.

Of the marketing strategies the most potential is for the farmer to obtain more of the gains from seasonal price variation rather than the merchant or the processor capturing all these gains. In the long run the returns from a quality premium and the expansion of the food and feed sectors are expected to have substantial impacts on farmers' incomes. In the short run the farmers need to benefit from the seasonal price variation and some type of inventory credit program enables them to do that. In a bad rainfall year, such as 2002-03, millet prices in the four Sahelian countries doubled during the off-season.

However, as many farmers store and sell in later periods the seasonal price swings will smooth out. Hence, we need to be developing several marketing strategies to increase farm incomes over time and to moderate the price declines of good rainfall years. The Marketing-Processing Project works with food and feed processors: (1) to supply a higher quality product, (2) to make contracts with farmers for purchasing later in the season (after the post harvest price recovery) and for processors to pay a price premium for a higher quality product to farmers.

Striga resistant cultivars and associated technology introduction in two major zones of Ethiopian sorghum production

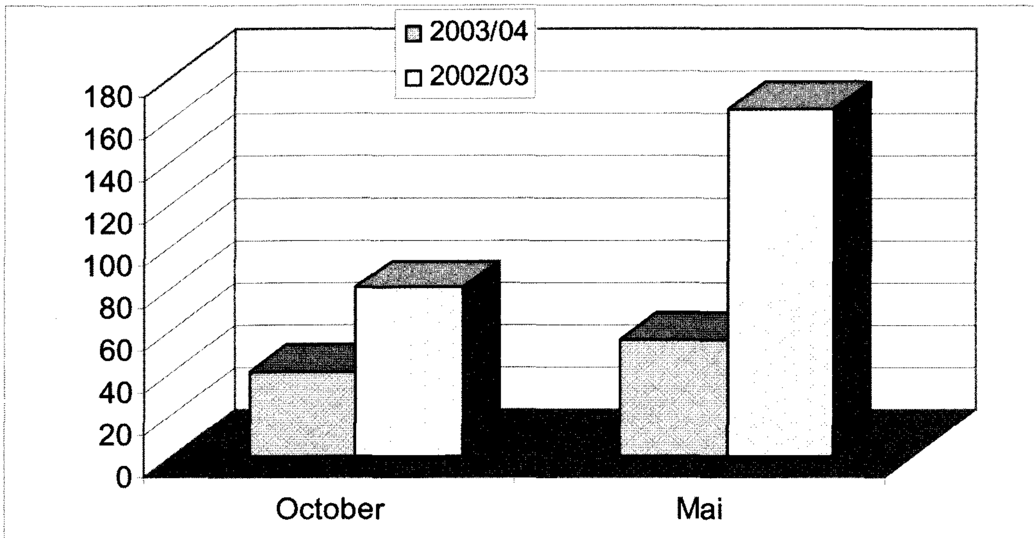
In earlier (INTSORMIL Annual Report, 2002) work we reported the results for the diffusion of new *Striga* resistant sorghum cultivars and associated technologies in northern Tigray. There a series of water retention techniques had been introduced with government organized farmer collaboration to dig trenches and do ridges with dirt, stones and plants. The introduction of the tied ridger was included in this *Striga* technology diffusion program but the ridger was not used on the hillsides (due to stones or incline according to farmers). Moreover, there were only a limited number of ridgers made available in the region. Nevertheless, use of some water retention technique was pervasive. Ninety percent of the farmers used one or more water retention techniques with the most popular being soil or stone ridges (65%).

The diffusion of inorganic fertilizer was still limited. Twenty percent of the farmers utilized inorganic fertilizers but none on the short season, *Striga* resistant cultivars. For the fertilization it will be important to make sure that farmers can get a higher return as they use higher input levels. One technique for achieving this objective is by selling later in the season and the potential returns from this activity and whether it leads to increased sorghum technology diffusion are presently being examined with Nega Wubenah re-interviewing the Tigray survey participants in 2003.

In Tigray only 8% of the farmers were using the *Striga* resistant cultivars in 2001. The diffusion process was still very early as the official release of the new cultivars had only been in 1999 and 2000. Unofficially these cultivars began to be available from the regional trials after 1996. Nevertheless, the majority of the farmers sampled had not even heard about the *Striga* resistant cultivars in the 2001 interviews. Note that a significant statistical factor in the diffusion of the new cultivars was

[1] In the sandy soils of semiarid regions millet is the predominant cereal with sorghum replacing it in the heavier or better soils with more clay as in the river valleys, the water recession areas, under the legume tree and around the household compound.

Figure 1: Millet prices (CFA/kg) in good (2002/03) and bad (2003/04) cropping years, Cinzana, Mali.



1US $=500 CFA
Source: Field interviews

participation in the local governmental administration. This awareness of the new cultivars was a type of insider information.

Besides *Striga* resistance the cultivars are much earlier than the local cultivars. So farmers prefer them when the rains start late, approximately 37% of the time. With normal or early rainfall (two thirds of the time) the longer season, local cultivars respond better to being in the field longer. Note that some farmers were using inorganic fertilizers on the local sorghums but none on the new shorter season cultivars. When the rains are early or normal, farmers do not plant the shorter season *Striga* resistant cultivars. Moderate and longer season *Striga* resistant cultivars will be very important in the next stage of introduction of new technologies. This over-emphasis on drought avoidance via shorter season material is a pervasive behavior in semiarid regions. However, as improved water retention and soil fertility improving technologies are being introduced, breeders can return to a focus on biotic resistances and higher yield characteristics.

Table 1. Use of the *Striga* resistant sorghums in the North Kobo sample (2001-2003).

Local name of Striga resistant cultivar	Crop Year 2001	2002	2003	Total
Gobiye	3	6	17	26
Abshir	0	0	10	10
Birhan	0	1	2	3
Total	3	7	29	39*

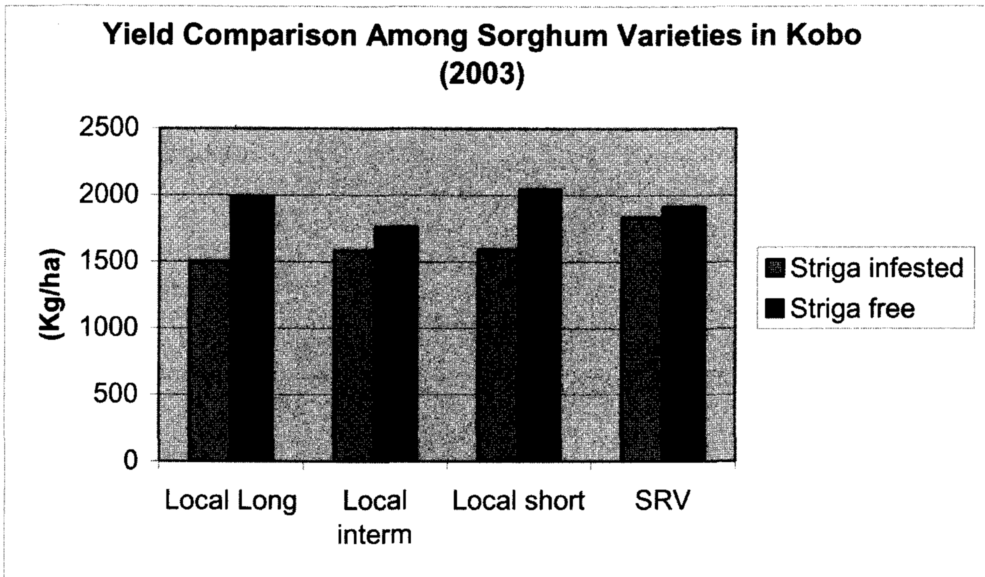
*/There were 101 farmers in the survey and one of the farmers planted Gobiye in the last two years so only 38 innovators. The seed distribution scheme needs to be improved as farmers expected to be given the seed each year.
Source: Yigezu, 2004 (unpublished survey data)

In 2003 surveying began in the older settled, north Kobo valley in Amhara state. A similar diffusion program of *Striga* resistant cultivars and associated technologies has also been implemented there in the last three years and in the two other major zones of Ethiopia.

Diffusion of water retention techniques was a national priority of the extension services after the drought of 2002. So a series of measures especially the Chinese lined pit technique were promoted in this crop year. These valley soils are regularly flooded with the erosion of the highlands. Many farmers also do some supplemental irrigation of higher value crops. So in these naturally fertilized fields with generally abundant water, yields are high even without inorganic fertilizers. The diffusion of the new *Striga* resistant cultivars is rapidly reaching 38% in the third year of the program to extend these technologies (Table 1). As in Tigray farmers did complain about the earliness of the *Striga* resistant cultivars but they also expressed substantial interest in continuing to grow them. With some support to continuing quality seed systems this diffusion is expected to accelerate over time.

Farmer recall data generally are not very accurate as these Ethiopian farmers (and most small farmers in developing countries) do not know their exact areas and the principal crop use is for subsistence so they are not very accurate about quantities. More accurate estimation of yields would need to employ crop cutting and surveying. Nevertheless, we obtained farmers' estimates of their yields with different varieties and fertili-

Figure 2. Yield Comparisons between the New *Striga* Resistant and other sorghum varieties in Kobo valley



zation techniques. Sorghum yields are fairly high in this fertile valley. Figure 2 indicates that farmers generally perceive that the new cultivars are out yielding the local cultivars and that there are returns even in this fertile valley to the recommended *Striga* resistant cultivars and inorganic fertilizer.

Marketing Strategies and Introduction of New Technologies in central Mozambique

From the involvement in the Marketing-Processing development project (see Figure 1 above in this section) has come the recognition that the intensification of sorghum and millet production depends upon farmers receiving higher prices. Low farmer prices are due to selling at the post harvest price collapse period, the price inelastic demand for most staples in developing countries resulting in price collapses in good rainfall years, and the downward price pressures from food aid in bad rainfall years.

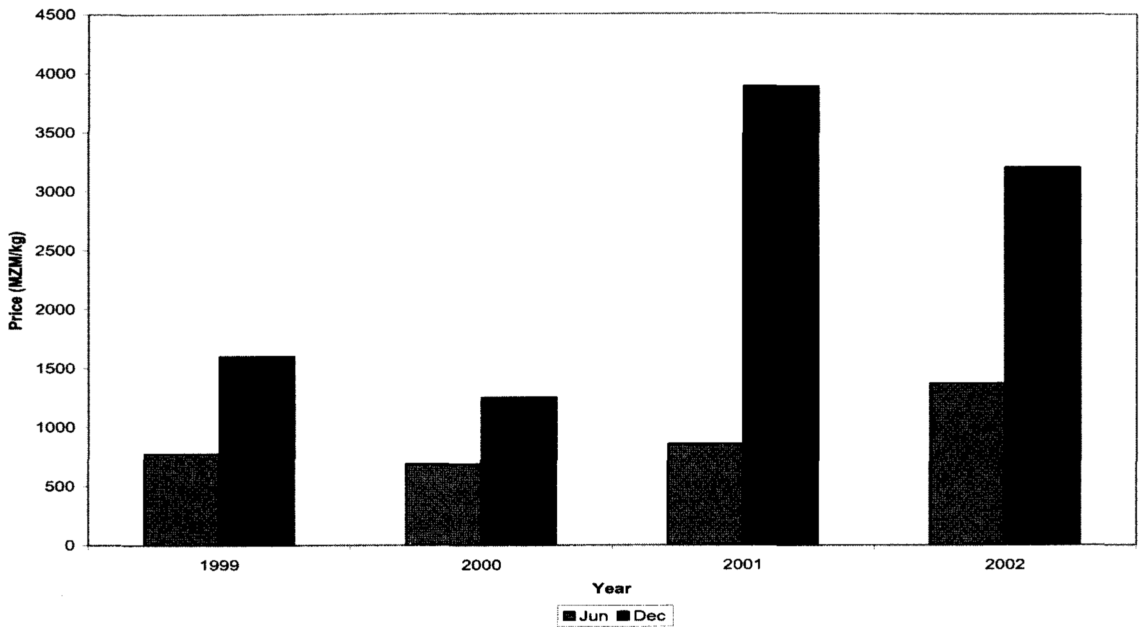
The fieldwork of Rafael Uaiene was in the main maize zone in Central Mozambique, Manica. Sorghum is also an important crop here but rainfall averages 1100 mm/year, soils are fertile and infrastructure is good. In spite of numerous activities of the public sector and various NGOs new cereal technology introduction has been minimal and, where successful, has been associated with subsidized inputs as for fertilizer and/or credit.

Available new sorghum technologies were not an improvement over traditional cultivars as most new sorghum cultivars were early and therefore subject to bird attack, increased head bug and mold complexes, and lack of farmer interest during normal and good rainfall years. Local cultivars were also predominantly Guineas as opposed to the new Caudatum cultivars, which are much more subject to birds and the head bug-mold complex. In higher rainfall, prime zones, such as Manica, sorghum is there principally to take advantage of the lower fertility soils and to diversify the production of the basic food staple for the bad rainfall years. So unless a longer season, higher yielding sorghum is produced not only is new sorghum technology not going to be introduced but also we would expect sorghum to disappear from the crop combination as improved maize technologies are introduced. Nevertheless, the results for maize here would be expected to be relevant for sorghum in other regions where rainfall is lower and sorghum is the principal cereal.

The potential gains to two types of marketing intervention are illustrated in Figure 3. By selling six months after the post harvest price collapses there are substantial differences in prices. These price differences indicate the potential benefits to an inventory credit program. The costs are the direct storage costs, grain losses over the six-month period of storage, and the costs of borrowing the money to store (opportunity cost of capital). When simple economic analysis was undertaken (partial budgeting), inventory credit was a profitable activity for both of the traditional cereal production techniques (sorghum and millet) and for the new maize technologies.

Using farm-programming models no new technology would not be introduced for maize production in the absence of at least one of the new marketing strategies (Table 2). If inventory credit were available, 1.5 ha of new maize technology would be adopted and farm income increased by 58%. The farm needs to moderately expand liquidity but this can be done by selling small animals. There is still a very high return to further capital invested, with a shadow price of capital of 82%. So we would expect a further dynamic effect of farmers' reinvesting their

Figure 3. Maize price variation between June and December in Manica, Mozambique (1998-2002)



1 US$=MZM 23,854
Source: SIMA (various years)

increased profits. Over time the income effect would be even larger as farmers respond to the high potential returns of further investments in inputs.

There are two other marketing strategies evaluated. The expansion of the processing demand for food and feed would moderate the price collapse in good rainfall years (see C and E above in Table 2). A modification by the public sector of polices to drive down the prices of agricultural products in bad rainfall years would also help increase the expected prices for farmers and thereby encourage more investments in purchased inputs (see D and E). The combination of all three marketing strategies would further increase the crop area in new technologies to 1.8 ha and increase farmers' incomes from present levels by 81%. A further dynamic effect of continuing adoption is expected from the high return on capital once the adoption process is begun.

Table 2. Technology introduction and the income effects of the different marketing strategies in Manica, Mozambique

	Model				
Technology	A	B	C	D	E
Traditional maize technology	3.2	2.5	2.5	2.5	2.3
Improved Maize+NPK	0	1.5	1.5	1.5	1.8
Traditional sorghum tech.	0.5	0	0	0	0
Beans	0.4	0.4	0.4	0.4	0.4
Cowpeas	0.50	0.5	0.5	0.5	0.5
Cotton	0.9	0.6	0.6	0.6	0.5
Expected income	$357	$565	$610	$598	$645
Income increase (%)	-	58	71	68	81
Shadow price of capital (%)		82	82	82	82

A. Base Model; B. Inventory Credit; C. Inventory credit and moderation of price collapse in good and very good states of nature; D. Inventory credit and moderate public intervention in bad years and E. Combination of scenarios B+C+D

1 USD $ =MZM 23,854 (IMF, 2004) Source: Model results

Networking Activity

Dr. Rooney, Felix Baquedano and Dr. Sanders spent approximately two weeks in El Salvador and Nicaragua in the summer of 2003. The objective of the trip was to explore extending the Marketing-Food Technology project into Central America. Felix Baquedano submitted a research proposal to a local funder and that was useful for his present field research even though not successful in obtaining funding. A new potential graduate student was identified from El Salvador and future funding promised by the INTSORMIL Central American program. An extensive trip report reporting on marketing and food/feed processing was also produced.

Dr. Sanders participated in the Eritrean workshop in September 2003 in Asmara, Eritrea to introduce *Striga* resistant sorghums and associated technologies in the highlands. Sorghum is the principal cereal in Eritrea. He presented a paper there and interacted with participants.

Botorou Ouendeba spent two months in the fall of 2003 with Drs. Sanders and Tahirou Abdoulaye at Purdue developing a five-year research program for funding from the USAID regional office in Bamako, Mali. One objective of this work was the revision of the two concept papers on Marketing and Food Technology respectively and a third paper on the first year results from the Marketing-Processing development work. The three papers were combined and printed in a bulletin and widely distributed.

Ouendeba Botorou and Dr. Sanders spent two weeks in Nigeria in March 2004. This trip was in response to the request from Dr. A. Levine of USAID, Nigeria to evaluate the possible extension of our Sahelian Marketing-Processing program into northern Nigeria. Collaborating with on-going programs of IITA, Global 2000, IFDC and the Nigerian government we visited farm trials and processors and made a report to Dr. Levine and others on our observations and suggestion for future activities.

In May-June 2004 Ouendeba Botrou, Tahirou Abdoulaye and Dr. Sanders spent six weeks reviewing the progress of the Marketing-Processing project visiting farmers' groups, food and feed processors in four Sahelian countries. A summary trip report is now available and Tahirou Abdoulaye is making the calculations to estimate the income gains from the new technologies and from the marketing strategies. These estimates will be incorporated into another paper and compared with the results for 2002-03.

Publications and Presentations

Journal Articles

Abdoulaye, Tahirou and J.H.Sanders, in press. Stages and determinants of fertilizer use in semiarid African agriculture. Agricultural Economics, 39 pages.

Sanders, J. H. and B. I. Shapiro, 2003. Crop technology introduction in semiarid West Africa: Performance and future strategy. Journal of Crop Production, 9, 2 and 3, 559-592.

Vitale, Jeffrey D. and J. H. Sanders, in press. New markets and technological change for the traditional cereals in semiarid Sub-Saharan Africa: The Malian case. Agricultural Economics, 55 pages.

Book Chapter

Sanders, J.H. and B. Shapiro, in press. Policies and market development to accelerate technological change in the semiarid zones: A focus on Sub-Saharan Africa. Dryland Agriculture, American Society of Agronomy, 40 pages.

Conference Proceedings

Sanders, J.H. and B. Shapiro, (in press) Policies and market development to accelerate technological change in the semiarid zones: A focus on Sub-Saharan Africa. Proceedings from the international INTSORMIL conference held in Ethiopia in November 2002, 26 pages.

Bulletin

Ouendeba, B. 2003. Market improvements and new food crop technologies in the Sahel. INTSORMIL, University of Nebraska, Lincoln, Nebraska.

Conference Presentations

Sanders, J.H. 2003. Public policies, markets and new sorghum technologies. Workshop on the Introduction of *Striga* Resistant Sorghums, Asmara, Eritrea.

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

Project UNL 213
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Summary

Principal investigators in INTSORMIL Project UNL-213 continue with international research efforts related to nutrient management and use efficiency in West Africa and Central America. Microdose fertilizer application increased pearl millet grain yield across three years and three West African countries by 249 kg ha^{-1} (49%), but results were variable as indicated by interaction effects. Microdose application resulted in similar net nutrient removal as the zero fertilizer control. Over 30 kg ha^{-1} N and approximately 10 kg ha^{-1} P were required to eliminate mining of nutrients from the soil. The highest grain and stover yields required 20 kg ha^{-1} P and 30 kg ha^{-1} N. Rotation of rows between pearl millet and cowpea in a row-intercropping system increased pearl millet grain yields by 114 kg ha^{-1} (9%) over monoculture pearl millet, thus increasing the land efficiency ratio by 42%. Zaï plus 300 g manure per hill increased grain sorghum grain yields greatly due to water conservation and nutrient application. Study was initiated to determine best management practices for production of grain sorghum for dolo (traditional beer) in Burkina Faso.

In Nicaragua, nitrogen application increased sorghum grain yields quadratically for both photoperiod insensitive varieties with the highest yields of 3.9 Mg ha^{-1} being produced at the highest N rate of 194 kg ha^{-1}, but economic analysis indicated 129 kg ha^{-1} to be the optimal rate. Little difference in nitrogen use efficiency was found among the photoperiod insensitive varieties tested, indicating that broader screening of germplasm in Central America sorghum breeding programs will be needed to identify and develop high nitrogen use efficient photoinsensitive sorghum varieties. In El Salvador, the photoperiod sensitive varieties 85SCP805 with 47 kg ha^{-1} N application increased grain yield by approximately 800 kg ha^{-1} (26%) over the local check without N application

Research in the United States determined that 90 kg ha^{-1} N produced optimum pearl millet grain yields in Eastern Nebraska, but N application often resulted no economic yield increase in the drier western Nebraska production environment. Yield component studies indicated that newer released grain sorghum had more interaction among yield components, although yield was only slight higher.

INTSORMIL Project UNL-213 emphasizes capacity development through graduate education, short-term training, and coordination of the Central America Regional Program. Graduate students from Chad and the U.S. are working on M.S. degrees.

Objectives, Production and Utilization Constraints

Objectives

Conduct multi-year research on microdose, N and P fertilizer application on pearl millet grain yield, nutrient removal, and changes in soil nutrient levels in Burkina Faso, Mali and Niger.

Conduct research on mechanized (i.e. animal traction) Zaï production system for pearl millet in Burkina Faso, production practices for traditional beer production in Burkina Faso, weed control interactions with fertilizer rates in Mali, fertilizer rate by plant population for hybrid grain sorghum seed production in Niger, and use of poultry manure as nutrient and soil improvement for pearl millet production in Niger.

Evaluate grain sorghum and maize hybrid from the 1950s, 1970s and 1990s under low and high water holding capacity soils, wide and narrow rows, and dryland and irrigated environments to better understand the shift of dryland sorghum area to maize in the western corn belt.

Determine recommended production practices for pearl millet production in Nebraska.

Conduct N rate and N use efficiency studies for grain sorghum production in El Salvador and Nicaragua to identify N use efficient varieties and determine N rate recommendations.

Increase research human capital in West African and Central American countries where pearl millet is an important crop through graduate education, short-term training and through mentoring former students upon return to their home country.

Collaborate with national extension services and NGO/ PVOs in transferring improved pearl millet and grain sorghum agronomy practices.

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher pearl millet and sorghum grain and stover yields. This involves systems which increase nutrient and water availability to growing crops, and produces desired uniform stands. Present efforts emphasize inorganic and organic fertilizer management, developing varieties and cropping systems to improve nitrogen use efficiency of sorghum, water management of traditional and improved cultivars, and weed control strategies. Cropping system research efforts require long-term investments of well-trained, interested scientists and stable funding. Education of additional scientists in crop management 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 and grain sorghum are 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, project activities are generally conducted as either as graduate education programs for scientists from this region and as mentored collaborative activities upon return of former graduate students. Studies have been initiated with collaborators in Central America on nitrogen fertilizer management and identification of nitrogen use efficient genotypes for grain sorghum production which is also a critical issue in the region. In the U.S. Great Plains, production practice recommendations for planting date, nitrogen rate and water supply for high yielding, dwarf pearl millet hybrids are being determined to help adoption as an alternate grain crop. Due to pearl millet having relatively higher grain yields than other crops with late planting, double cropping research with winter wheat will be conducted. 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)

Nitrogen Rate Recommendations for Pearl Millet Production in Nebraska (Nouri Maman, Ph.D. Thesis)

Research Methods

Field experiments were conducted in five different environments in eastern and western Nebraska. The pearl millet hybrids '68 x 086R' and '293A x 086R' were grown at N rates of 0, 45, 90 and 135 kg N ha^{-1}. Grain and stover yield, and yield components were determined, nitrogen use efficiencies calculated, and marginal product economic analysis was conducted.

Research Results

Grain and stover yield and protein concentration varied among environments. Low yield potential in western Nebraska due to drought limited pearl millet response to N application. Hybrids had similar yield, protein concentration and N use efficiency responses to N rate, although the hybrid '293A x 086R' produced approximately 200 kg ha^{-1} more grain. In the higher rainfall environments of eastern Nebraska, maximum grain yields were between 4040 and 4890 kg ha^{-1} with 90 to 135 kg N ha^{-1}. Protein concentration increased with N rate in all environments, and most measures of N use efficiency. Economic analysis indicated 90 kg N ha^{-1} to be the optimal rate for eastern Nebraska.

Grain Sorghum - Maize Hybrid Yield Components in Dryland and Irrigated Environments (Delon Kathol, M.S. Thesis)

Research Methods

A three-year study was initiated in 1999 to determine the importance and physiological basis for shift in dryland sorghum production to maize production in eastern Nebraska. Best hybrids were identified from the 1950s, 1970s and 1990s as the best performing hybrids in the University of Nebraska Performance Tests and they were produced in three environments each year. The environments were sandy loam and silty clay loam soil types, and irrigated and dryland water regimes on the silty clay loam soil. Yield and yield component relationships were determined by correlation and path analysis procedures.

Research Results

Correlation analysis indicated that for corn and sorghum hybrids released during the last 50 years, all yield components were very important for yield determination. No interaction among yield components was present for corn hybrids, and sorghum hybrids from the 1950's. Newer grain sorghum hybrids had more interactions than old hybrids, especially for the effects of the number of panicles m^{-2} with kernels $panicle^{-1}$ and to a lesser extent with kernel weight. In all environments panicles (or ears m^{-2}) were correlated with yield of both crops, while kernels $panicle^{-1}$ (or ear) was significant under irrigation for both crops, and on dryland silty clay loam soil for maize.

Rotation of Sorghum with Nodulating and Non-Noduating Soybean Influence on Grain Yield, N Nutrition and Grain Quality (Nanga Kaye Mady, M.S. Study)

Research Methods

A long-term crop rotation experiment with continuous sorghum, sorghum rotated with nodulating soybeans, sorghum rotated with non-nodulating soybeans, continuous nodulating soybean and continuous non-noduating soybean with different fertilizer applications (zero, 90 kg ha^{-1} N to sorghum and 45 kg ha^{-1} N to soybean, and annual feedlot manure) is being studied with the goal to separate N and non-N effects of crop rotation. Data collection started in 2003, and included grain and stover yield, soil water, soil NO_3-N, relative greenness using a SPAD chlorophyll meter, yield components and grain quality assessment. Preliminary results have been analyzed using analysis of variance.

Research Results

Cropping sequence * Fertilizer interaction effects were present for most parameters measured (Table 1). Irregardless of cropping sequence, manured plots had the highest grain and stover yield, grain N concentration and TADD recovery, which is a measure of kernel hardness. Without fertilizer application, the zero control with sorghum following non-nodulating soybean had the lowest grain and stover yields. Kernel weight, test weight (bulk density) and true density were either not influenced or influenced to a small degree by treatments in the study. These preliminary sorghum yield results suggest that approximately 80% of the yield increase from the nitrogen contribution from the previous soybean crop, while about 20% of the yield increase is due to other rotational benefits. In addition, increasing nitrogen supply, whether from fertilizer application or cropping sequence, increases the grain N (i.e., protein) concentration to a greater extent than quality measures related to kernel hardness.

International

Microdose Fertilizer Study (Taonda Jean-Baptiste - Burkina Faso, Minamba Bagayoko and Samba Traoré - Mali, and Seyni Sirifi - Niger)

Research Methods

Three-year central studies were initiated on-station in

Table 1. Influence of cropping sequence and fertilizer treatments on grain sorghum yield and grain quality in 2003, Mead, NE.

Cropping sequence	Fertilizer treatment	Grain yield	Grain nitrogen	100-kernel weight	Test weight	True density	TADD recovery
		Mg ha^{-1}	%	g	lbs. bu^{-1}	g cc^{-1}	%
Sorghum following nodulating soybeans	Zero	6.6	0.89	2.35	59.9	1.333	27.3
	Nitrogen fertilizer	7.2	1.38	2.05	60.1	1.310	30.8
	Manure	7.2	1.48	2.32	60.5	1.393	34.0
Sorghum following non-nodulating soybeans	Zero	4.9	0.88	2.45	59.7	1.463	27.6
	Nitrogen fertilizer	7.5	1.03	2.34	60.4	1.453	27.6
	Manure	7.8	1.30	2.34	60.8	1.205	38.8
Continuous sorghum	Zero	4.4	1.04	2.39	56.5	1.400	33.4
	Nitrogen fertilizer	6.4	1.09	2.21	60.7	1.286	33.2
	Manure	6.8	1.27	2.31	61.0	1.384	43.2
		---------------------------- F Probability --------------------------------					
Cropping sequence		<0.01	NS	NS	NS	NS	0.02
Fertilizer		<0.01	<0.01	0.02	<0.01	NS	<0.01
Cropping sequence * Fertilizer		<0.01	<0.01	0.05	<0.01	NS	0.06

Burkina Faso (pearl millet), Mali (pearl millet on sandy soil and grain sorghum on heavy soil) and Niger (pearl millet) in 2001. A randomized complete designed study was used with four replications. Treatments consisted of zero, microdose (cap-full of complete fertilizer in the seed hill at planting), Microdose + 20 kg/ha $^{-1}$P, microdose + 40 kg ha^{-1} P, microdose + 30 kg ha^{-1} N, microdose + 60 kg ha^{-1}, microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N, and microdose + 40 kg ha^{-1} P + 60 kg ha^{-1} N. Each plot was sampled prior to initiating the experiment so that soil nutrient levels after three-years could be determined. Grain and stover yield were collected and estimated net N and P removal calculated using data from Maman et al. [African Crop Science Journal 8: 35 - 47, 1995]. In addition, satellite studies were conducted on farms using zero, microdose and microdose + 20 kg ha^{-1} P or 20 kg ha^{-1} P + 40 kg ha^{-1} N treatments. One replication was planted per farm, and in the data analysis farms were considered to be replications.

Research Results

Analysis of variance indicated that grain and stover yields to fertilizer treatments varied by country and year. However, on the average, microdose fertilizer application increased grain and stover yield by 49%, with the 42 to 62% increase in all three countries (Table 2). Clearly the microdose application is a low cost investment that has a high probability to increase grain yields across the West Africa pearl millet production area. Yield responses were greater for P application than N application, but application of microdose plus 40 kg ha^{-1} P and 60 kg ha^{-1} N was required to maximize yields of grain and stover. Estimated net N and P removal indicated that the microdose and zero treatments remove approximately the same amount of P annually, and 25 to 34 kg ha^{-1} N. Applications of over 30 kg ha^{-1} N was necessary to replace removal in grain and stover. The data suggests that less than 10 kg ha^{-1} application is necessary to replace removal.

Pearl Millet -Cowpea Intercrop/Rotation Study (Samba Traoré - Mali)

Research Methods

A randomized complete block designed experiment to evaluate the interactive effects of intercropping and rotation of crops within intercropping systems was conducted at the Cinzana Research Station in 2000, 2001 and 2002. Recommended row intercropping systems was used with three genotypes, and rotation was incorporated by alternating the rows in the field. Grain yield and land equivalent ratios were determined, and data were analyzed using analysis of variance procedures.

Research Results

Intercropping usually reduces the grain yield of both intercropped species. In the intercrop system of rotating rows with cowpea over three years actually increased grain yield by 114 kg ha^{-1} over that of sole cropped millet, resulted in a land use of efficiency of 1.42 indicating a 42% increase use efficiency, and a substantial increase in profit. Although this presents some logistical problems in the field (i.e. marking rows), the increased productivity likely merits the extra management effort.

Zaï and Other Fertilizer Treatments on Grain Sorghum (Taonda Jean Baptiste - Burkina Faso)

Research Methods

A study was conducted at SARIA in 2002 and 2003 to compare a no fertilizer check (farmer practice), microdose fertilizer application at planting, Zaï with compost 300 g $hill^{-1}$ compost application and the recommended fertilizer rate of 75 kg ha^{-1} of 15-15-15 complete fertilizer at planting and 24 kg ha^{-1} N 45 days after planting.

Research Results

Microdose and recommended fertilizer rates increased grain yield by approximately 600 kg ha^{-1} stover yield by approximately 1000 kg ha^{-1}. The Zaï plus compost increased grain yield over the control by 1200 kg ha^{-1}, and stover yield increased by 2000 kg ha^{-1}. The water conservation and nutrient supplying of the Zaï plus compost system clearly increases yields greater than the other systems in the study.

Sorghum Production Practices for Dolo (Traditional Beer) Production in Burkina Faso (Siebou Pale)

Research Methods

Previous research has shown that the red grain sorghum varieties IRAT 9 and ICSV 1001(Framida) to be superior for

Table 2. Fertilizer treatment influence on pearl millet, grain and stover yield, and estimated net nutrient removal/addition (averaged over 3 years and 3 replications).

	Grain Yield				Stover Yield				Estimated Net Nutrient Removal/Addition	
Fertilizer Treatment	Burkina Faso	Mali	Niger	Mean	Burkina Faso	Mali	Niger	Mean	N	P
	kg ha^{-1}									
Zero	398	772	341	504	1072	1644	3006	1907	-34	-4
Microdose	646	1091	524	753	1735	2789	3033	2519	-25	-4
Microdose + 20 kg Pha^{-1}	844	1140	743	909	2039	2974	4121	3045	-43	+19
Microdose + 40 kg Pha^{-1}	904	1349	624	959	2009	3854	3264	3042	-44	+34
Microdose + 30 kg N ha^{-1}	657	1050	608	771	1600	2870	3882	2784	-11	-4
Microdose + 60 kg N ha^{-1}	727	1080	608	805	1716	3090	4113	2973	+20	-5
Microdose + 20 kg Pha^{-1} + 30 kg N ha^{-1}	941	1216	960	1039	2239	3630	4840	3569	-20	+13
Microdose + 40 kg Pha^{-1} + 60 kg N ha^{-1}	1108	1274	917	1100	2402	4231	4389	3674	+8	+33

dolo (traditional beer) production. A study was initiated in 2003 to develop production practice recommendations for grain yield and dolo quality. The study is being conducted with a randomized complete block and split plot treatment arrangement. The whole plot is water management (shallow cultivation control, tied ridges, manual Zaï, mechanized (animal traction Zaï, and dry soil tillage) and split plots of fertilizer levels (zero, micodose with 4g 15-15-15 per hill, recommended rate of 75 kg ha^{-1} 15-15-15 plus 50 kg ha^{-1} urea, and microdose plus 20 kg ha^{-1} P and 30 kg ha^{-1} N). Grain yield and quality tests associated with dolo production are being collected.

Research Results

In 2003, tied ridges and mechanized Zaï resulted in the highest yields for Framida, while tied ridges and dry soil tillage produced the highest yields for IR12. Also the microdose plus 20 kg ha^{-1} and 30 kg ha^{-1} produced yields that were more than 50% higher than all the other fertilizer treatments. Dolo quality tests are presently being conducted.

Nitrogen Use Efficiency (NUE) of Photoperiod Insensitive Sorghum Germplasm (Max Hernández, Leonardo García and Orlando Téllez - El Salvador and Nicaragua)

Research Methods

A three-year study was conducted at two locations in El Salvador and two locations in 2002 - 2003 in Nicaragua in 2002 - 2003, and three locations in Nicaragua and one in El Salvador in 2003 - 2004 with the objective to determine if NUE differences exist among photoperiod insensitive sorghum varieties and optimal N fertilizer rates for grain sorghum production, and to identify high NUE varieties. At each location either 24 or 13 lines from breeding programs were grown with and without N in a randomized complete block design with four replications. Grain and stover yield, and N concentration of grain and stover at harvest were collected, and agronomic characteristics. Data analysis was done using analysis of variance procedures.

Research Results

The El Salvador location in 2003 provided little useful information due to site selection of a soil with relatively high nutrient level. In Nicaragua, large differences among sorghum lines and locations were present, but a line by N level interaction was only present for one out of three locations. It appears likely that a wider range of germplasm will be needed to incorporate high nitrogen use efficiency into photoperiod insensitive varieties in Central America.

Determination of the optimum N application Rate for Grain Sorghum Production in the Pacific Zone of Nicaragua (Orlando Téllez Obregón, INTA, Nicaragua)

Research Methods

The white grain sorghum varieties (INTACNIA, RCV, Pinolero 1, and Tortillero Precoz) were grown in four years between 2000 and 2003 at the CEO experiment station near Leon, Nicaragua with N application rates of zero, 65, 129 and 194 kg ha^{-1} N. Grain and stover yield, and N concentrations were collected and analyzed using analysis of variance.

Research Results

Increasing N application from zero to 194 kg ha^{-1} increased sorghum grain yield quadratically from 2.1 to 3.9 Mg ha^{-1}, and the response would suggest that yields would be further increased with higher application rates. This yield response to N fertilizer application was consistent across varieties, except Tortillero Precoz had a small yield increase than other varieties between the highest N rates of 129 and 194 kg ha^{-1}. Economic marginal return analysis indicated that the optimal rate to recommend to producers is 129 kg ha^{-1}.

Nitrogen Use Efficiency (NUE) of Photoperiod Sensitive (Maicillo Criollos) Sorghum Varieties for Relay Intercropping with Maize (Maximo Hernández - El Salvador)

Research Methods

Validation and transfer trials were conducted on 40 farms in collaborations with several NGOs. Validation trials with local variety with and without 47 kg ha^{-1} N, the new improved nitrogen use efficient variety 85SCP805 without N and with 47 kg ha^{-1} N were tested on hillside locations with poor soils. Plots were planted in June and harvested in December. In addition, the improved varieties 85SCP805, SOBERANO, CENTA S-3 and RCV were planted on 430 farms in Zone 3 to facilitate transfer to farmers fields, with 226 reports with results obtained.

Results

The improved variety 85SCP805 produced 130 kg ha^{-1} more grain than the local check without N application. Nitrogen application increased grain yield of 85SCP805 by approximately 700 kg ha^{-1}, and of the local check by approximately 300 kg ha^{-1}. In spite of the clear yield advantage of using the improved variety 85SCP805 with N application, the economic analysis indicated that the improved variety without N fertilizer application had the greatest net return due to the high local cost of N fertilizer. In the improved variety transfer plots, all improved varieties produced higher yields than the local check variety, with the previously released RCV consistently yielding better than the local check.

Simulation Modeling of Growth, Development and Yield of Pearl Millet in Nebraska and Niger

Dr. Gerit Hoogenboom, SANREM CRSP, University of Georgia, Griffin, GA

Methods

The CSM-CERES-Millet model of the DSSAT Version 4.0 was calibrated for conditions in Nebraska, USA and Sadore, Niger. The observed data for calibration were obtained from two experiments conducted at the University of Nebraska under rainfall conditions in 1995 and 1996. Daily weather records were obtained from an automated weather station located at Mead, Nebraska (latitude 41.25; longitude 96.58; elevation 366 m). The soil at the experimental site was a silty clay loam. The experiment included three pearl millet hybrids, i.e., 59022A x 89-083, 1011A x 086R and 1361M x 6Rm and two nitrogen fertilizer levels, i.e., a control with no N and 78 kg ha^{-1} of N.

For Sadore, Niger, two experiments were conducted in 1995 and 1996. The soil was sandy and the daily weather records were obtained from ICRISAT, Sadore, Niger (latitude 13.23; longitude 2.28; elevation 210 m). These two experiments consisted of three hybrids, i.e., Heini Kirey, Zatib and 3/4HK and two nitrogen fertilizer levels, i.e., a control with no N and 23 kg ha^{-1} of N.

The CSM-CERES-Millet model includes seven cultivar-specific coefficients that require modification for new cultivars that have not been previously used with the crop model. The specific cultivar coefficients adjusted for millet during the calibration process were:

- P1: Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 10ºC) during which the plant is not responsive to changes in photoperiod.
- P20: Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values greater than P20, the rate of development is reduced.
- P2R: Extent to which the phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P20.
- P5: Thermal time (degree days above a base temperature of 10ºC) from beginning of grain filling (3-4 days after flowering) to physiological maturity.
- G1: Scaler for relative leaf size.
- G4: Scaler for partitioning of assimilates to the panicle (head).
- PHINT: Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

The cultivar coefficients were determined in sequence, starting with the phenological development parameters, followed by the crop growth parameters. This order was required because of the dependence of the latter parameters on the performance of the vegetative and reproductive development simulations. An iterative procedure was used to select the most appropriate value for each phenological and development parameter. Emergence, flowering, and maturity dates, growth analysis data and yield were used to calibrate the performance of the CSM-CERES-Millet model. The combination of coefficients that resulted in the smallest RMSE and the highest d value were selected as final cultivar coefficients.

Results

The 1996 growing season in Nebraska was characterized by abundant rainfall, while the 1995 growing season had only a small amount of rainfall. The rainfall in Niger for the millet growing season was higher than the rainfall in Nebraska.

The CSM-CERES-Millet model was able to accurately simulate crop phenology for millet grown in 1995 and 1996 in Nebraska. The average days observed from planting to anthesis was 62, while the simulated value was 63, with relative low values for RMSE and high values for the d statistic. In general, millet yield for the conditions in Nebraska was accurately simulated for 1995 and was underestimated for 1996. In 1996, abundant rainfall resulted in an increase in observed and simulated yield when compared to 1995.

For the conditions in Sadore (Niger), the observed and simulated values for days from planting to anthesis and from planting to physiological maturity were very similar, indicating that millet phenology was very accurately predicted by the model.

There was a large difference in yield between Nebraska and Niger. Average observed yield for three hybrids for the two years was 2788 kg ha^{-1} for Nebraska and only 838 kg ha^{-1} for Sadore. The poor soil fertility conditions in Niger can explain in part these results as well as the low level of N that was applied.

The CSM-CERES-Millet model was able to accurately simulate growth, development and yield for millet grown in two contrasting environments, e.g., Nebraska, USA and Sadore, Niger, and under different management practices that included various hybrids and nitrogen fertilizer treatments.

Networking Activities

Workshops

American Society of Agronomy Meetings, Denver, CO. 2 - 6, Nov. 2003.

West Africa Principal Investigators Meeting Followed by UNL-213 Meeting, 17 - 22 April, Ouagadougou, Burkina Faso.

Max Hernández (El Salvador) and Orlando Téllez Obregón, PCCMCA Meeting, 18 – 22 April, 2004, San Salvador, El Salvador.

Research Investigator Exchange

Delon Kathol (U.S.) will complete his M.S. degree in the coming year. Nanga Kaye Mady (Chad) started an M.S. degree in May 2003 and should finish his degree in August 2005.

Research Information Exchange

Funds passed through to Burkina Faso, Mali and Niger to assist with collaborative research.

Pearl millet growth and nutrient uptake data was shared with Dr. Gerrit Hogenboom, Univ. of Georgia and SANREM CRSP for modeling research and development of decision aid tools.

Visited INTSORMIL research efforts in El Salvador and Nicaragua in Dec. 2003, and Burkina Faso in April 2004.

Seminar on "INTSORMIL Crop Management Research in West Africa and Nebraska" was presented at CIRAD, Montepellier, France, 15 April, 2004.

Publications and Presentations

Abstracts

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Maman, Nouri, D.J. Lyon, S.C. Mason, T.D. Galusha and R. Higgins. 2003. Pearl millet and grain sorghum yield response to water supply in Nebraska. Agron. J. 95: 1618 - 1624.

Traoré, Samba, S.C. Mason, A.R. Martin, D.A. Martinson and J.J. Spotanski. 2003. Velvetleaf interference effects on yield and growth of grain sorghum. Agron. J. 95: 1602 - 1607

Maman, Nouri, S.C. Mason and D.J. Lyon. 2004. Yield components of pearl millet and grain sorghum across environments in the Central Great Plains. Crop Sci. 44: (In Press).

Undergraduate Theses

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Ajax Fonseca, Lenin Lopez, Eliezer Manzanares y Francisco Calero. 2004. Evaluacion de 25 lineas de sorgo en San Ramon, Matagalpa (Evaluation of 25 sorghum lines for nitrogen use efficiency at San Ramon, Matagalpa). Universidad Nacional Agraria, Managua, Nicaragua

Ruby Altamirano y Mario Gadea..2004. Evaluacion del uso de frijol Mungo como fuente alternativa de N en sorgo en San Ramon, Matagalpa [Evaluation of mungbean as an alternate N source for sorghum at San Ramon, Matagalpa].Universidad Nacional Agraria, Managua, Nicaragua

Ramiro Manzanares y Roberto Hernadez. 2004. Evaluacion del uso de frijol Mungo como fuente alternativa de N en sorgo en Tisma, Masaya (Evaluation of mungbean as an alternate N source for sorghum at Tisma, Masaya). Universidad Nacional Agraria, Managua, Nicaragua

Alex Gonzalez y Willar Green. 2004. Evaluacion de 25 lineas de sorgo en Posoltega, Leon. (Evaluation of 25 sorghum lines for nitrogen use efficiency at Posoltega, Leon.) Universidad Nacional Agraria, Managua, Nicaragua

Maury Gurdian. 2004. Evaluacion de 16 lineas de sorgo en Posoltega, Leon. (Evaluation of 16 sorghum lines for nitrogen use efficiency at Posoltega, Leon.) Universidad Nacional Agraria, Managua, Nicaragua

Soil and Water Management for Improving Sorghum Production in Eastern Africa

Project UNL 219

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Summary

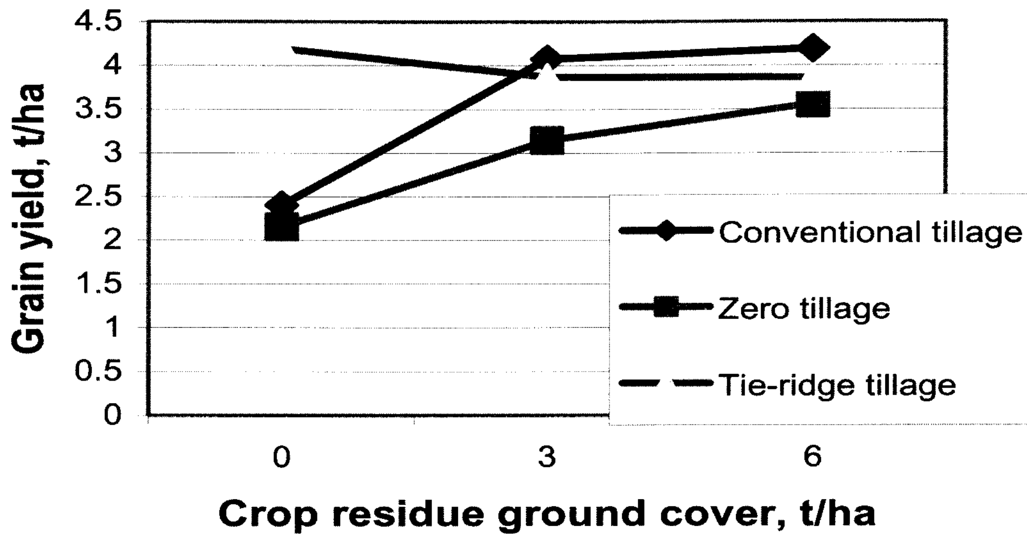
Opportunities to increase yield or to reduce production costs have been identified while promising research continues. Researchers working with farmers in Ethiopia have verified that tie-ridge tillage can result in higher yields in many places. They have tentatively identified likely niches and opportunities for tie-ridge tillage and for tie-ridging and planting implements; research is continuing in four semi-arid sorghum production areas. Low levels of fertilizer and manure use, nitrogen credits from legumes in rotations, and research with farmers for the development of a reduced tillage system are being addressed in two semi-arid areas of eastern Uganda using participatory approaches. Soil properties have been related to P availability for diverse soils of Ethiopia, Uganda and Mozambique; the importance of termite activity to P sorption on sandy soils has been determined. The second year of research on the use of starter fertilizers for no-till sorghum production in eastern Nebraska was completed with a total of 12 trials conducted in 2002 and 2003; the results show little profit opportunity for the use of starter fertilizer with typical planting dates. Seeking to improve the productivity of no-till sorghum production systems, research on occasional tillage for no-till situations was started in 2003.

Improved institutional capacity has been achieved in Ethiopia and Mozambique. Two students completed their M.S. degrees at Alemaya University with partial support from this project. Their thesis research focused on water management for sorghum production; results will be presented at the 2004 ASA annual meeting. Soares Xerinda reported results of his research at the 2003 ASA annual meeting, and has completed his oral defense. Two international students are involved in the occasional tillage research, one for his Ph.D. dissertation and another for an M.S. thesis; the research is partly supported by INTSORMIL. The project supports the research of another graduate student on strategic lime placement for amendment of sandy soils. Data was collected for sorghum production areas of Ethiopia, Kenya and Uganda. A GIS referenced database is to be created that should be valuable to regional networking activities. Dr. Wortmann visited collaborators and research areas in Ethiopia and Uganda.

Objectives, Production and Utilization Constraints

- Evaluate tie-ridge and row-planting implements with farmers under their management at four locations in Ethiopia.
- Co-supervise soil and water management research projects of two M.Sc. students at Alemaya University.
- Conduct research with farmers in four villages in Eastern Uganda to evaluate soil fertility management practices and to develop a reduced tillage system with farmers.
- Explore opportunities for collaboration in Tanzania.
- Complete research on P sorption for soils of central and northern Ethiopia, eastern Uganda, and southern Mozambique.
- Define sorghum production areas and collect data for Ethiopia, Uganda and Kenya.
- Conduct research on starter fertilizer use in Nebraska under rainfed no-till conditions.
- Continue mentoring of an INTSORMIL sponsored graduate student at UNL.
- Initiate a study on the effect of occasional tillage on no-till sorghum-soybean systems.
- Initiate a study on the effect of pH stratification and localized lime placements on sorghum yield.

Fig. 1. Tillage and ground cover effects on sorghum yield in the Central Rift Valley of Ethiopia. LSD 0.05 for the interaction was 0.89 t/ha.



Inadequate nutrient supply and water deficits are the primary production constraints addressed in this water and nutrient management research.

Research Approach and Project Output

Nutrient and water management research in Ethiopia. Research to evaluate tillage and implement options continued with trials established in four semi-arid sorghum production locations in 2003 and 2004 which vary in elevation from 1300 to 1800 m. The locations include Welench'iti, Miesso, Sirinka, and Mekelle at Abergele. Tillage treatments differ according to location but generally include some variation of the following:

- Traditional, e.g., tilled with *maresha*, broadcast sowing, and *shilishalo* for weed control.
- Tie ridging using modified *maresha* (a test implement) with tie ridges made before planting. Plant in the furrow with a row planter (test implement).
- In-furrow row planting with test implement but tie ridge at first weeding with the modified *maresha.*
- Conservation tillage or reduced tillage.

Nearly all farmers found tie-ridging to be superior to their typical practice of flat cultivation for runoff control and crop performance. Tie-ridging at planting was generally preferred with some suggesting rebuilding the ridges when the crop is 'knee high' and to control weeds. The tie-ridger was seen as culturally appropriate as it is a simple modification of the *maresha* and it was well rated for agronomic effectiveness, usability and affordability.

In his thesis research, Tewodros Mesfin's observed improved yield with tie-ridging than with no-till or conventional tillage in the Central Rift Valley with little or no ground cover by crop residues (Fig. 1). Application of 3 t ha^{-1} of crop residues after tillage resulted in significant yield increases for no-till and conventional tillage but had no benefit for tie-ridging which had a relatively high yield with no crop residue applied. Soil water availability was greater throughout the season with tie-ridging as compared to other tillage practices.

Gebreyesus Brhane completed his M.S. degree and evaluated various tie-ridging options for effects on soil water and crop yield in Tigray. Making the tie- ridges either before planting or at planting resulted in better soil water conditions and grain yield than tie-ridging at weeding time or with traditional tillage practices (Table 1). This research is being repeated in 2004, and a subset of the treatments is being evaluated at Nazret as well.

Preparations are underway to conduct training workshops for extension staff in early 2005 on practices to reduce water loss and to improve efficiency of water and nutrient use. Discussions are underway with partners in Ethiopia for a second phase in our support to soil and water management research in Ethiopia. Gebreyesus and Tewodros have been invited to visit UNL in 2004.

Table 1. Sorghum grain yield as influenced by tillage practices, Tigray, Ethiopia, 2003.

Treatments	Grain yield (t/ha)
Flat bed planting, traditional tillage	1.48
Tied-ridging four weeks before planting with planting in furrows	2.87
Tied-ridging four weeks before planting with planting on ridges	2.38
Tied-ridging at planting with planting in furrows	2.52
Tied-ridging at planting with planting on ridges	2.16
Shilshalo at four weeks after sowing	1.78
Tied-ridging at four weeks after sowing	2.12
LSD (P = 0.05)	0.725

Nutrient and water management research in Uganda. Research has been conducted with farmers in two communities each of Kumi and Katikwe Districts. Priority problems and research topics were determined with farmers in 2003. Following exploratory research during the first season of 2003, research protocols were revised. The second season of field research with the revised protocols is underway. Three research areas are being addressed: the use of low levels of fertilizer and manure; N credits from rotations with cowpea or green gram as compared to mucuna; and the development of a reduced tillage system with farmers. This research is to continue for another two seasons with the expectation of reporting results at the 2005 ASA meeting and decision on future directions when Dr. Kaizzi visits Nebraska in 2005.

Project activities in Tanzania. Communications with researchers at Ilonga ARC in Tanzania has not lead to a workplan; further discussion is planned for 2004-2005.

Phosphorus fixation of soil in Ethiopia, Uganda, and Mozambique. Phosphorus sorption isotherms were determined for 36 soil samples collected from Ethiopia, Uganda, and Mozambique. As termites have much influence on soil properties in Uganda and Mozambique, companion soil samples were also obtained from and near termite mounds. Percent clay content was generally well correlated with P sorption maximum. P sorption maximum increased moving south from Entisol and Inceptisol of northern Ethiopia to the more developed central and eastern vertic and/or calcareous soils. Phosphorus sorption maxima were 44 to 390% higher in sandy soils of Uganda and Mozambique with termite mounds as compared to the nearby sandy soils. The texture of soil in termite mounds was finer than for the surrounding sandy soil which accounts for some of the increase in P sorption capacity. P sorption maxima decreased by about 8% in fine-textured soil influenced by termites. P sorption of Uganda and Mozambique soils were well correlated with acid ammonium oxalate extractable aluminum but not iron. In sandy soils influenced by termites, there was also an increase in acid ammonium oxalate extractable aluminum. Correlation of acid ammonium oxalate extractable aluminum and iron with P sorption of Ethiopia soils was generally weak. This is probably due to the greater influence of carbonates on P availability in these soils as compared to aluminum or iron.

Creation of sorghum database for Eastern and Southern Africa. Working with sorghum researchers in Ethiopia, Kenya and Uganda, 19 sorghum production areas were delineated for these three countries. Production data have been obtained for Ethiopia at the wereda level and for Uganda at the county level while preparations have been made to obtain these data for Kenya. Attribute data were obtained through interviews with sorghum experts, primarily with the national research organizations, on 45 production constraints, preferences for 11 phenotypic characteristics, six socio-economic issues, six sorghum-cropping systems and management practices, and the importance of 15 uses of sorghum products. A contract has been made with a GIS person in Uganda to compile the data into database and GIS formats, integrate data with soil and climate layers, analyze it and create tables and maps. We plan to obtain similar data for Mozambique in 2004-2005, and for Tanzania and Eritrea by the end of 2005. Collaboration with ASARECA-ECARSAM and ICRISAT in this project has been explored, and we hope to obtain support when results for Ethiopia, Uganda and Kenya are presented.

Mozambique. Soares Xerinda is completing his M.S. degree at UNL in August of 2004 and plans to return to Mozambique in September, in time to conduct field research during the 2004-2005 seasons. A workplan has been developed for field research at Chokwe and Manica, and to interview farmers and extension workers experienced with reduced tillage options and working with Sasakawa-Global 2000 in the Manica area.

Starter fertilizer for no-till sorghum production in Nebraska. This work was conducted by Soares Xerinda in partial fulfillment of the M.S. degree. Twelve rainfed sorghum trials were established in eastern Nebraska at different sites and topographic positions. The combinations of sites, topographic positions, variety, and soil properties resulted in 15 environments. Three starter fertilizer placements were compared: in the furrow, over the row, and five cm to the side and five cm deep (5x5 cm). Starter fertilizer treatments were applied as liquid formulations containing N+P and N+P+S at the rates of 22.4 kg ha^{-1} each for N and P_2O_5, and 11.2 kg ha^{-1} S, but half rates were applied with the in-furrow placement. Ammonium sulfate (AS) was compared to ammonium thio-sulfate (ATS) as the S source. Early-season growth was increased with starter fertilizer application in most trials. Sorghum yield responded only to N+P+S placed 5x5 cm or in-furrow in 20% of the environments with increases of 0.5 to 1.0 Mg ha^{-1} (Fig. 3). Relatively warmer temperature associated with the traditional planting time (late May) of sorghum most likely reduced the probability of sorghum response to starter. Overall, yield response was more frequent in upland environments than in bottomlands where 5x5 and in-furrow placement were generally more effective than over-the-row placement. Soil P and organic matter level did not consistently correlate with sorghum starter fertilizer responsiveness. The effect of starter fertilizer on grain moisture reduction at harvest was more frequent than the yield

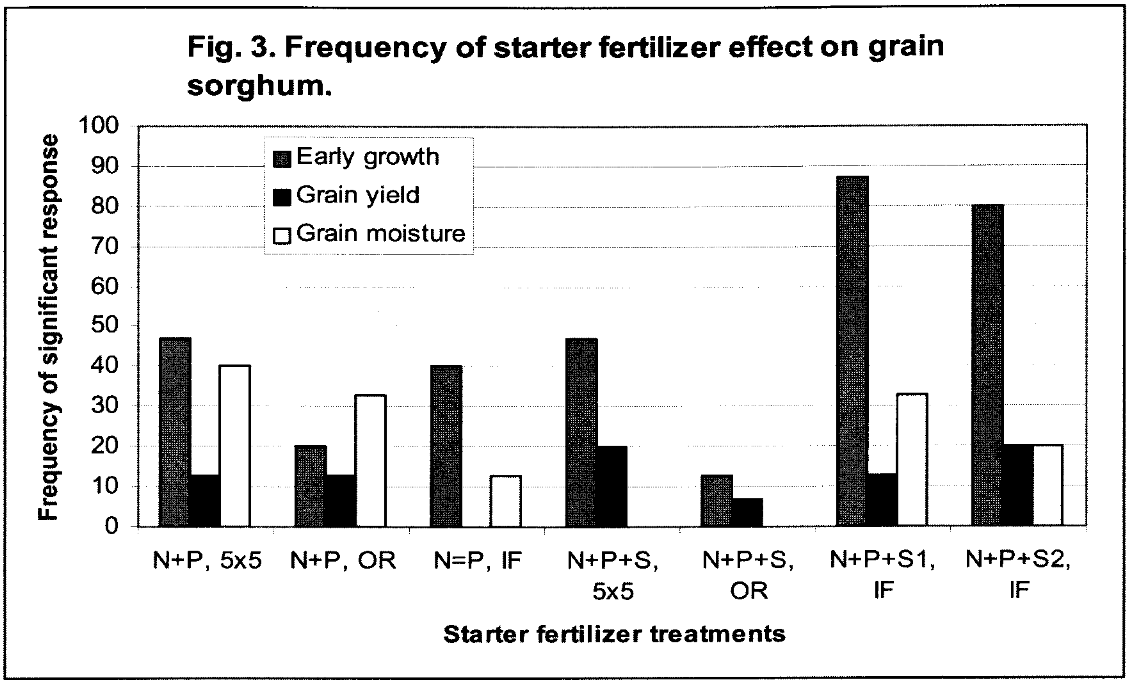


Table 2. Effect of one-time tillage in a no-till system on panicle number and size, and sorghum grain yield in eastern Nebraska.¥

Tillage practice	Grain yield	Panicles	Panicle wt.
	kg ha^{-1}	per ha	g $panicle^{-1}$
No-till	7.20 a	124189 ab	56.4
Disk	7.18 a	139043 a	52.1
Chisel, 8"	5.17 b	99028 c	52.1
Chisel, 12"	5.86 ab	113559 bc	51.5
Moldboard plow	6.79 a	131320 ab	51.6

¥ Means with the same letter are significantly different at P = 0.05.

increase. Starter fertilizer reduced grain moisture at harvest by 9 to 28 g kg^{-1} in 25% of the environments. The NP 5x5 cm and over-row, and the NPS ammonium sulfate in-furrow resulted in higher frequencies of grain moisture reduction at harvest. It is expected that responses to starter fertilizer would be greater if sorghum is planted earlier than the traditional planting time of eastern Nebraska. However, with the traditional planting time of late May, moisture reduction at harvest could be beneficial.

Additional starter fertilizer research is being conducted for early-planted no-till sorghum. We are also investigating the interaction of row cleaning with starter fertilizer application in this research.

Soybean N credit verified for grain sorghum in Nebraska. This field research was put on hold in 2003 due to time constraints but 11 trials have been established in three southeast Nebraska counties in 2004.

Occasional tillage to improve the no-till sorghum-soybean rotation. Research is underway to determine the effects of one time tillage in no-till systems on crop performance, soil C dynamics, and on soil chemical, physical and microbiological properties. Two graduate students, Juan Pablo Garcia and Andres Quincke, are involved in this research. The effects of four tillage practices, conducted in one year only, relative to continuous no-till, and the effects of P management regimes are being evaluated. For his Ph.D. dissertation, Andres is investigating the effects of: soil C dynamics and microbial activity; crop yield; and soil physical properties. Juan Pablo is doing his M.S. research to investigate effects on: nutrient redistribution with tillage, mycorrhyzal colonization, and plant nutrient uptake. Tillage was done when soil temperature was low and the resulting CO_2 emissions were similar with tillage as compared to no-till. Nutrients, which were highly stratified with no-till, were best redistributed with the moldboard plowing. Yield was similar for no-till, disking and moldboard plowing, but reduced with chisel plow tillage, apparently due to reduced panicle number and size (Table 2). Various aspects of this research, including treatment effects on yield and soil organic matter, will continue for another five years. First year preliminary data of this research was presented at the 2003 ASA meeting.

Soil pH stratification and localized liming on sandy soils. Research is underway to evaluate the effects of soil pH stratification and localized lime application on sorghum yield, nutrient uptake, root distribution and surface area, soil and solution chemistry, and mycorrhizal establishment. A M.S. graduate student, Greg Miller, is conducting this research in 2004 and 2005.

Networking Activities

We are planning to cooperate with different projects/organizations/departments in Ethiopia to conduct training for extension staff on soil and water management. The USAID Amhara Rural Development Project (Dr. Brhane and Dr. Fakaru) will partner with USAID-INTSORMIL to conduct a soil and water management-training event in the Amhara region in February-March 2005. The ASARECA-ECARSAM network apparently has had financial constraints and we have not identified any opportunities for collaboration. The development of the sorghum production database is expected to be a valuable resource for future networking activities as it will strengthen the basis for germplasm and information exchange, identification of screening environments, constraints prioritization, etc.

Publications and Presentations

Miscellaneous

Wortmann, C. 2004. Nebraska trials test starter fertilizer in no-till sorghum. Crop Watch Newletter 04-7. Available at http://cropwatch.unl.edu/.

Wortmann, C.S., S.A. Xerinda, M. Mamo, and C. Shapiro. 2003. Starter fertilizer for row crop production under no-till conditions in eastern Nebraska. Proceedings of the North Central Regional Extension and Industry Conference, Des Moines, IA, Nov. 19-20, 2003. Also presented at UNL Agronomy and Horticulture Highlights in Dec. 2003.

Abstracts

Quincke, J.A., C. Wortmann, M. Mamo. 2003. Effect of occasional tillage of no-till systems on soil carbon. Agron. Abstr. #614154, CD-ROM. Amer. Soc. of Agron., Denver, Colorado.

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Germplasm Enhancement and Conservation

Breeding Pearl Millet for Improved Stability, Performance, and Pest Resistance

Project ARS 206
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Summary

Pearl millet [*Pennisetum glaucum* (L.) R. Br] provides a staple, primary caloric source to millions of people in semi-arid tropical areas of Africa and Asia, and a high quality temporary grazing crop in livestock production in the U.S. The characteristics of the crop have encouraged its development for use as grain crop in certain settings in the U.S.

Despite being a hardy crop for dry production areas, yield and stability of grain, stover, and forage are vulnerable to a number of biotic and abiotic stresses. Diseases and pests can be significant production constraints and significant effort is directed toward identifying resistance sources. Primary biotic constraints in West Africa include downy mildew (*Sclerospora graminicola* (Sacc.) Schroet.), *Striga* (*Striga hermonthica* Benth.), and head miner (*Heliocheilus albipunctella* (de Joannis)). Constraints in the U.S. include rust (*Puccinia substriata* var. *indica*), pyricularia leaf blight (*Pyricularia grisea* / *Magnoporthe grisea*), root knot nematode (*Meloidogyne arenaria*), and chinch bug (*Blissus leucopterus leucopterus*).

The goals of this research are to improve the productivity, yield stability, and pest resistance of pearl millet cultivars. Achieving these goals throughout Africa or in the U.S. require 1) identifying constraints limiting production or utilization within and across environments, 2) acquiring and evaluating new germplasm for desirable characteristics, 3) crossing selected germplasm with regionally adapted breeding lines or cultivars, 4) selecting and evaluating improved progeny as potential new cultivars.

Objectives, Production and Utilization Constraints

Objectives

- Broaden diversity of pearl millet germplasm available to breeders and researchers.
- Identify sources of disease and pest resistance for pearl millet improvement
- Identify genetic characteristics associated with desirable pearl millet grain quality, and biotic and abiotic influences on grain quality.
- Develop and release pearl millet with resistance to multiple diseases, high yield, and superior quality.

Developing the commercial potential of pearl millet will require that growers produce a consistent product to sell to processors. In addition to yield stability, grain quality is also likely to be affected by both abiotic and biotic constraints. The impact of pearl millet genotype, diseases, and environmental constraints are not well defined, in part because grain quality standards for pearl millet are poorly defined. Quality represents the combination of several factors, such as grain shape, color, and size, endosperm hardness, proximate composition, and the presence of grain molds, mycotoxins, and insects.

Table 1. Mean values for agronomic characteristics and disease and pest resistance of diverse pearl millet varieties grown in Ghana, Mali, Nigeria, and Senegal in 2003.

Entry	Flowering (days to 50%)	Height (cm)	Panicle length (cm)	Panicle diameter (cm)	Downy mildew incidence	Striga emerged	Head miner incidence	Yield (kg/ha)
CIVT	50.9	231.8	53.2	2.2	9.1	58.6	3.7	1661.5
ICMV IS 89305	56.8	224.8	48.3	2.1	9.2	41.1	3.1	1659.3
SoSat C-88	52.9	193.1	25.0	3.0	13.6	24.5	7.1	1536.3
Gwagwa	57.4	225.4	24.4	2.4	17.9	6.9	2.7	1451.9
SoSank	55.3	191.2	27.9	3.2	8.6	35.8	5.0	1395.8
HKP (GMS)	53.7	227.4	51.6	2.1	9.1	15.5	2.0	1383.7
Taram	56.0	220.4	63.1	2.4	8.0	39.1	3.1	1280.8
Indiana 05	74.0	246.5	43.9	2.4	23.3	13.5	6.3	1226.0
NKK	71.5	263.1	42.5	2.5	26.1	12.3	0.9	1215.2
Zatib	52.5	212.8	52.2	2.4	3.4	26.0	4.9	1158.7
NKO x TC1	71.5	247.7	35.6	1.8	15.1	13.5	2.6	1147.3
Manga Nara	43.8	169.5	19.5	2.9	33.0	9.3	6.1	1120.9
Kapielga (Burkina local)	82.3	243.5	27.2	1.9	33.2	6.0	1.7	1095.1
Guefoue 16	74.4	253.2	35.3	1.9	18.0	9.3	1.1	1079.3
ICMV IS 90311	56.9	205.0	44.0	2.1	5.2	21.4	5.1	1073.0
P1449-2	55.5	166.3	29.7	2.1	27.2	6.5	2.3	1054.7
Synthetic 1-2000	72.4	240.3	33.4	2.7	4.6	34.5	3.9	1048.1
Arrow	47.3	199.7	32.2	2.0	27.2	30.5	2.7	1026.5
Toronio (Mali local)	69.8	262.3	33.9	2.2	33.9	11.3	2.3	1020.2
Sadore (Niger) local	65.0	228.8	52.1	2.1	14.1	7.8	5.4	993.2
GB 8735	43.4	152.7	21.7	2.7	41.8	5.3	6.0	984.8
Tongo Yellow	47.3	171.3	24.7	3.0	38.9	10.5	7.3	961.4
Bongo short head	46.7	169.1	11.5	3.5	30.0	10.5	5.3	960.2
Zongo	60.1	251.3	75.4	2.2	10.4	18.3	2.0	920.3
IBMV8401Mx68A4R4w	46.1	107.8	30.2	2.3	14.4	10.1	2.1	903.9
DMR 15	59.2	168.0	25.0	2.6	18.3	6.6	6.6	858.8
PT732B	54.3	117.6	25.1	2.0	61.3	4.3	8.7	731.7
DMR 72	61.2	204.6	31.1	2.3	13.3	17.5	9.3	730.3
3/4 HK	60.6	130.9	43.4	2.1	9.3	6.3	7.3	710.0
68A x 086R	38.8	100.5	20.2	1.8	45.9	0.4	0.4	709.4
3/4 ExBornu	52.0	122.2	38.5	2.2	6.8	12.8	3.7	699.4
99M59043Mw x 68A4R4	44.3	91.0	22.8	3.0	49.1	2.8	5.9	684.5
DMR 68	60.6	193.3	27.6	2.4	31.8	7.6	7.1	676.8
01Miso NCD2-NE	47.4	98.8	31.7	1.8	30.9	8.9	1.1	655.7
LCIC 9702	48.4	142.2	23.3	2.6	22.6	3.6	3.6	581.7
3/4 Souna	57.1	119.8	36.4	2.1	7.6	5.6	4.6	559.9
TG102	43.1	97.6	23.2	2.3	53.9	16.0	0.3	542.8
99-72	56.3	113.9	19.3	2.5	7.7	9.8	18.0	461.9
T454	50.6	104.8	25.9	2.0	60.9	5.9	3.4	308.7
T99B	45.8	82.8	29.8	1.8	68.4	9.1	3.1	235.0
lsd (P=0.05)	4.2	20.6	5.5	0.5	2.0	34.8	5.6	341.6

Research Approach and Project Output

Genotype and Environmental Effects on Pearl Millet Grain Quality

Research Methods

Collaborative, multi-locational trails throughout West Africa are being used for characterizing germplasm with desirable agronomic characteristics and superior resistance to pests and diseases. Multi-location evaluation of genotype x environment interactions affecting grain quality are needed to identify genotypes with inherently superior grain yield and quality, and the relative importance of diseases and other constraints on yield and quality. These studies were designed in part to define more clearly grain characteristics among genotypes, and the stability of expression over a range of production environments. This study will help to identify characteristics that contribute directly or indirectly to stability of grain yield and quality.

Forty pearl millet germplasms selected by colleagues on the basis of their high grain quality, their fertility restoration for specific cytoplasms, resistance to diseases or pests, agronomic traits, or commercial usefulness were distributed to collaborators in Ghana, Mali, Niger, Nigeria, and Senegal for multi-location evaluation of stability of grain yield and quality traits. Data were recorded for days to flowering, height, panicle dimensions, downy mildew and head miner incidence, *Striga* infestation, and yield.

In an effort to expand the diversity in the breeding populations in the U.S. program, several African cultivars are being used to develop new maintainer and restorer germplasm for the A_1 and A_4 male sterile cytoplasms. Selected germplasm and hybrids of the African germplasm crossed to A_1 and A_4 fertility restorer inbreds were grown in the field in the U.S. Data were recorded for days to flowering, height, panicle dimensions, 1000 seed weight, and yield.

Research Findings

Data was obtained for the first year of this study from collaborators in Mali, Nigeria, Senegal, and Ghana. Although seed was distributed to two collaborators in Niger, no data was obtained. Germplasm varied for several characteristics (Table 1). Zatib had the lowest incidence of downy mildew and Tift 99B

Table 2. Agronomic characteristics of West African pearl millets and hybrids with A_1 (Tift 454) and A_4 (99-70) fertility restorers grown in Tifton, GA in 2003.

Entry	Flowering (days to 50%)	Height (dm)	Panicle length (cm)	Panicle diamter (mm)	Seed weight (g/1000)	Yield (kg/ha)
3/4 HK-B78 S1	84.0	12.5	34.6	20.7	8.35	190.3
Ankoutess S1	79.0	22.0	23.1	33.7	9.63	520.3
Ex-Bornu	72.3	21.8	26.6	21.9	9.43	220.3
GCP V6 S1	71.0	22.5	23.6	29.0	12.33	295.5
GGT S1	85.0	26.0	35.1	25.9	8.70	440.0
HKP-GMS S1	72.5	21.5	42.2	22.9	8.65	231.8
Iniari	66.3	21.2	22.8	27.6	10.63	570.8
Mansori	71.3	20.5	25.9	22.9	9.85	323.3
P3Kollo	72.8	19.0	35.2	22.6	10.67	205.0
SoSank S1	77.0	23.5	24.9	30.7	10.80	408.0
SoSat C-88 S1	74.8	25.0	24.4	30.7	9.48	732.0
Taram S1	79.5	21.0	44.6	22.3	7.48	294.0
Ugandi	63.3	18.8	18.0	26.4	10.55	295.3
Zatib S1	84.4	21.2	42.2	22.5	9.83	194.6
Zongo S1	87.0	21.7	48.0	20.5	10.90	31.3
99-70	67.3	7.8	16.1	23.3	6.10	53.5
Tift 454	63.8	13.3	26.1	19.8	4.98	72.0
3/4 HK-B78 x Tift 454	61.5	18.3	39.3	24.3	8.80	1316.8
Ankoutess x 99-70	59.5	23.0	25.0	35.0	12.90	2185.3
Ankoutess x Tift 454	68.0	23.8	29.1	34.4	10.15	1368.0
Ex-Bornu x 99-70	62.0	22.3	29.7	27.9	11.95	1789.8
Ex-Bornu x Tift 454	61.0	26.8	31.5	24.9	9.35	1390.8
GCP V6 x 99-70	62.3	23.5	26.7	32.3	14.48	1159.0
GCP V6 x Tift 454	56.8	25.5	30.3	32.1	12.90	2083.0
GGT x Tift 454	74.5	28.8	35.5	29.7	9.30	1871.3
HKP-GMS x 99-70	66.3	25.5	36.3	31.6	13.25	2109.0
HKP-GMS x Tift 454	68.5	28.5	45.1	27.5	10.90	2666.8
Iniari x 99-70	55.7	21.0	21.5	28.7	11.43	1437.3
Iniari x Tift 454	56.8	23.3	34.3	28.2	14.10	1960.8
Mansori x 99-70	54.8	23.0	26.1	29.4	12.15	2333.3
Mansori x Tift 454	57.0	22.8	24.3	27.8	11.25	1512.3
P3Kollo x 99-70	59.0	20.3	28.9	27.2	10.80	1205.0
P3Kollo x Tift 454	59.8	26.3	36.8	26.6	11.40	2137.0
SoSank x 99-70	63.5	24.0	29.5	34.4	12.48	1876.5
SoSank x Tift 454	64.3	27.5	29.8	30.3	10.63	1941.5
SoSat x 99-70	63.0	25.0	27.4	32.0	11.50	2500.0
SoSat x Tift 454	58.8	26.0	28.6	30.8	11.50	2225.5
Taram x 99-70	58.0	23.8	34.9	27.1	12.78	2537.8
Taram x Tift 454	65.5	26.5	42.0	25.1	9.35	1827.8
Ugandi x 99-70	55.3	21.0	23.1	31.6	13.20	2099.5
Ugandi x Tift 454	55.8	23.5	25.9	26.5	14.40	1975.0
Zatib x 99-70	58.3	24.8	34.9	28.4	10.63	1065.0
Zatib x Tift 454	65.5	28.0	41.6	28.2	10.18	1419.0
Zongo x 99-70	63.3	23.0	42.7	30.0	11.63	1719.3
Zongo x Tift 454	65.3	27.8	47.3	26.0	11.95	2040.5
lsd (P=0.05)	4.6	2.9	4.6	2.8	0.25	725.9

was the most susceptible. 68A x 086R had the lowest *Striga* emergence and HKP GMS was most susceptible. Tifgrain 102 had the lowest level of head miner incidence, and 99-72 had the highest level. Grain yield was lowest for Tift 99B and greatest for CIVT and ICMV IS 89305. Grain yield was negatively correlated with downy mildew incidence (R^2=0.268) and positively correlated with plant height (R^2=0.532).

In the U.S. trial, germplasm and hybrids likewise differed for multiple characteristics (Table 2). Most notably, 1000 seed weight was lowest for Tift 454, and greatest for GCP V6 x 99-70. Grain yield was lowest for Zongo, and greatest for HKP-GMS x Tift 454. Neither Tift 454 nor 99-70 exhibited consistently superior heterosis with the African germplasm. Grain yield was negatively correlated with days to flowering (R^2=0.437) and positively correlated with plant height (R^2=0.320).

Nematode Resistance in Pearl Millet

Research Methods

Pearl millet germplasm from African countries can be a source of important characteristics for breeding populations in the U.S. Disease and pest resistances are likely to be identified in the African gene pool. In prior experiments, diverse germplasm of African origin was evaluated for resistance to root knot nematodes (*Meloidogyne incognita*) in two replicated experiments in the greenhouse. Pots containing five plants were inoculated with eggs of *Meloidogyne incognita*. After grain harvest, eggs were extracted from roots. Differential reproduction of the nematode on the different genotypes was determined and assayed as eggs per gram of root tissue. From these experiments, progeny of twenty plants of P3Kollo, Zongo, SoSat C-88, and Gwagwa were evaluated in 5 replicates to determine heterogeneity for resistance within landraces.

Research Findings

In the first evaluation, all African accessions were more resistant to the southern root knot nematode than was HGM 100 when evaluated with several plants per pot. When individual progeny were assessed, distribution of eggs per gram of root was continuously distributed from essentially no reproduction to levels exceeding that on HGM 100. These data indicate that considerable heterogeneity for resistance to reproduction of root knot nematode exists within these four varieties. If these varieties are to be used as sources of nematode resistance, it would be necessary to identify specific resistant progeny to be used as source material. Because each of the tested varieties expressed the continuous distribution of reaction from resistance to extreme susceptibility, it is probable that heterogeneity exists in the other varieties also.

Striga Resistance in Pearl Millet

Research Methods

Wild pearl millets were selected from previous multi-location trials to be used as sources of resistance to *Striga hermonthica*. The genetic variability and the relationship was surveyed among 80 wild pearl millet accessions collected from different regions in Africa that showed various levels of *Striga* resistance, and a selection of cultivars and germplasm from Africa and the United States. We tested 30 PCR primer pairs targeting conserved gene sequences. PCR products of genomic DNA were digested with HinfI restriction enzyme and separated on 8% polyacrylamide gels. Twenty-two primer pairs produced reproducible and scorable DNA fragments. Most loci showed no amplicon length variation, but polymorphisms were revealed upon digestion of the PCR products with restriction enzymes.

Research Findings

Preliminary analysis indicated that the genetic similarity among the accessions ranged from 0.66 to 1.00. Genotypic identity was not resolved in a number of accessions due possibly to the conserved nature of the gene sequences that we surveyed or perhaps that these genotypes are either identical or share a common parentage. For most accessions, the amount of variation that exists was sufficient for us to draw several conclusions regarding the relationships among these accessions. First, the tendency of improved cultivars and germplasm lines from the United States to cluster reflects their shared history in modern breeding. Second, the lack of clear clustering of African varieties and wild pearl millet accessions confirms that cultivation and improvement of pearl millet in Africa is not accompanied by genetic isolation. Finally, the observation that most of the known wild accessions with *Striga* resistance fall into different clusters suggests that different sources of resistance may be available for use in breeding for *Striga* resistant cultivars.

Networking Activities

Attended the American Phytopathological Society meeting, Charlotte, NC. August 10-13, 2003. Served as chair of the Collections and Germplasm Committee, member of the Office of International Programs Research Committee, and as senior editor of *Phytopathology*.

Participated in the McKnight Foundation, Collaborative Crop Research Program "Consultation Workshop on Millet and Sorghum Based Systems in West Africa". Presented " Genetic variability of wild pearl millets with *Striga* resistance". Niamey, Niger, January 27-30, 2004.

Participated in the External Evaluation Panel Review of INTSORMIL pearl millet research, breeding, and technology transfer activities in the Southern Africa Region; Botswana, Zambia, and Namibia. March 3-11, 2004

Participated in Middle Georgia pearl millet production meeting, University of Georgia Cooperative Extension Service, Oglethorpe, GA. March 18, 2004.

Participated in INTSORMIL West Africa Regional Research Meeting. Presented – "Multilocation assessment of yield, disease, and pest resistance of pearl millet germplasms in West Africa". Ouagadougou, Burkina Faso. April 18 to 21, 2004.

Served as member of Sorghum and Millet Crop Germplasm Committee.

Served on Advisory Committee for the University of Georgia's Office of International Agriculture.

Served 30 day detail in the USDA-ARS Office of International Research Programs, Beltsville, MD. Assessed ARS' role in and made recommendations concerning the project "Research Internship for Early Career South African Agricultural Research Scientists". May 10 - June 4, 2004.

Hosted visit to Tifton by Odillio Balbinotti, Luiz Bonamigo, and Jose Franca-Neto, from Adriana Seed Co. Brazil. Developed plans for material transfer agreement for Adriana to evaluate advanced pearl millet germplasm in Brazil. October 8, 2003.

Hosted visit to Tifton, GA by Ouendeba Botorou to cooperate in developing concept paper and progress report on "Market Improvements and New Food Crop Technologies in the Sahel". November 11 to 20, 2003.

Submitted information for the University of Georgia's proposal for SANREM CRSP Management June 18, 2004

Experimental pearl millet germplasm developed in the U.S. was distributed to collaborators at Cornell University, University of Georgia, Cornell University, Kansas State University, University of Nebraska, University of Natal, South Africa, CSIRO Australia, and seed companies in South Dakota and Brazil. Seed from West Africa was sent to collaborators in Zambia, Botswana, and Namibia.

Publications and Presentations

Journal Articles and other publications

Wilson, J.P., Gates, R.N., and Hanna, W.W. 2004. Strip-till establishment of pearl millet. International Sorghum and Millets Newsletter 44:158-159

Wilson J.P., Hess, D.E., Hanna, W.W., Kumar, K.A. and Gupta, S.C. (In press) *Pennisetum glaucum* subsp. *monodii* accessions with *Striga* resistance in West Africa. Crop Protection. http://www.sciencedirect.com

Lee, D., Hanna, W.W., Buntin, G.D., Dozier, W., Timper, P. and Wilson, J.P. 2004. Pearl Millet for Grain. University of Georgia Cooperative Extension Service Bulletin 1216 (Revised). 8 pp. http://pubs.caes.uga.edu/caespubs/pubs/PDF/B1216.pdf (Extension Service bulletin)

Books, Book Chapters, and Proceedings

Chee, P. and Wilson, J.P. 2004. Genetic variability of wild pearl millets with *Striga* resistance. Proceedings: Millet and Sorghum-Based Systems in West Africa: Current Knowledge and Enhancing Linkages to Improve Food Security. McKnight Foundation Collaborative Crop Research Foundation. Niamey, Niger, January 27-30, 2004. http://mcknight.ccrp.cornell.edu/WEB-INF/documents/partic_docs/Niger04/WAf_Wilson_full(EN).pdf (Conference proceedings)

Angarawai I.I, Wilson, J. Ndahi, W.B., and Turaki, Z.G.S. 2004. Enhancing Resource – Poor Farmers Productivity by Pearl Millet Hybrid (sic). Proceedings: Millet and Sorghum-Based Systems in West Africa: Current Knowledge and Enhancing Linkages to Improve Food Security. McKnight Foundation Collaborative Crop Research Foundation. Niamey, Niger, January 27-30, 2004. http://mcknight.ccrp.cornell.edu/content/Papers%20and%20Abstracts/WAf_Angarawai_full(EN).doc (Conference proceedings)

Abstracts

Wilson, J.P., Hanna, W.W., Wilson, D.M., and Coy, A.E. 2004. Host specific differences in pre-harvest grain infection by toxigenic fungi in dryland pearl millet and corn. Mycopathologia 157: 503.

Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Biotic and Abiotic Stress

Project PRF 207
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Summary

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Research and germplasm development activities in PRF-207 attempt to address these essential requirements.

PRF-207 addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in some of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed. In this report, we have included observations relative to identification and characterization of sorghum genetic variants in glycinebetaine accumulation and their role in tolerance to drought and salinity stresses.

Objectives, Production and Utilization Constraints

Objectives

Research

- To study the inheritance of traits associated with resistance to biotic and abiotic stresses in sorghum and/or millets.
- To elucidate mechanisms of resistance to these stresses in sorghum and/or millets.
- To evaluate and adapt new biotechnological techniques and approaches in addressing sorghum and millet constraints for which conventional approaches have not been successful.

Germplasm Development, Conservation, and Diversity

- To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.
- To develop and enhance sorghum germplasm with increased levels of resistance to drought, cold, diseases, and improved grain 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, Indiana for an array of traits, including high yield potential, grain quality, as well as certain chemical constituents that we have found to correlate well with field resistance to pests and diseases. We also evaluate our germplasm for tropical adaptation and disease resistance during the off-season at the USDA Tropical Agricultural Research Center at Isabella, Puerto Rico. Selected progenies from relevant populations are then sampled for evaluation of specific adaptation and usefulness to collaborative programs in Sudan, Niger, and more recently Mali. Evaluation of the drought tolerance of our breeding materials have been conducted at Lubbock, Texas in collaboration with Dr. Darrell Rosenow, in a winter nursery at Puerto Vallarta, Mexico, as well as the University of Arizona Dryland Station at Yuma, Arizona, and several locations in Africa. 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 closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali and some in Southern Africa through SADC/ICRISAT.

Project Output

Research Findings

Genotypic variation for glycinebetaine in *Sorghum bicolor*. Glycinebetaine (GB) is thought to play an important role in plant adaptation to saline and arid environments. Genes determining GB accumulation are thus of considerable interest in plant breeding for stress environments. It has been found that GB accumulates in sorghum in response to salinity stress. It was of interest to determine the range and extent of variability for this trait among diverse genotypes of this species. We tested the hypotheses that GB represents the major QAC in sorghum, as it does in maize, and that this QAC is genetically and environmentally regulated. In this paper we also report on the identification and preliminary biochemical characterization of several GB-deficient sorghum genotypes.

A total of 240 sorghum genotypes were initially screened for QAC level at the Purdue University agronomy farm in West Lafayette, IN. Samples were taken from the flag leaf of five individual plants of each genotype. All of the genotypes were at the post-flowering stage at sampling. Leaves were excised from plants selected at random from the center row of 3-row plots. A representative sub-sample of the leaf tissue bulked from the five individual leaves (1 to 1.5 g FW) was taken from the leaf lamina (excluding midrib). Leaf tissue was then extracted by immersion in preweighed vials containing 10 mL methanol at the field site (one sample per genotype).

Two greenhouse studies involving growth of sorghum genotypes under non-salinized and salinized conditions were conducted. The first study was designed to determine the effect of salinization on GB accumulation in a number of GB-deficient or GB-accumulating lines and on GB accumulation in various organs of representative GB-deficient (IS2319) and GB-accumulating (P932296) lines. A second greenhouse study was conducted to evaluate the levels of GB accumulated under various salinity regimes and at different stages of seedling development.

Significant differences were found in the total QAC levels in the betaine fraction of the flag leaves of the 240 sorghum genotypes screened. The maximum-recorded values for GB in maize are in the range of 10 to 16 mmol·g FW^{-1}. In contrast, total quaternary ammonium compound (QAC) levels in the betaine fraction of the flag leaves were found to range from as low as 0.1 mmol·g FW^{-1} to over 33 mmol·g FW^{-1}. Stable isotope dilution desorption chemical ionization mass spectrometry of six genotypes with high QAC levels and five genotypes with low QAC levels confirmed that this variation could be attributed almost exclusively to genetic variability for GB level. GB-deficient sorghum genotypes were confirmed to be GB-deficient in a second year of field-testing, and in greenhouse studies under salinized and non-salinized conditions. GB levels increased with seedling age and/or salinization in GB-accumulating genotypes. Also, GB levels were highest in the youngest leaves of GB-accumulating sorghum genotypes. This work shows that GB is the major QAC in sorghum, that genetic differences in GB accumulation exist in sorghum as they do in maize, and that the level of GB in GB-accumulating lines is developmentally and environmentally regulated. A list of GB levels of publicly available lines of sorghum is also provided. Certain sorghum genotypes appear to have a much higher capacity for total QAC accumulation than the highest GB accumulating maize genotypes so far identified. Sorghum genotypes that are apparently GB-deficient were also identified. Eight genotypes of sorghum were found that exhibited total QAC levels of <1.0 mmol·g FW^{-1}.

Genetic studies suggest that a recessive allele of a single locus is the cause of this deficiency in one GB-deficient sorghum genotype, IS2319, but it remains to be tested whether the various sources of GB-deficient in sorghum so far identified are allelic. The precise metabolic basis of the GB deficiency phenotype of sorghum also remains to be elucidated. An understanding of the metabolic and genetic basis of this genetic variation in GB level in sorghum should assist in devising breeding strategies to develop near-isogenic lines differing solely for the GB trait. These lines could then be used to test the contribution of this trait to salt and drought tolerance.

Development and characterization of near isogenic lines of sorghum segregating for glycinebetaine accumulation.

The breeding of crop plants for tolerance to environmental stresses is often considered a difficult and slow process. This is primarily because of the quantitative inheritance of the trait of environmental stress and the problems associated with developing suitable testing environments where stress can be reproducibly applied. A better understanding of plant stress tolerance could be developed by identifying and characterizing those traits that are proposed to contribute to stress tolerance and determining their relative importance. Complex quantitative traits such as osmotic stress tolerance can be studied by identifying individual components and then using traditional breeding methods to select plants that possess the specific trait. This approach has been employed to study the osmoregulatory compound, glycinebetaine (GB) accumulation in various crops. Cellular dehydration is a general consequence of osmotic stresses, including water deficit and salinity. In response to this dehydration, many organisms synthesize compatible solutes that help retain water within cells. Accumulation of solutes, either actively or passively, is an important adaptation mechanism for plants in response to osmotic stress. Some of these solutes may also protect cellular components from injury caused by dehydration. Organic compounds that function as solutes include amino acids such as proline, sugar alcohols such as mannitol, and quaternary ammonium compounds (QACs) such as glycinebetaine (GB)

Glycinebetaine is synthesized in plants from serine via ethanolamine, choline, and betaine aldehyde with S-adenosyl methionine serving as the methyl donor. Although other pathways may exist (such as direct N-methylation of glycine), the pathway from choline to GB is the only one that has been identified to date in GB-accumulating plant species

Many cereal crops accumulate GB, although rice is a notable exception. The levels of GB found in sorghum are as much as ten-fold higher than those observed in maize. However, GB-deficient genotypes of both sorghum and maize have been identified. In a screen of over 200 sorghum landraces, approximately 3% were GB-deficient. Furthermore, there is a wide range in the level of GB within both sorghum and maize. Genetic analysis of this trait in several crosses between GB-deficient and GB-accumulating sorghum lines indicated that a single nuclear gene was responsible for GB deficiency Similar results have been obtained in studies on the genetics of GB accumulation in maize, where GB deficiency results from an inability to convert choline to betaine aldehyde, the first committed step in the synthesis of GB.

The primary objective of these experiments was to utilize a recombinant-inbred (RI) population, developed from a cross between a GB-deficient line and a GB-accumulating line, to characterize the genetics of GB accumulation in sorghum. Near-isogenic lines were derived from advanced RI lines. These lines also provide an excellent tool with which to test the hypothesis that GB accumulation is an important factor in sorghum osmotic stress tolerance.

A recombinant inbred (RI) population was developed from a cross between IS2319, a naturally occurring GB-deficient genotype, and P932296, a GB-accumulating. F_2 progeny from this cross were randomly selected and 150 lines were advanced by single seed descent to the F_7 generation. Seed of selfed plants from the F_7 generation of each RI line were grown in a head-row, and several panicles from each row were selfed and bulked to represent the $F_{7:8}$ generation. In each subsequent generation, the RI lines were planted in rows and 10 to 15 plants were selfed and the seed bulked to represent the next generation. For GB analysis of the $F_{7:8}$ generation of the RI population, plants were grown in a growth chamber with a light level of 161 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and at a constant temperature of 26°C. Four plants per line were grown to the five-leaf stage in 14.4 cm pots, at which time the plants were salinized with 100 mM NaCl for 10 days to stimulate production of GB, and therefore accentuate differences in GB levels between non-accumulators and accumulators. Leaf lamina (including midrib) from the four plants were harvested and combined for analysis. F_5 generation plants that were analyzed for QAC were grown in the greenhouse in individual 9.6 cm pots to the five-leaf stage and then salinized with 100 mM NaCl for 10 days before leaves were harvested for QAC analysis. For each line, a bulk sample composed of equal amounts of tissue from ten F_5 plants was analyzed. Glycinebetaine concentrations of $F_{7:8}$ lines were quantified by plasma desorption mass spectrometry (PD-MS) using a BIOION 20R Plasma.

For all other GB determinations, the spectrophotometric periodide method was utilized. For these assays, the purified betaine fraction eluted from the Dowex-50-H^+ resin was dissolved in 0.5 mL 1N H_2SO_4. After adding 0.2 mL KI-I_2 reagent, the contents were mixed and allowed to precipitate overnight at 4°C. The samples were then centrifuged at 5000 rpm for five minutes and the supernatant discarded. After washing the pellet with 1 N H_2SO_4 and centrifugation, the precipitate was dissolved in 2 mL dichloroethane and absorbance at 500 nm was read. Glycinebetaine amounts were quantified by comparison with a standard curve of GB (Sigma, St. Louis, MO) prepared in dH_2O.

NILs were grown to flowering (50% anthesis) and then destructively harvested for determination of morphological characteristics. Flowering date was determined as the number of days from planting to 50% anthesis. Leaf area was determined using a Li-Cor 1600 area meter (Li-Cor Instruments, Lincoln, NE). Whole-plant dry weight was determined by drying plant tissue in an oven at 80°C to a constant weight (ca. four days). Isolation of total QACs from these plants and quantification by the colorimetric assay were conducted as described above.

Significant variation was found in glycinebetaine levels among the RI lines. Within this population, the predicted percentage of GB-deficient lines should be 47 and 49% in the F_5 and $F_{7:8}$ generations, respectively. However, the proportion of GB-accumulating lines in both the F_5 and $F_{7:8}$ generations of this RI population was higher than expected, possibly due to some beneficial effect of GB accumulation on plant growth, survival, or seed set. GB levels varied widely in lines of the RI population that were grown under controlled conditions, suggesting genetic control not only for the presence or absence of GB, but also for the level of GB. This hypothesis was tested by analyzing individual plants from lines identified as accumulating low, medium, or high concentrations of GB based on the F_5 and $F_{7:8}$ screens. The level of GB was conserved within lines, supporting the hypothesis of genetic control of relative GB levels within accumulating lines. Two pairs of near-isogenic lines (NILs) with contrasting GB levels within pairs were developed from the RI population. The stable inheritance of the GB phenotype and isogenicity of these NILs were confirmed with progeny tests and RAPD analysis, respectively. Labeling studies demonstrated that the deficiency in GB accumulation was the choline oxidation step.

Skewed segregation ratios have been noted in other species when F_1 progeny were selfed to develop an inbred population. In rice, skewed segregation for genes from a single parent was noted, and in maize, higher than expected levels of heterozygosity still existed in advanced generations of a RI population. The observed segregation patterns could be explained if the GB-deficient parent was in fact heterozygous when it was assumed to be a homozygous inbred. However, several experiments have shown that this is not the case. GB accumulation may contribute some selective advantage (plant growth, survival, or seed set) under the conditions used to develop the RI population, resulting in the inadvertent selection of plants that accumulated GB to advance the population.

Among GB-accumulating lines, there was significant variation in the level of GB, which was approximately nine-fold in the $F_{7:8}$ screen and approximately four-fold in the F_5 screen. Several reasons could account for these differences in GB accumulation among lines. Environmental heterogeneity (i.e. light, moisture) could result in accumulation differences. Also, differences in actual salinity level of the medium could influence the final GB level. This may be especially true in the case of plants grown in soil (as opposed to sand or hydroponics), because binding of ions to soil particles or variation in leaching fraction could affect the level of salinity among pots of plants. Furthermore, although plants were all the same age when leaves were harvested, developmental differences could also contribute to the observed differences in GB accumulation. Since the $F_{7:8}$ screen was conducted in a small growth chamber, and the F_5 screen was conducted under controlled conditions in the greenhouse, we consider it unlikely that environmental variation in temperature or light conditions contributed significantly to these differences. While the other factors discussed above may have contributed to the observed variation in GB accumulation, it is possible that the relative level of GB in accumulating lines is under genetic control.

Near-isogenic lines (NILs) provide useful material for studying the effects of specific traits on plant stress tolerance. This is especially true for highly heritable traits in crop plants such as GB accumulation in sorghum or barley. We have used traditional breeding methods to develop sorghum NILs that differ for GB accumulation. The first step in this process was to identify advanced generation RI lines that were heterozygous for the gene responsible for GB accumulation. At the F_7 generation, less than 2% of the individuals in the population should be segregating for a given locus, while the rest of the lines should be fixed at that locus. F_7 lines that are heterozygous at the locus responsible for GB deficiency should have intermediate levels of GB. With this in mind, individual plants from lines that contained low- to mid-level amounts of GB (8 to 20 $\mu mol \cdot gFW^{-1}$) in the $F_{7:8}$ screen were screened in an attempt to identify lines that were still segregating for GB. Plants within these lines that were heterozygous at the major locus that conditions GB accumulation would serve as the starting point to develop NILs that differed in GB accumulation.

Germplasm Exchange

We continue to provide an array of sorghum germplasm from our breeding program to national research programs in developing countries. Our germplasm is provided in either a formally organized nursery that is uniformly distributed to all collaborators that show interest or upon request by a national program of specific germplasm entries or groups from or germplasm pool. Germplasm was distributed to cooperators in 20 countries in 2002. Sorghum germplasm from our program was sent to Ethiopia, Kenya, Tanzania, Eritrea, Niger, and Mali in 2003.

Publications

Refereed Papers

Cisse, N., and G. Ejeta. 2003. Genetic variation and relationships among seedling vigor traits in sorghum. Crop Sci. 43:824-828.

Grenier, C., P.J. Bramel, J.A. Dahlberg, A. El-Ahmadi, M. Mohammed, G.C. Peterson, D.T. Rosenow and G. Ejeta. 2003. Sorghums of the Sudan: Analysis of regional diversity and distribution. Genet. Res. And Crop Evol. 48: 1-12.

Mickelbart, M.V., G. Peel, R.J. Joly, D. Rhodes, G. Ejeta and P. Goldsbrough. 2003. Development and characterization of near-isogenic lines of sorghum segregating for glycinebetaine accumulation. Physiol. Plant. 118: 253-261.

Yang, W.J., P.J. Rich, J.D. Axtell, K.V. Wood, C.C. Bonham, G. Ejeta, M.V. Mickelbart and David Rhodes. 2003. Genotypic variation for glycinebetaine in sorghum. Crop Sci. 43:162-169.

Menkir, A. and G. Ejeta. 2003. Selection for grain yield in sorghum under moisture stress and nutrient stress environments. Afric. Crop Science Journal 11:55-64.

Invited Presentations

Ejeta, G. 2003. Sorghum and millets: crops of the hungry. Exploring the Potential Use of Biotechnology to Alter Plant Development Programs. 8-14 June, Bellagio, Italy.

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

Project TAM 222
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Summary

The principal objectives of TAM 222 are to identify and develop disease resistant and drought resistant sorghum germplasm in genetically diverse backgrounds for use by host country and U.S. scientists, to identify, evaluate, and utilize new elite exotic germplasm, and to collaborate with host country scientists in all aspects of their crop improvement programs. The disease and drought resistance-breeding program continued to develop and evaluate new germplasm for use in the U.S. and host countries. Forty-nine new fully converted exotic lines and 71 partially converted lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released. Sixty diverse breeding germplasm lines ranging from advanced generation to early generation with Pathotype 3 downy mildew resistance were selected for release. Numerous advanced generation B and R lines developed in TAM 222 were identified as potential releases for distribution to private companies and U.S. and host country public programs as the project moves to closure of the sorghum breeding project with the retirement of the project leader. Over 750 items were distributed to private seed companies with MOA's upon their request based on observation of a 500 entry B/R-line Observation Nursery in 2003. Several very unique and promising new Durra and Durra-Bicolor and Durra-Dochna type cultivars from the dry northern part of Mali were identified in the Mali Sorghum Collection, and hold promise in sorghum improvement in the drought prone areas of Africa and the U.S.A. The B/R-line reaction and hybrid vigor of selected Malian and Sudanese cultivars continued. Twenty-five sorghums from the Mali Collection were selected for entry into the Sorghum Conversion Program. The Conversion Program, however, is in a temporary holding status since the USDA-ARS program in Puerto Rico dropped their portion of the Conversion Program in early 2004.

Breeding progeny developed in TAM 222 which had showed excellent potential in the Zambia, South Africa, Nicaragua, El Salvador, and in south and west Texas with various combinations of high yield, drought resistance, grain quality, and disease resistance was again distributed to several host country scientists. They offer good potential for use as varieties directly where appropriate and also as parental lines for use in hybrids. Macia (an improved cultivar from Mozambique) derivative lines looked especially promising and also offer po-

tential to develop some improved white-seeded, tan-plant parental lines for U.S. use.

Sterilization and evaluation continued on a large number of new B-line breeding genotypes to assist decisions on which ones to release. These lines contain various combinations of stay green drought resistance, lodging resistance, improved grain quality, and head smut resistance. Several are white-seeded, tan-plant A-B pairs that could be useful in food-type hybrids.

The acceptance of white-seeded, tan-plant improved Guinea type sorghum cultivars, developed in the INTSORMIL/IER collaborative breeding program in Mali, by both farmers and in the marketplace has been excellent. The interest of farmers involved in the flawed 2002 identity preserved grain increase with N'Tenimissa in doing a similar thing with a different grain/market entrepreneurs is real encouraging. It shows that new cultivars with improved grain quality traits can stimulate the development and commercialization of new sorghum-based products. Some of the new N'Tenimissa breeding progenies in Mali promise to be superior to N'Tenimissa in production and grain quality. Several (N'Tenimissa*Tiemarfing local Guinea) derivative breeding lines have been given cultivar names and released, including 97-SB-F5DT-63 as Wassa, 97-SB-F5DT-64 as Kénikédiè, 99-BE-F4P-128-1 as Darrellken, 97-SB-F5DT-74-2 as Niéta, 96-CZ-F4P-98 as Zarra-blè, and 96-CZ-F4P-99 as Zarra-djé, along with one intermediate caudatum-guinea type 97-SB-F5DT-150 as Niétichama.

Collaborative INTSORMIL activities recently initiated in Senegal and Ghana continued in the areas of sorghum breeding, disease resistance, and *Striga*, as well as in entomology and agronomy research. The consolidation of all the West African INTSORMIL collaborative programs in six countries into one overall regional program was initiated in early 2004.

Objectives, Production and Utilization Constraints

Objectives

U.S.

- Develop and release agronomically improved disease, drought, and lodging resistant lines and germplasm and identify new genetic sources of desirable traits. Evaluate new germplasm and introgress useful traits into useable lines or germplasm.
- Current year objectives emphasize the evaluation and seed increase of U.S. and Host Country adopted breeding germplasm from TAM-222 for distribution/released/transfer to U.S. and host country collaborators, and private companies as the project is being closed.

Western Region/West Africa (Mali, Ghana, Senegal)

- Develop, release, and distribute agronomically acceptable white-seeded, tan-plant Guinea type sorghum cultivars to enhance the commercial value and demand for improved value, high quality sorghum grain.
- Develop high yielding white, tan non-Guinea type improved cultivars with high levels of resistance to head bug and grain mold with adaptation to the drought and soil conditions of West Africa, and with acceptable levels of disease resistance. Characterize and describe the selected indigenous Mali and Sudan sorghum cultivars and evaluate for useful traits and breeding potential.
- Strengthen the collaboration with scientists in Ghana and Senegal including breeding, pathology, entomology, agronomy, and *Striga* research, and encourage across country collaboration with scientists in Mali, Niger, Burkina Faso, and Nigeria.

Central America

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

Horn of Africa and Southern Africa

- Enhance drought resistance, disease resistance, and germplasm base with the development of improved high yielding, adapted germplasm and elite lines.

Constraints

Drought is the major constraint to sorghum and millet production around the world. West Texas has a semiarid environment ideal for large-scale field screening for both pre- and post-flowering drought response and breeding for improved resistance to drought.

Diseases are important worldwide and most internationally important diseases are present and are also serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. 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 over much of West Africa and is primarily due to the head bug/grain mold complex. Head bugs are a major constraint to the use of improved high yielding nonguinea type sorghums in much of West Africa, with head bug damage often compounded by grain mold, resulting in a soft, discolored endosperm, which is unfit for decortication and traditional food products. Early maturity of introduced types also increases the grain deterioration problem. In the southern regions, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season.

Much of West Africa, especially the more northern areas, are drought prone areas and drought tolerance is important. Foliar diseases such as anthracnose and sooty stripe are important in the central and southern parts and in certain areas of Southern Africa along with leaf blight. In much of East Africa, the major constraint is drought, and related production problems. Moisture-stress related charcoal rot and subsequent lodging are serious problems. *Striga* is a major constraint in most areas including Mali, Niger, and Sudan.

In Central America, diseases and grain quality are major constraints, with drought 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 is a unique challenge and must be done on site in Central America.

There is a constant need in host countries and in the U.S. to conserve genetic diversity and utilize new diverse germplasm sources with resistance to pests, diseases, and environmental stress. Many developing countries are an important source of diverse germplasm in sorghum and millet. The collection, preservation and utilization of genetic diversity in sorghum is important to long-term, sustainable sorghum improvement programs needed to insure sufficient food for increasing populations of 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. or worldwide lines or 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.

Disease resistant breeding material is generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance. 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.

Breeding crosses involving sources of drought resistance are selected under field conditions for pre- and/or post flowering drought resistance, yield, and adaptation at several locations in west Texas. Selected advanced materials are incorporated into standard replicated trials for evaluation at several locations in Texas and sent to host countries for evaluation and use.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials are screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm is assembled or collected as opportunities exist and introduced into the U.S. through the quarantine greenhouse (small number of items) or the USDA Plant Quarantine Station in St. Croix (many items), and are then evaluated in Puerto Rico and Texas for useful traits. Selected photoperiod sensitive cultivars are entered into the cooperative TAES-USDA Sorghum Conversion Program. Cooperative work with NARS assures their country's indigenous sorghum cultivars are preserved in long-term permanent storage in the U.S. at the NSSL, as well as evaluated and used in germplasm enhancement programs. Grow outs of entire collections (Sudan and Mali) have been grown in their country of origin for characterization, seed increase and evaluation prior to introduction into the U.S. Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs.

Research Findings

In 2002, a new pathotype of downy mildew was identified in the upper coastal region of Texas. This new pathotype of P3 attacked Apron treated hybrids. This created great concern among the sorghum seed trade since Apron seed treatment has been the primary (and very successful) method of central for sorghum downy mildew in south Texas for many years. In 2003 and 2004 a large number of breeding progenies (advanced to early generation) were evaluated for resistance to this new pathotype under field conditions near El Campo, Texas. Fortunately, essentially all the sorghum lines identified with resistance to P3 downy mildew in past years still were resistant to the Apron resistant pathotype. Sixty R and B diverse breeding lines with genetic resistance were identified for release, being derived from nine different sources of resistance (Table 1). These diverse agronomically acceptable breeding lines should be useful to private and public sorghum workers in developing genetic resistance parental lines and hybrids.

Breeding, selection, and screening for drought resistance continued using major field screening nurseries at Lubbock, Halfway, Corpus Christi and Beeville. Extreme late season stress at Lubbock and Halfway resulted in excellent post-flowering stress and lodging ratings. The "stay-green" line, BTx642/B35, continues to be an excellent source of post-flowering drought resistance and lodging resistance in breeding progeny. Breeding derivatives of the parental line, BTX643(B1), a derivative of B35, showed some good drought resistance, with many showing outstanding lodging resistance especially the pedigrees (B1*(B7904*(SC748*SC630))), (B1*BTx635), and (B2-1*BTx635). Sterilization and hybrid evaluation continued on the above mentioned B lines which includes several white seeded, tan plant lines.

Table 1. Downey Mildew (Pathotype 3) resistant sorghum lines for germplasm release (resistant to Apron-resistant P3 Pathotype near El Campo, TX in 2003 and 2004).

Designation	Pedigree	Pericarp color/[1] plant color
82BDM 499	(SC173*SC414)	W,P
86PL2120	((SC748*SC650)*SC414)	R,P
92BD1016	(R5646*(SC414*SC326-6))	W,T
90CW8147	(82BDM499*87EO366)-HF8	W,T
91BD1319	(Sureno*82BDM499)BD18	W,T
92BD1982-4	(86PL2120*87EO366)-BD6	R,T
90EO328	(Sureno*82BDM499)-HD5	W,T
96CD635	(SRN39*90EO328)-HF4	W,T
98CD187	(87EO366*90EO328)-HF6	W,T
96CD677	(87EO366*90EO328)-HF3	W,T
95ED509	(86PL2120*87BH8606)-BD19	R,P
95ED508	(86PL2120*87BH8606)-BD19	R,P
--	(86PL2120*87BH8606)-BD5	R,P
--	(TAM428*SC502)/03B/R906(w,ch)	W,P(ch)
--	(TAM428*SC502)/03B/R918(w,tr)	W,P
--	(SC173*SC414)	W,P
--	(SC414*TAM428)	W,P
--	(SC23*QL3(I))	R,P
--	(R4317*SC425(uc)	R,P(uc)
--	(R4317*SC425(nouc)	R,P
--	(Tx432*SC38)	W,P
--	(BTx625*SC33)-BD5	R,P
--	(TP24R*SC33)-4B	W,T
--	(R4317*SC418)-4	R,P
--	(82BDM499*SC574)-WE6	W,P(uc)
--	(Tx430*DurDoc)?Ped(w,tn)	W,T
--	(SRN39*90EO328)-HF3	W,T
--	(SRN39*90EO328)-HF5	W,T
--	KS/(87EO366*90EO328)-HF6-ED5	W,T
--	(87ED366*90EO328)-HF6-ED6	W,T
--	(87ED366*90EO328)-LD30	W,T
--	(87ED366*90EO328)-HF14-BD1	W,T
--	(87ED366*90EO328)-HF14-BD2	W,T
--	(87ED366*(Sureno*82BDM499))-HD40	W,T
--	(87ED366*90EO328)-LD31	W,T
--	(87ED366*90EO328)-HF1	W,T
--	(87ED366*90EO328)-HD8	W,T
--	(87EO366*Tx2891)-BD2	W,T
--	(Sureno*Tx2891)-HF17-BE5	W,T
--	(Sureno*82BD499)-HD9	W,T
--	(Sureno*82BEM499)-14B	W,T
--	(Malisor84-7*90EO328)-HF14	W,T
--	(Malisor84-7*90EO328)-HF9	W,T
--	(CE151*82BEM499)-LD17	W,P
--	(90EO328*CE151)-LD11	W,T
--	(90EO328*CE151)-LA49	W,T
--	(90EO328*CE151)-LA37	W,T
--	(90EO328*CE151)-BD18	W,T
--	(90EO328*CE151)-LA59	W,T
--	(86PL2120*M50069)	W,T
--	(88BE2668*82BD499)-HD14	R,P
--	(90EO328*Kuyuma)-BE7	W,T
B-Lines		
--	((BTx623*QL3(I))*B.HF13)-HL3	W,T
--	((BTx623*QL3(I))*B.HF13)-HL7	W,T
--	((BTx623*QL3(I))*B.HF13)-HL14-BD2	W,T
--	((BTx623*QL3(I))*B.HF13)-HL15	W,T
03L-B/R614	((BTx623*QL3(I))*B.HF14)-HL13	W,T(ch)
03L-B/R615	((BTx623*QL3(I))*B.HF14)-HL13	W,T
--	((BTx623*QL3(I)*(B1*B9501)-HL14	R,P
--	((BTx623*QL3(I)*(B1*B9501)-HL30	W,P

[1] Pericarp color: W = white, R = red
Plant color: T = tan; P = purple
(ch) = chalky (thick) pericarp
(uc) = undercoat (testa) present

New disease resistant breeding materials were developed, screened, and selected along with advanced generation breeding materials for improved agronomic types with high levels of, and/or multiple, disease resistance. Screening and selection was done primarily in large disease screening nurseries, mostly in south Texas. Major diseases involved were downy mildew, head smut, anthracnose, grain mold/weathering, and charcoal rot.

Approximately 30 A-B pairs and R lines developed cooperatively with L.E. Clark in the cooperative drought-breeding program have been identified for possible release. These lines contain many traits with emphasis on stay green and lodging resistance. Several are white-seeded tan plant lines and some show enhanced weathering resistance. These will be proposed for release mostly as germplasm stocks. Another set of advanced generation potential germplasm releases containing 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 have been identified. See Table 1 in the 2003 INTSORMIL Annual Report for a listing of several breeding lines for potential release.

Forty-nine new fully converted lines and 71 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS sorghum conversion program were released.

Sureño, a white-seeded, tan-plant cultivar, with excellent food grain quality, released in the Honduras-INTSORMIL collaborative program was officially released in El Salvador as an open-pollinated sorghum cultivar named SV3.

Near isogenic lines (NILs) developed (BC6 of (B35*Tx7000)) to do fine mapping of stay green QTLs and to do functional genomics and stress physiology research in cooperation with scientists in Australia were evaluated for stay green in Texas and Australia. In another project, advanced backcross populations and hybrids were generated and evaluated to identify QTLs for yield and heterosis in exotic germplasm. One donor parent, Lian Tang Ai, a Chinese landrace cultivar appeared to enhance both grain yield and earliness in hybrids and could be useful in enhancing yield in hybrids.

Several new tan-plant N'Tenimissa derivative guinea type breeding lines looked promising in Mali in 2001, showing less stalk breakage, and better head bug resistance than N'Tenimissa. Six new N'Tenimissa breeding derivative tan-plant guinea lines were released and named in Mali, along with one intermediate caudatum-guinea line (Table 2). Also, some new, shorter N'Tenimissa derivative F_4 and F_5 lines showed real promise. Selection also continued among non-guinea type, tan-plant breeding lines with improved levels of head bug tolerance and grain mold resistance. Several farmers involved in the large-scale identity preserved production of N'Tenimissa in five villages in 2002 were visited in 2003, and all seemed very interested in contract planting of new cultivars but with different grain/marketing entrepreneurs.

In Nicaragua, several of the breeding lines which have looked outstanding in the Southern Africa region, were evalu-

Table 2. New Malian white-seeded, tan-plant sorghum breeding lines recently released and named in Mali.[1/]

Name	Designation	Pedigree	Days to flower
Wassa	97-SB-F5DT-63	(N'Tenimissa*Tiemarfing)	77
Kénikédiè	97-SB-F5DT-64	(N'Tenimissa*Tiemarfing)	78
Darrellken	99-BE-F5P-128-1	(N'Tenimissa*?)	79
Niéta	97-SB-F5DT-74-2	(N'Tenimissa*Tiemarfing)	83
Zarra-blè	96-CZ-F4P-98	(N'Tenimissa*Tiemarfing)	94
Zarra-djé	96-CZ-F4P-99	(N'Tenimissa*Tiemarfing)	90
Niétichama	97-SB-F5DT-150	(92-SB-F4-14*92-SB-F4-97)	89

[1/]The top six cultivars are all true guinea types, but with tan plant. The last cultivar is an intermediate caudatum-guinea type. Tiemarfing is a Malian local landrace guinea type sorghum.

ated and some performed very well. From a 25 entry observation nursery of African/Central American type breeding lines from TAM222, six agronomically promising lines were selected for further evaluation and potential use as new cultivars. The six selected lines were 02CA4778/(ICSV1089BF*Macia)-HF2; 02CA4624/(Macia*Dorado)-HD12; 02L-SABN1094/ (Sepon82*87EO366)-HF38; 02CA4597/(Macia*Dorado)-HD2; 02CA4738/(Macia*Dorado)-LL2; and 02CA4747/ 9Macia*Dorado)-LL6. Three of the six lines were also identified in the 2002 season as combining high yield with appropriate plant height, maturity and agronomic traits for potential use as new cultivars under mechanized production: LL2, LL6, and HD12.Also, the white, tan cultivar, Macia, introduced by Dr. Gary Odvody from Southern Africa region, has been selected in Nicaragua for release (Africana). Macia was one of several elite African sorghums sent to Central America in 1999 is an INTSORMIL nursery.

Thirty-five selected diverse Malian indigenous sorghums, including some new unique Durras, Durra-Bicolor, Bicolor, and Durra Dochna from northern Mali, along with 30 primarily Guinea-Caudatum sorghums from southern Sudan were evaluated for B/R fertility reaction, hybrid vigor and presence of the dominant B1 gene (gives testa with U.S. females) in Mali and Puerto Rico. Most Malian cultivars were restorers except for a few Guinea types, especially Margaritaferum types. Essentially all the Guinea-Caudatum derivative cultivars from southern Sudan were strong restorers but showed good heterosis and yield potential. The dominant B1 gene was absent in most Durra and Durra-Bicolor Malian lines, and some of these lines showed promising heterosis. There appeared to be rather good differences in hybrid vigor among lines, especially under Mali conditions.

Networking Activities

Workshops/Conferences

Participated in the INTSORMIL West African Regional Conference in Ouagadougou, Burkina Faso, April 16-22, 2004 where the structure of one West African Regional INTSORMIL/ host country collaborative program was put in place and future research plans developed.

Participation in the American Seed Trade Association Production and Research Conference at Chicago, IL, December 10-11, 2003, and participated in the Sorghum Germplasm Committee meeting held at the ASTA Conference on December 10.

Mr. Niaba Teme, Mali Ph.D. student, participated in the Annual American Society of Agronomy (ASA) meetings, November 2-6, 2003 at Denver, CO, and presented two poster papers.

Research Investigator Exchanges

Interacted with numerous host country and U.S. INTSORMIL scientists to discuss and plan future collaborative research plans and activities at the West African Regional Conference in Ouagadougou, Burkina Faso, April 16-22, 2004.

Traveled to Senegal, October 4-9, and Mali, October 10-21, 2003 to evaluate INTSORMIL/Host Country collaborative research, plan future activities, and assist in coordinating the INTSORMIL External Evaluation Panel (EEP) review of the INTSORMIL collaborative programs in Senegal and Mali, as well as the Ghana program as presented by two Ghanian INTSORMIL scientists who traveled to Bamako, Mali to be reviewed by the EEP.

Traveled to Purdue University, September 8-9, 2003 to meet with Purdue and Nebraska administration and Bruce Hamaker to plan the April, 2004 West Africa Regional Meeting in Burkina Faso, and discuss strategies for merging the Western Region and Eastern Region of West Africa into one overall West African Region.

Traveled to Manhattan and Hesston, Kansas in late August 2003 to visit with Dr. Mitch Tuinstra and evaluate sorghum breeding plots at the two locations.

Participated in the Sorghum Germplasm Committee meeting at Chicago, IL, December 10, 2003 and discussed sorghum germplasm issues and concerns with most of the public and private sorghum researchers in the USA, and the USDA/ARS sorghum germplasm workers and administrators.

Traveled (with Niaba Teme) to College Station, TX, January 5-8, 2004 to develop 2004 research plans and discuss the closing out of my TAES sorghum breeding program as well as INTSORMIL related activities.

Traveled to Washington, DC, February 1-4, 2004 to receive the BIFAD International Research Award and meet BIFAD and USAID Administrators.

Traveled to Corpus Christi and College Station, TX June 28-July 1, 2004 to participate in the INTSORMIL EEP Review of the Texas A&M Projects as well as my INTSORMIL Project.

Organized and led sorghum field days at Corpus Christi, July 10, and at Lubbock, September 15, 2003 where private and public sorghum workers were invited to observe and evaluate my 500 B/R-Line Observation Nursery (possible releases) for interest in requesting and obtaining seed of any of the material through a pre-release distribution MTA (Material Transfer Agreement).

Traveled to Tampico, Mexico, March 3-5, 2004 as a member of the Texas Seed Trade Association Advisory Committee to read sorghum hybrid purity growouts, and interacted with several private seed company breeders.

Coordinated the training of Mr. Niaba Teme, Malian sorghum scientist who is currently working on his Ph.D. in sorghum breeding at Texas Tech University, cooperative with Texas A&M.

Hosted R.E. Schaffert, EMBRAPA sorghum research director from Brazil and Banjerd Boonsue, Thailand sorghum consultant in September 2003 where they toured plots and discussed sorghum breeding and germplasm research.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Continued the coordination of the work with the Mali Sorghum Collection. The Collection has been evaluated, characterization completed, and a tentative working collection identified. After the seed sent to Experiment Georgia has been processed, seed of the entire collection will be sent to NSSL at Ft. Collins, Colorado and will be distributed as appropriate to ICRISAT, ORSTOM (now IRD), and IER. The complete set of data on the over 40 grain, glume, and plant characterizations has been complied by Jeff Dahlberg and sent to the USDA-ARS for entry into the GRIN system.

Selected indigenous sorghums from the Mali Working Collection (35) and the Sudan Working Collection (30) were evaluated for B/R reaction and hybrid vigor in Mali and Puerto Rico.

Forty-nine new fully converted exotic cultivars from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released along with 71 partially converted lines and are in the process of being distributed. Twenty-five Mali entries, including some new, diverse types from northern Mali, were selected as candidates for entry into the Sorghum Conversion Program.

A large number of advanced generation breeding lines from my sorghum breeding program of potential use in host countries and/or U.S. were increased for storage and made available to U.S. collaborating scientists for future distribution and/or use. Selected elite breeding lines were assembled and distributed to host country scientists in South Africa, Zambia, Botswana, Nicaragua, Mali, Ghana, Senegal, and Niger.

Seed Production and Distribution

A large number of sorghum breeding and germplasm lines, from early to advanced generation 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, sooty stripe, leaf blight, rust, and charcoal rot, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance.

Seed of many basic A/B and R-line breeding stocks, RIL populations, photoperiod insensitive introductions, and all the fully converted released lines from the Sorghum Conversion Program were increased in preparation for closing my breeding project.

Assistance Given

Joint evaluation of germplasm and nursery and test entry decisions was done collaboratively with national scientists. 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 several visitors. Pollinating bags, coin envelopes, and other breeding supplies were provided to the Mali breeding program. Purchases included computers for Ghana, Senegal, and Mali, and other miscellaneous supplies for Mali.

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.

Dr. Zenbaba Gutema, Sorghum Breeder, EARO, Nazareth, Ethiopia

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Publications and Presentations

Abstracts

Teme, N., D.T. Rosenow, G.C. Peterson, W. Xu, C.A. Woodfin, H.T. Nguyen, A. Herring, and R.J. Wright. 2003. Backcross method for heterosis enhancement in grain sorghum. Annual American Society of Agronomy Abstracts. CD-ROM. November 2-6, 2003. Denver, CO.

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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

Increase Yield and Promote Economic Growth

Research activity has emphasized the breeding for resistance to insects component of the Texas Agricultural Experiment Station sorghum improvement program. Primary objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars, germplasm, or parental lines resistant to selected biotic and abiotic stresses. Primary insect pests are the greenbug (*Schizaphis graminum*), sorghum midge (*Stenodiplosis sorghicola*), and sugarcane aphid (*Melanaphis sacchari*). Segregating populations are concurrently selected for resistance to economically important diseases including but not limited to: sorghum downy mildew (caused by *Peronosclerospora sorghi* (Westan and Uppal) Shaw), head smut (caused by (*Sphacelotheca reiliana* (Kuhn) Clinton), and anthracnose (caused by *Colletotrichum graminicola* (Cesati) Wilson). Selections are also made for resistance to zonate leaf spot (caused by (*Gloeocercospora sorghi* Bain and Edgerton), bacterial leaf streak (caused by *Xanthomonas holcicola* (Elliot) Star and Burkholder), bacterial leaf stripe (caused by *Pseudomonas andropogoni* (E.F. Smith) Stapp), and charcoal rot (caused by *Macrophomina phaseolina* (Tassi) Goid). Project emphasis is evolving with increased research on drought resistance and food type sorghums and a smaller resistance to insects component. Research activities use primarily conventional methodology. Populations with diverse parents are evaluated to identify superior lines with wide adaptation, resistance to specific diseases, and biotype I greenbug resistance. Relevant populations are also evaluated for drought resistance, primarily stay-green (post-flowering drought tolerance).

A primary research objective has been to develop sorghum midge-resistant hybrid parental lines. Primary research emphasis was to incorporate pest resistance into lines with high grain yield under high pest density, acceptable yield with the pest absent, and incorporate other traits including adaptation, disease resistance, etc. Although significant progress has been achieved the best midge-resistant hybrids produce 10-15% less grain than the best susceptible hybrids when sorghum midge

are absent at anthesis. When sorghum midge are present at anthesis, or when planting occurs two weeks later than normal, resistant hybrids produce significantly more grain than susceptible hybrids. With a shift in project emphasis research on sorghum midge resistant hybrids for the U.S. has decreased with increased emphasis placed on sorghum midge resistant varieties for use in developing country production systems.

Increase Yield, Promote Economic Growth, Improve Nutrition

Eighteen biotype I greenbug resistant and 19 biotype C greenbug/disease resistant lines are in final line evaluation and hybrid yield testing. Most of the biotype C resistant lines also express wide adaptation and resistance to several diseases. Within the group is a diverse array of plant and grain color combinations including tan plant, white grain and tan plant, red grain. Tan plant red or white grain sorghum hybrids with multiple stress resistance and high yield potential may help increase utilization of sorghum in new or non-traditional uses. Multiple stress resistant widely adapted sorghums will be used by private industry in hybrid development programs.

Improve Institutional Capacity

The principal investigator serves on the graduate committee of one Ph.D. student (from Mali) at Texas Tech University and two M.S. students (from Zimbabwe and Mozambique respectively) at Texas A&M University. Mr. Niabe Teme (Mali) will complete requirement for the Ph.D. degree in mid-to-late 2006. Mr. Leo Mpofu (Zimbabwe) and Mr. Joaquim Mutiliano (Mozambique) should complete their M.S. degrees in mid-2005. Mr. Mpofu is a non-INTSORMIL supported student.

Objectives, Production and Utilization Constraints

Objectives

- Obtain and evaluate germplasm for resistance to arthropod pests and other stresses including drought and selected diseases.
- Develop and release high-yielding, agronomically improved sorghums resistant to selected insects and other biotic or abiotic stresses.
- Develop and release high grain yield sorghums with multiple stress resistance and improved grain quality traits.
- Utilize molecular biology to increase understanding of plant traits for stress resistance.

Sorghum Production Constraints

Grain sorghum yield stability and production is constrained by biotic (insects and diseases) and abiotic (drought) stresses. Insects pose a risk in all sorghum production areas with damage depending on the insect and ambient environment. To reduce stress impact sorghums with enhanced environmental fitness are needed. In farmer production stress occurs concurrently and genetic resistance to multiple stresses reduces environmental risk and enhances productivity. This becomes especially important as production ecosystems change with the natural balance between the crop and biotic stresses experiencing change.

Farmers use hybrids or cultivars with improved genetics for adaptation, stress resistance, and quality to meet the demands of increased food production in economically profitable, environmentally sustainable production systems. This requires a multi-disciplinary research program to integrate resistant genotypes into the management system. Varieties or hybrids with genetic resistance to stress readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Research Approach and Project Output

Research Methods

Collaborative LDC research is supported through graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas. Activity is conducted in two regional programs - Southern Africa and Central America. Southern Africa research is primarily focused on incorporating resistance to sugarcane aphid into adapted cultivars. Additional selection criteria include disease resistance, adaptation, and end-use traits. Activity in Nicaragua and El Salvador involves research on sorghum midge, drought resistance, disease resistance, adaptation, and end-use traits. In the United States, sorghum midge and greenbug-resistant sources have been identified and used to develop elite resistant sorghums. Through collaborative ties with other projects genetic inheritance, resistance mechanisms, molecular mapping, and marker-assisted selection research has been conducted. Appropriate selection methodology is used to concurrently select for other biotic or abiotic stress resistance to develop germplasm with wide adaptation, multiple stress resistance, and improved end-use traits.

Germplasm is evaluated for resistance to economically important insects in field nurseries or greenhouse facilities depending on the insect. Sources of germplasm for evaluation are introductions from other programs (domestically and internationally), exotic lines, and partially or fully converted exotic lines from the sorghum conversion program. Introduced germplasm is crossed to elite resistant germplasm, and to germplasm with superior trait(s). Although a primary selection criteria is insect resistance, additional significant selection criteria include wide adaptation, resistance to diseases, drought resistance, weathering resistance and improved end-use traits. Based on phenotypic evaluation and data analysis crosses are made among elite lines to produce germplasm for subsequent evaluation. The goal is to combine resistance genes for multiple stresses into a single high grain yield genotype. For insects important in LDC's but not in the U.S., germplasm is selected for adaptation, grain yield potential, and disease resistance in nurseries in the Texas Coastal Bend (Corpus Christi and/or Beeville). The germplasm is provided to the LDC cooperator in replicated trials for evaluation for resistance to the specific insect under the local production system (fertilizer, tillage, plant population, etc.) and agronomic and yield data collected if possible.

Research Findings

Sorghum Midge Resistance

Primary emphasis has been directed to identify new superior A- or R-lines. The lines should exhibit a high level of sorghum midge resistance, superior agronomic traits, and high grain yield potential. Grain yield potential of elite breeding lines in hybrid combination was evaluated at Corpus Christi. The midge hybrid test (30 entries x three replications) was evaluated in a late planting (about four weeks after farmer planted sorghum) date. The growing season was characterized by moderate rainfall from planting through maturity. Results are shown in Table 1. Sorghum midge population density at anthesis was low with test mean of 2.9 (rated on a scale of 1 = 0-10% damaged kernels, 2 = 11-21%, up to 9 = 80-100% damaged kernels). The standard resistant check is ATx2755*Tx2882 and the standard susceptible check is ATx2752*RTx430. Grain yield was moderately low with test mean of 2714 kg/ha^{-1} due to the harsh environmental conditions during the growing season. The standard susceptible check, ATx2752*RTx430, produced the most grain in the test (4947 kg/ha^{-1}). This was significantly more grain than all other entries in the test except the experimental resistant hybrid A8PR1011*Tx2882 (4324 kg/ha^{-1}).

Table 1. Mean grain yield, midge damage rating, insecticide phytotoxicity rating, and desirability of entries in midge hybrid test at Corpus Christi, TX, 2003.

HYBRID	DESIGNATION	GRAIN YIELD	MIDGE DAMAGE RATING†	INSECTICIDE PHYTOTOXICITY‡	DESIRABILITY§
		kg/ha^{-1}			
ATx2752*RTx430	s-ck¶	4947	2.0	2.4	2.5
A8PR1011*Tx2882		4324	1.0	2.2	1.9
A8PR1013*MB108B		4163	1.5	2.2	2.2
A8PR1011*9MLT176		4074	1.0	2.8	2.5
A8PR1013*9MLT157		4040	1.0	2.5	2.3
A8PR1013*Tx2880		3941	1.0	2.6	2.4
ATx2755*Tx2880		3779	1.0	2.6	2.5
ATx399*RTx430	s-ck	3637	2.5	2.0	2.5
A0PR13*Tx2882		3634	1.0	2.4	2.4
A8PR1011*9MLT181		3377	1.5	2.2	2.3
ATx2755*97M17		3341	1.0	2.8	2.4
A8PR1011*9MLT157		3240	1.5	2.5	2.4
ATx2755*Tx2882	r-ck	3135	1.0	2.8	2.4
A8PR1013*9MLT181		3058	1.5	2.0	2.3
A8PR1011*MB108B		3055	3.0	2.4	2.1
A0PR13*Tx2880		2771	1.5	2.3	2.5
ATx2755*MB108B		2748	3.0	2.4	2.1
A8PR1011*9MLT180		2714	2.0	1.8	2.5
ATx2755*97M13		2648	3.0	3.0	2.5
A1*Tx430	s-ck	2410	3.5	2.4	2.4
ATx640*RTx430	r-ck	2385	1.5	2.6	2.5
A8PR1013*Tx2767		2114	2.0	2.5	2.5
ATx2752*Tx2862	s-ck	1803	4.5	2.5	2.4
A35*RTx430	s-ck	1678	4.5	2.5	2.4
A8PR1013*Tx2882		1557	3.0	2.5	2.6
A807*Tx2783	s-ck	970	4.5	2.4	2.5
A807*Tx2862	s-ck	729	7.5	2.2	2.4
ATx640*MB108B		714	7.5	2.3	2.7
A35*Tx2862	s-ck	289	8.5	2.3	2.4
A35*Tx2783	s-ck	148	9.0	2.3	2.5
MEAN		2714	2.9	2.4	2.4
LSD.05		773	2.0	0.5	0.4

†Rated on a scale of 1 = 0 to 10% aborted kernels up to 9 = 81=100% aborted kernels.
‡Rated on a scale of 1 = no insecticide phytotoxicity up to 5 = 100% insecticide phytotoxicity.
§Rated on a scale of 1 = most desirable up to 5 = least desirable.
¶s-ck = Susceptible check, r-check = Resistant check.

Most resistant hybrids were at least equal to the other susceptible checks with eight of the 10 hybrids with the highest grain yield being resistant hybrids. Of the 10 hybrids producing the least amount of grain six were susceptible checks. The six susceptible checks produced significantly less grain than most experimental resistant entries. Results confirm previous observations that with a late planting date and few sorghum midge present at anthesis most resistant hybrids will produce significantly more grain than susceptible hybrids. However, for many environments a grain yield difference will exist between resistant and susceptible hybrids.

There is concern that it will not be possible to develop sorghum midge resistant hybrids for use in the United States. The primary constraint to widespread use of currently potentially available resistant hybrids is the lower grain yield potential (averaging 10-15%) of resistant than susceptible hybrids in a normal planting. However, for production delayed at plant-

Table 2. Mean grain yield and selected agronomic characteristics in the biotype I greenbug resistance hybrid test at Lubbock, TX, 2003.

PEDIGREE	DESIGNATION	YIELD	DAYS TO 50% ANTHESIS	HEIGHT	EXERTION
		kg/ha		cm	cm
ATx645*RTx430	s-ck[†]	3803	62	44	2
ATx643*LI1/8LI182		3605	65	38	1
ATx643*LI4/8LI178		3587	63	44	2
A8PR1059*LG35		3556	65	43	0
ATx645*LG53/8LI155		3538	62	41	1
ATx642*LI1/8LI188		3432	65	46	1
ATx642*LI1/8LI182		3389	64	44	0
A0PR51*RTx430		3297	61	46	1
ATx642*LI4/8LI178		3266	69	44	1
A8PR1051*RTx430		3260	61	44	1
ATx631*LI4/8LI178		3235	61	44	1
ATx642*LG53/8LI156		3229	62	47	1
ATx645*LG70/8LI170		3204	62	46	1
ATx643*LG70/8LI170		3185	62	44	1
A8PR1053*Tx436		3142	62	47	1
A8PR1053*RTx430		3124	61	40	1
ATx631*RTx430	s-ck	3111	62	47	2
ATx399*RTx430	s-ck	3099	61	38	1
ATx631*Tx436	s-ck	3086	63	47	1
ATx642*LG35/8LI158		3074	63	44	2
ATx645*LG70/8LI172		3068	61	48	1
ATx643*PR8/8LI233		3037	65	40	1
ATx642*LG70/8LI170		2982	63	37	1
ATx642*LG41/8LI163		2976	68	45	1
ATx643*LG41/8LI163		2926	62	47	1
A0PR51*Tx436		2908	61	39	1
ATx642*LG35		2902	69	41	1
ATx645*LI1/8LI188		2889	63	40	1
ATx642*LG70/8LI172		2877	66	37	1
ATx642*LG53/8LI148		2840	63	43	1
ATx642*LG53/8LI155		2840	63	41	1
A0PR59*LG35		2828	62	44	1
A8PR1049*LI4/8LI178		2815	63	44	1
ATx643*RTx430	s-ck	2803	63	44	1
ATx643*LG53/8LI148		2797	64	38	1
ATx645*LG70/8LI173		2797	62	44	1
ATx645*LG53/8LI156		2784	59	46	1
ATx643*LI3/8LI174		2772	61	43	1
A8PR1053*LG35		2754	63	39	0
ATx642*PR8/8LI233		2722	68	42	1
ATx643*LG53/8LI150		2692	64	47	1
ATx645*PR8/8LI233		2655	63	36	1
ATx643*LG70/8LI172		2649	64	43	1
ATx645*LI1/8LI182		2617	62	42	1
A0PR55*LG35		2636	62	47	1
Mean		2463	63	41	1
LSD.05		1230	3	7	1

[†]s-ck = Biotype I greenbug susceptible check.

ing two weeks or more resistant hybrids will generally out-yield susceptibly hybrids without insecticide application. With increasing environmental concern regarding pesticide application a reduction in availability of insecticides to control sorghum midge could significantly increase interest in and potential use of resistant hybrids. The research focus of sorghum-midge resistance program is changing to reduce hybrid development activity and increase sorghum midge resistant variety development for use in developing country production. While some hybrid development research will continue more resources will be devoted to tan plant and white grain sorghum midge resistant varieties.

Greenbug Resistance

Selections to develop germplasm resistant to biotype I were made. The primary resistance sources are PI550607 and PI550610. Both sources are used in developing R-lines, and PI550610 is used in B-line development. Screening against the greenbug biotypes identified genotypes that express moderate resistance. Biotype resistance is conditioned by several genes and a moderate level of resistance is desired. Crosses to introgress resistance gene(s) into other germplasm were made.

New biotype I resistant R-lines resistant to biotype I were evaluated in a replicated yield trial (94 entries x 3 replications) at Lubbock under moderate drought stress. Partial results are shown in Table 2. The greenbug susceptible hybrid ATx645*RTx430 produced the most grain with 3803kg ha^{-1}. This hybrid did not produce significantly more grain than many experimental resistant hybrids. Fourteen of the to 15 hybrids with the highest grain yield are resistant to biotype I greenbug. The lines represent a range of plant types including tan plant, white pericarp and tan plant, red pericarp. New tan plant, red grain biotype E resistant A-lines were included in the hybrid test. The A-lines A8PR1059, A0PR51, and A8PR1051 produced the fourth, eighth, and tenth, respectively highest yielding hybrids. In addition to excellent grain yield potential many of the entries possess wide adaptation and resistance to several diseases.

New parental lines (either R- or A-lines) resistant to biotype E greenbug and many with excellent disease resistance and grain weathering resistant characteristics were evaluated in a replicated yield trial (46 entries x three replication). The trial was grown under moderate drought stress and limited irrigation at Lubbock, TX. The parental lines have been selected for diversity of plant type, wide adaptation, foliar disease resistance, and increased grain yield potential. This germplasm will be useful as sources of improved traits for other breeding programs, and selected germplasm might have potential as varieties in specific production systems. Test mean was 3266kg ha^{-1} (LSD.05 = 1303kg ha^{-1}). Sixteen experimental produced more grain than the test mean with two hybrids (ATx642*5BRON151 and ATx642*5BRON131) producing significantly more grain at 4635kg ha^{-1} and 4570kg ha^{-1}, respectively. The parental R-line designated 5BRON151 produced the second, eighth, and eleventh highest yielding hybrid when crossed with to ATx642, ATx643, and ATx2752, respectively. It is anticipated that the remaining data required to propose lines for release will be collected in the 2004 growing season and a release proposal will be developed in late-2004 or early-2005.

A replicated yield trial (80 entries x three replications) was grown at the INTA station near Managua, Nicaragua. Data on the 43 entries that produced more train than the test mean (2.1kg ha^{-1}) are listed in Table 3. Superior experimental hybrids produced at least as much grain as standard commercial checks. The highest yielding experimental, ATx635*5BRON139, produced as much grain (4.3kg ha^{-1}) as the best check, ATx631*RTx430. Most of the hybrids expressed acceptable maturity, plant height, and foliar disease resistance. Several of the parental lines including 5BRON139, two derivatives of LG35, 9BRON125, 5 BRON154, and 5BRON155, appear to have potential for use in the regional although additional evaluation is required.

Sugarcane Aphid Resistance

The sugarcane aphid (*Melanaphis sacchari*) is an insect pest of sorghum throughout Southern Africa. Collaborative research between TAM 223, the Botswana College of Agriculture (BCA), the South African Agricultural Research Corporation - Grain Crops Research Institute, and WTU 200 is directed at developing improved varieties with aphid resistance and other acceptable characteristics (maturity, height, grain yield, grain quality, disease resistance) for use in low input, small farmer areas of South Africa and the region. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, FGYQ336 have been crossed to locally adapted cultivars (include Segeolane, Marupantse, Macia, Town, SV1, and A964) and to elite lines from the Texas program to develop a range of populations. The segregating populations are planted at Corpus Christi and Lubbock, Texas for evaluation and selection in semi-tropical south Texas. Important selection criteria include plant height, foliar disease resistance, head smut resistance, grain yield potential, and lodging resistance. Evaluation for sugarcane aphid resistance and adaptation to local environments is done at Potchefstroom and the Haxyview Research Station near Burgershall, South Africa or Gaborone, Botswana.

The sugarcane aphid resistance test contains 100 entries. In South Africa, spreader rows of susceptible sorghum were planted two weeks prior to the sugarcane aphid resistance test to ensure presence of aphids. Aphid damage was evaluated when the majority of entries were in the milk stage. Severity of infestation is evaluated using a 1 to 5 scale, where 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present of two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered to be resistant, while a rating of 3 indicated an intermediate level of

Table 3. Grain yield and other agronomic traits of hybrids grown at Managua, Nicaragua, 2003.

HYBRID	GRAIN WEIGHT	DAYS TO 50% ANTHESIS	FOLIAR DISEASE†	PLANT HEIGHT	PANICLE EXSERTION	PANICLE LENGTH
	k/ha^{-1}			cm	cm	cm
ATx631*RTx430	4.3	58	2.0	167	3	34
ATx635*5BRON139	4.3	64	1.5	170	12	34
ATx631*LG35/8LI161	3.7	62	1.5	155	3	38
ATx631*LG35/8LI160	3.3	62	1.5	148	4	41
A8PR1059*9BRON125	3.2	61	2.0	150	6	31
ATx635*5BRON154	3.1	62	1.5	175	9	35
ATx635*5BRON155	3.1	62	1.5	166	10	31
ATx645*PR8/8LI233	3.1	62	2.5	137	2	35
ATx645*LG53/8LI148	3.0	58	3.5	145	13	36
ATx643*LI1/8LI182	2.9	62	3.0	147	4	29
ATx631*6OBS124	2.8	65	1.5	158	3	39
A8PR1051*9BRON125	2.8	60	1.5	153	9	36
ATx643*LG70/8LI173	2.8	64	2.0	137	11	36
ATx645*LI1/8LI182	2.8	62	3.0	150	5	30
ATx643*5BRON156	2.7	60	2.0	145	4	33
ATx631*6BRON167	2.7	62	1.5	160	22	34
ATx643*LG53/8LI148	2.7	58	2.5	148	12	29
ATx643*LG70/8LI172	2.7	62	2.0	151	15	32
ATx643*RTx430	2.6	56	2.0	160	9	27
ATx631*Tx436	2.6	58	2.0	165	9	32
ATx399*RTx430	2.6	51	3.0	145	17	27
ATx645*5BRON135	2.5	63	2.0	155	12	39
A8PR1059*6OBS124	2.5	63	1.5	142	11	33
A8PR1057*9BRON125	2.5	62	3.0	145	6	33
ATx643*LG70/8LI171	2.5	61	2.5	152	10	34
ATx645*LG70/8LI173	2.5	65	2.0	142	3	37
ATx399*RTx430	2.4	51	2.0	146	19	29
ATx643*LI4/8LI178	2.4	58	2.0	138	5	38
A8PR1049*LI4/8LI178	2.4	60	1.5	141	9	36
ATx643*LI1/8LI188	2.4	60	3.0	142	20	33
ATx643*6OBS167	2.3	68	2.0	142	3	40
ATx631*8BRON122	2.3	65	1.5	147	5	37
ATx645*LG53/8LI156	2.3	58	3.5	141	9	34
A8PR1057*LI4/8LI178	2.3	59	2.0	145	7	39
ATx631*R88B828	2.2	63	2.0	163	3	33
ATx643*6OBS124	2.2	62	2.0	153	11	34
ATx643*LG53/8LI156	2.2	58	3.0	140	8	38
ATx645*LG70/8LI172	2.2	63	3.0	136	4	30
ATx635*LI4/8LI178	2.2	55	2.0	190	14	39
A8PR1013*Tx2882	2.1	61	3.0	131	3	34
ATx643*5BRON139	2.1	65	2.0	138	3	36
A8PR1049*5BRON154	2.1	68	2.0	118	0	29
A8PR1053*6OBS124	2.1	60	2.0	140	9	32
Mean	2.1	63	2.2	142	8	34

†Rated on a scale of 1 = no foliar disease present up to 5 = leaves killed by foliar disease.

resistance. Plants with a rating of 4 or 5 were considered susceptible. Additionally, the percent of plants infested with aphids is estimated as a measure of resistance. Results of the trials are presented in Table 4.

Sugarcane aphid infestation levels at both South Africa locations were low. It was, however, higher at Burgershall than at Potchefstroom. Results from both trials indicated that 69 and 57 %, respectively for Potchefstroom and Burgershall, of the entries rated 1 on a scale of 1 to 5, indicating no to very slight damage. Ratings of 2 were scored for 18 % of the entries at both Potchefstroom and Burgershall. Since aphid infestation levels were low, a high level of damage was possible. One and 9 % of the entries at Potchefstroom and Burgershall respectively, died as a result of aphid infestation. In Botswana the abundance of sugarcane aphids on most of the sorghum lines was generally low. The abundance on 51 of the 100 lines was less than 10% infested plants per plot. Based upon the data collected 21 experimental entries were identified with a damage rating of 1 and fewer than 10% of the plants infested.

In Botswana the test was evaluated for the percent of plants infested by stem borers and termites. Ten lines were identified with fewer than 13.7% infested plants and therefore classified as expressing some level of resistance to stem borers. While the results show that some of the sorghum lines escaped stem borer and sugarcane aphid attack, termites infested all the 100 sorghum lines evaluated. Seven lines were identified with fewer than 9.2% infested plant and were classified as having a level of resistance to termites. From the data collected it was determined that while individual lines may be resistant to one insect (either sugarcane aphid, stem borers, or termites) none were resistant to all three insects. Additional breeding and selection will be necessary to develop improved varieties with resistance to multiple insects.

A late (January 2004) planting date of the sugarcane aphid test at Potchefstroom resulted in the test becoming infected with ergot. The test was therefore rate for severity of ergot as the percentage of ergot infection. It varied between 0 and 90 %, with 30 % of the entries showing less than 5 % infection. Thirteen entries were evaluated for sugarcane as very resistant (damage = 1) and possibly have some level of resistance to ergot (percent ergot infection less than 5%). Entries with less than 5% infection were classified, as possibly expressing some level of resistance to ergot but additional research is necessary.

Table 4. Mean sugarcane aphid damage rating, percent ergot infection, percent of plants infested with stem borers, termites, and sugarcane aphids, and number of coccinellids/plant at Potchefstroom and Burgershall, South Africa, and Gaborone, Botswana, 2004.

PEDIGREE	SCA DAMAGE†		Ergot‡	% infested plants per plot - Botswana			
	Potch	Burger	%	Stem Borers	Termites	Sugarcane aphids	# coccinellids /plot
((6BRON126/87BH8606-14*GR107-90M46)*CE151)-LG2-CG1-BG2-BG3	1.0	1.0	23.5	22.1	21.7	6.7	0.3
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E#14/SADC)-LG2-LG1-BG2	1.0	1.0	6.0	36.7	59.5	8.1	0.7
(6BRON161/(7EO366*Tx2783)*EPSON2040/E#15/SADC)-CG2-BG2-BGBK	1.0	1.0	1.0	42.2	19.0	0.0	0.7
(6OB124/(GR134B-LG56)*WM#177)-LG7-CG2-BGBK-CCBK	1.0	1.0	70.0	50.5	37.8	10.4	0.7
(6OB128/(Tx2862*6EO361)*CE151)-LG19-CCBK-CCBK	1.0	1.0	27.5	50.0	11.1	0.0	0.3
(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BG2-BG2	1.0	1.0	84.0	33.6	53.8	11.4	0.0
(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BGBK-CCBK	1.0	1.0	85.0	29.3	12.3	11.1	0.0
(96AD34/6BRON116/5BRON131/(80C2241*GR108-90M30)-HG46-*WM#177)-CG2-BG1-LG1	1.0	1.0	40.0	51.7	12.5	4.2	0.7
(A964*FGYQ336)-LG4-LG2-BG1-BG3	1.0	1.0	56.5	35.1	33.3	12.5	0.0
(CE151*TAM428)-CG1-BG1-BG3	1.0	1.0	3.0	45.4	25.4	5.1	0.3
(CE151*TAM428)-CG1-BGBK-CCBK	1.0	1.0	27.5	34.8	24.1	21.0	0.3
(CE151*TAM428)-LG1-BGBK-CCBK	1.0	1.0	30.0	38.9	38.0	26.2	0.3
(EPSON2-40/E#15/SADC*A964)-LG2-CG1-BG1-BG2	1.0	1.0	37.5	25.5	26.6	10.8	0.3
(EPSON2-40/E#15/SADC*TAM428)-CG1-BGBK-CCBK	1.0	1.0	2.5	35.8	5.1	11.1	0.7
(EPSON2-40/E#15-SADC*TAM428)-CG1-BG1-BG2	1.0	1.0	4.0	42.4	44.4	3.0	0.3
(EPSON2-40/E#15-SADC*TAM428)-LG3-BG1-BG1	1.0	1.0	72.5	22.3	24.4	6.7	1.7
(Macia*TAM428)-LL9	1.0	1.0	37.5	36.1	46.3	25.4	0.0
(SDSL89426*6OB124/GR134B-)-LG5-CCBK-CCBK	1.0	1.0	21.5	61.5	22.2	4.2	1.0
(Segaolane*WM#322)-CG1-BGBK-CCBK	1.0	1.0	42.5	32.2	34.1	16.7	0.0
(SV1*Sima/IS23250)-LG15-CG1-BG2-BGBK	1.0	1.0	6.0	19.2	34.1	3.3	0.0
(Tx430*Sima/IS23250)-LG18-LG2-BG2-BG2-CG2	1.0	1.0	6.0	40.8	15.0	21.0	0.0
PRGC/E#222878	1.0	1.0	12.0	18.5	6.7	5.6	1.3
PRGC/E#69414	1.0	1.0	1.0	13.7	33.3	7.1	0.3
Sima (IS23250)	1.0	1.0	2.5	55.6	14.4	5.0	0.0
WM#177	1.0	1.0	8.5	0.0	25.0	13.3	0.3
WM#322	1.0	1.0	19.5	37.0	20.2	21.0	0.0
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-CG3-BGBK-CCBK	1.0	1.3	45.0	30.8	23.6	4.2	0.0
(6BRON161/(7EO366*Tx2783)-HG54-*EPSON2-40/E#15/SADC)-LG1-BG2-BG2	1.0	1.3	1.5	47.0	40.5	13.3	0.3
(6OBS124/94CE81-3/GR134B-LG56-*WM#177)-LG1-LG1-BG3-BGBK	1.0	1.3	3.0	3.3	35.3	13.3	0.0
(BRON161/(7EO366*Tx2783)*EPSON2-40/E#15/SADC)-LG5-CC2-BG1-BGBK	1.0	1.3	5.0	34.5	14.8	11.4	0.3
(CE151*(6BRON119/(6EO361*GR107der)*CE151))-CG5-BG1-BG2-CG1	1.0	1.3	60.0	22.2	8.3	3.7	0.0
(Macia*GR128-92M12)-HM16-CM1-CG1	1.0	1.3	50.0	21.3	29.3	7.4	0.3
(Macia*GR128-92M12)-HM20-CA2-CG1	1.0	1.3	9.0	50.4	16.7	12.5	1.0
(Segeolane*WM#322)-LG2-LG2-BG1-LG1	1.0	1.3	30.0	72.8	38.2	8.3	0.0

Table 4. Cont'd - Mean sugarcane aphid damage rating, percent ergot infection, percent of plants infested with stem borers, termites, and sugarcane aphids, and number of coccinellids/plant at Potchefstroom and Burgershall, South Africa, and Gaborone, Botswana, 2004.

PRGC/E#222879	1.0	1.3	3.5	29.7	30.4	21.8	0.0
SDSL89426	1.0	1.3	27.5	55.1	52.8	33.3	0.0
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E#14/SADC)-LG3-CG1-BG1	1.0	1.7	37.5	30.4	30.0	17.2	0.7
(6BRON161/(7EO366*Tx2783)*CE151)-LG2-CG3-BG2-BGBK	1.0	1.7	12.5	37.1	31.7	6.7	1.0
(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-BG1-BG2	1.0	1.7	40.0	20.6	17.3	19.4	1.3
(6BRON161/(7EO366*Tx2783)*EPSON2-40/E#15/SADC)-LG4-CG1-BG1-LG2	1.0	1.7	5.0	40.0	4.8	4.8	0.0
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BG1-LG1	1.0	1.7	30.0	30.6	44.4	34.8	0.7
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BGBK-CCBK	1.0	1.7	35.0	36.6	49.6	12.2	0.7
(6OBS128/94CE88-3/(Tx2862*6EO361)*EPSON2-40/E#15/SADC)-LG15-CG2-BG2-BGBK	1.0	1.7	27.5	20.7	30.9	7.3	0.3
(CE151*TAM428)-LG2-CG1-BG1	1.0	1.7	1.5	30.6	26.2	0.0	0.7
(Tx430*Sima/IS23250)-LG5-CCBK-CCBK	1.0	1.7	40.0	33.3	8.3	11.1	0.0
(6BRON126/((87BH8606-14*GR107-90M46)-HG10)*CE151)-CG1-BGBK-CCBK	1.0	2.0	4.5	32.1	49.3	0.0	0.7
(96AD34/6BRON116/5BRON131/(80C2241*GR108-90M30)-HG46-*WM#177)-LG2-BG1-LG2	1.0	2.0	51.0	42.4	46.6	18.3	0.0
(Macia*GR128-92M12)-LG1-LG1	1.0	2.0	52.5	0.0	41.2	5.6	0.3
(Town*FGYQ336)-CG1-BG1-LG2	1.0	2.0	27.5	66.7	25.0	3.3	1.3
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-LG1-BGBK-CCBK	1.3	1.0	14.5	27.8	26.8	0.0	0.7
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG4-BG1-BG1	1.3	1.0	27.5	11.6	35.9	7.1	0.3
CE151	1.3	1.0	2.0	41.0	34.3	17.6	0.3
FGYQ336	1.3	1.0	15.0	4.7	36.5	5.6	0.7
FGYQ353	1.3	1.0	27.5	13.3	48.9	3.3	0.0
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG3-CG1-BGBK-CCBK	1.3	1.3	25.0	62.5	20.8	0.0	0.3
(Macia*TAM428)-LL2	1.3	1.3	14.0	6.7	23.3	6.7	0.0
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG3-BG2-BG2	1.3	1.7	40.0	20.7	24.6	0.0	0.3
(EPSON2-40/E#15/SADC*A964)-CG3-BGBK-CCBK	1.3	2.0	17.0	28.9	32.2	0.0	1.0
Kuyuma	1.7	1.0	0.5	63.3	45.5	11.4	0.3
TAM428	1.7	1.0	17.5	34.2	16.7	18.1	0.7
(Segaolane*FGYQ336)-CG5-BGBK-CCBK	1.7	2.3	20.0	11.1	31.9	16.9	1.0
(Town*EPSON2-40/E#15/SADC)-LG1-BGBK-CCBK	2.0	3.3	14.0	25.9	9.2	11.1	0.0
(Macia*(Tx2882*SRN39))-HM5-CA2	2.3	3.0	82.5	60.0	24.8	0.0	0.0
(Macia*(MR112-90M5*87EO366))-HM8-CA1-CG1	2.3	3.3	32.5	16.7	47.4	0.0	0.3
(Macia*GR128-92M12)-LG33-LG1-CG2	2.7	4.3	37.5	41.7	41.7	0.0	0.7
((6BRON126/(87BH8606-14*GR107-90M46))*CE151)-LG2-CG1-BG2-BGBK	3.0	4.7	4.5	35.2	17.1	0.0	0.0
(Macia*GR128-92M12)-HM14-CM1-CG2	3.7	4.7	49.0	13.3	34.1	0.0	0.0
Macia	4.0	5.0	16.5	21.0	13.3	30.6	0.3
Segaolane	4.7	5.0	1.5	53.6	23.8	0.0	0.3
MEAN	1.5	1.9	17.6	33.9	29.2	10.6	0.4
LSD	0.7	0.9	21.7				

†Rated on a scale of 1 = no damage to 5 = 100% plant damage. Potch = Potchefstroom, Burger = Hazyview Research Station near Burgershall.
‡Rated as a percent of ergot infection.

West Africa (Mali) Graduate Education

Mr. Niaba Teme, a Ph.D. graduate student at Texas Tech University from IER in Mali continued his graduate education. Mr. Teme is in the second year of his Ph.D. program. Research activities were in two major areas. First, collection of phenotypic data of the SC170-14E derived hybrid population for the third year grown at Lubbock and Halfway. Data was collected for grain yield, plant height, panicle length, panicle exertion, number of panicles harvested, thousand-kernel weight, and agronomic desirability. This was the last year the hybrid trial will be grown in the field. Molecular analysis of the 200 entries in the SC170-14E derived population and the parental checks (Tx2783 and SC170-14E continues. Leaf tissue samples from all parental line entries was collected, DNA extracted using the potassium acetate method, and DNA was stored at -20^{0}C. In the next year restriction fragment length polymorphism (RFLP) analysis will be conducted to identify QTLs from the population that influence grain yield and grain yield components. It is anticipated that Mr. Teme will complete requirements for the Ph.D. in the fall of 2006. Following completion of the degree he will return to IER in Mali.

Networking Activities

Workshops and Meetings

Planned and coordinated the INTSORMIL External Evaluation Panel (EEP) review of the Southern Africa regional program 2-12 March 2004 in Lusaka, Zambia and Hilton, Cape Town, and Pretoria, South Africa.

Participated in INTSORMIL Technical Committee meeting 6-7 May 2004, Kansas City, MO.

Participated and was on-site host for the INTSORMIL Board of Directors meeting 13-14 May 2004, Lubbock, TX

Participated in External Evaluation Panel Review of the Texas A&M Univ. sorghum improvement program 29 June - 2 July 2004 in Corpus Christi and College Station, TX.

Research Investigator Exchanges

Interacted with private seed company scientists and Texas Grain Sorghum Association representatives on several occasions. Participated in a Sorghum Field Day at the Texas Agricultural Experiment Station, Lubbock, September 2004.

Zambia, Botswana, Namibia, and South Africa - 8-22 November 2003. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss national and regional sorghum and millet research. Met with the Executive Director of the Golden Valley Agricultural Research Trust to discuss future collaboration between Golden Valley and INTSORMIL. In Botswana met with Department of Agricultural Research and Botswana College of Agriculture scientists and administrators to discuss the status of research in Botswana. In Namibia met with the Deputy Director, Food Production, Ministry of Agriculture, Water and Natural Research to discuss the status of the national pearl millet breeding program. In South Africa met with ARC and Potchefstroom Univ. collaborators to discuss the on-going research program. Met with representatives of the University of Free State to discuss the status of the Ph.D. program of an INTSORMIL sponsored student. Discussed the External Evaluation Panel review with collaborators at all locations to plan the review and associated logistics.

Mozambique, Zambia, and South Africa - 21 February - 12 March 2004. In Mozambique evaluated the status of sorghum research at Sussundenga, Namiolo, and Nampula. Met with INTA scientists to discuss their sorghum activity and evaluated on-farm trials. Met with the INTA Director General to discuss the findings and present recommendations regarding establishing INTA/INTSORMIL collaboration when the Mozambique training grant students return to INTA. In Zambia and South Africa participated in the External Evaluation Panel review of regional activity. In Zambia the review was conducted at Lusaka, Golden Valley, Mount Makulu, and Livingstone with scientists from Zambia, Namibia, and Botswana present. In South Africa the review was conducted at Hilton, Cape Town, and Pretoria with scientists from South Africa and Botswana present.

Germplasm and Research Information Exchange

Germplasm Conservation Use

- Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Mali, Senegal, Ghana, Nicaragua, El Salvador, South Africa, Botswana, and Zambia. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.
- Germplasm previously developed and released by this project is used by commercial seed companies in hybrid production.
- Co-chair of Ph.D. committee for R. Gorena (USA) at Texas A&M University. Served on M.S. committees of N. Teme (Mali) at Texas Tech University and L. Mpofu (Zimbabwe) and J. Mutiliano (Mozambique) at Texas A&M University.

Other Cooperators

Collaboration with the following scientists was important in the activities of TAM 223:

Mr. Leo Mpofu, Department of Research and Specialist Service, Matopos Research Station, P.O. K5137, Bulawayo, Zimbabwe (Currently graduate research assistant at Texas A&M University)

Dr. R. D. Waniska, Cereal Chemistry, Dep. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843

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

Dr. Roy Parker, Extension Plant Pathologist, Texas Cooperative Extension, Texas A&M University Agricultural Research and Extension Center, Route 2 Box 589, Corpus Christi, TX 78406-9704

Dr. John Byrd, USDA-ARS, Plant Science and Water Conservation Research Lab., 1301 N. Western Road, Stillwater, OK 74075

Dr. R.G. Henzell, Sorghum Breeding, Hermitage Research Station, via Warwick, QLD 4370, Australia

Publications and Presentations

Abstracts

Coulibaly, S.B., G.C. Peterson, D.T. Rosenow, H.T. Nguyen, W. Xu, V. Chamarek, M.S. Pathan, and P.K. Subudhi. 2003. Expression of grain yield QTLs in sorghum under stress and non-stress environments. *In* Proc. of the 23rd Biennial Sorghum Industry Conference. Albuquerque, N.M., Feb. 17-18, 2003. (CD-ROM, no page numbers).

Teme, N., D.T. Rosenow, G.C. Peterson, W.Xu, C.A. Woodfin, H.T. Nguyen, and A. Herring. 2003. Heterosis and breeding potential of a Chinese cultivar for grain yield in sorghum. *In* Proc. of the 23rd Biennial Sorghum Industry Conference. Albuquerque, N.M., Feb. 17-18, 2003. (CD-ROM, no page numbers).

Books, Book Chapters and Proceedings

Peterson, G.C., B.B. Pendleton, and G.L. Teetes. 2003. PROFIT - Productive Rotations On Farms In Texas: A New Paradigm for Sorghum Research and Information Delivery.

Pp.365-370. *In* Sorghum and Millet Diseases. Edited by John F. Leslie. Iowa State Press.

Dissertations and Thesis

Gorena, R.L. 2004. Characterization of *Schizaphis graminum* (Rondani)(Homoptera: Aphididae) biotype evolution via virulence and fitness on *Sorghum bicolor* (L.) Moench and *Sorghum halepense* (L.) Persoon

Miscellaneous Publications

Rosenow, D.T., L.E. Clark, J.A. Dahlberg, R.A. Frederiksen, G.N. Odvody, G.C. Peterson, F.R. Miller, C.A. Woodfin, K. Schaefer, S.D. Collins, J.W. Jones, and A.J. Hamburger. 2002. Release of four A/B sorghum parental lines ATx642 through ATx645. International Sorghum and Millets Newsletter 43:24-30.

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF 212
Bruce R. Hamaker
Purdue University

Principal Investigator

Bruce R. Hamaker, Dept. of Food Science, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Mr. Kaka Saley, Cereal Scientist; Mr. Moustapha Moussa, Cereal Technologist; Ms. Ramatou Seydou, Chemist; Dr. Issoufou Kapran, Sorghum Breeder; INRAN B.P. 429, Niamey, Niger
Ms. Senayit Yetneberk, Cereal Scientist, IAR, Nazret Research Station, P.O. Box 436, Nazret, Ethiopia
Ms. Betty Bugusu, Cereal Scientist, KARI, Katumani Natl Dryland Farming Research Cte, P.O. Box 340, Machakos, Kenya
Mr. Ababacar N'Doye, Research and Development Director, ITA, B.P. 2765, Dakar, Senegal
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Mr. Boniface Bougouma, Cereal Scientist, IRSAT/DTA, B.P. 7047, Ouagadougou, Burkina Faso
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Dr. Gebisa Ejeta, Sorghum Breeder; Dr. Layi Adeola, Poultry Nutritionist; Ms. Chia-Ping Huang, Cereal Chemist; Ms. Debra Sherman, Microscopist; Dr. Moustapha Benmoussa, Plant Molecular Biologist, Purdue University, West Lafayette, IN 47907
Dr. Brian Larkins, Plant Molecular Biologist, University of Arizona, Tucson, AZ 85721
Dr. Tae Wae Moon, Food Chemist, Seoul National University, Seoul, Korea

Summary

In the past year, major findings for PRF-212 were in the areas of improved nutrition of sorghum grain and better understanding of fundamental grain factors for sorghum improvement. The overall aim of our research is to make sorghum and millet more competitive grains for human and animal nutrition, and for utilization in traditional and processed foods. In 2004, Betty Bugusu, a Kenyan student from KARI, obtained her Ph.D. degree. Perhaps our most notable work centers on the comparably lower starch and protein digestibilities of sorghum grain versus other cereal grains. This is somewhat an issue for animal feed use of sorghum, and is more pronounced in some cooked sorghum foods with at least the exception of fermented foods and processed extruded foods. Last year we showed that during the cooking process sorghum proteins form web- and sheet-like structures that constrain gelatinizing starch granules. This appeared to be the reason that the starch was less digestible; as such structures were not found, to any appreciable degree, in cooked maize or rice porridges. This report shows that these extended protein structures are formed due to intermolecular disulfide bonding that creates large polymers. Addition of reducing agent to break disulfide bonds, and to prevent their formation, led to formation of protein aggregates, and gelatinized starch that was more easily digested. Confocal laser scanning micrographs, before and after amylase digestion, showed a prevalence of protein-starch associated structures remaining after digestion. Normal sorghum grain apparently contains a third component that acts to promote protein polymerization that affects starch, as well as protein, digestibility.

In the area of animal feed use, starch granule properties were shown to affect raw starch digestibility rates. Specifically, amount of channels, which are found in sorghum, maize and millet starch granules, appears to affect digestion rate. The high protein digestibility mutant sorghum oddly, but consistently, has a high degree of channelization, and has somewhat enhanced starch digestion rate. Another sorghum line was identified, IS6986, with a subpopulation of abnormal "doughnut" shaped starch granules with rapid digestion properties.

A study on fundamental factors that affect sorghum flour pasting properties showed that starch amylopectin fine structure (lengths and proportions of linear chains), specifically proportion of the longest chains, highly correlated (r=0.92) to retrogradation (starch reassociation) tendency during storage. This could relate to the staling property and the comparably poor shelf life of some sorghum products (e.g., injera). Noted vari-

ability in this property among different cultivars may lead to selection of lines with improved storability.

Objectives, Production and Utilization Constraints

Objectives

- Determine the relationships between the physical, structural, and chemical components of grains and food and nutritional aspects to improve 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.
- Optimize processes and improve quality of commercializable sorghum and millet-processed foods, and facilitate transfer of technologies.

Constraints

Research on food and nutritional quality of sorghum and millet grains is necessary to improve grain quality characteristics and stimulate commercial processing in developing countries. Factors affecting milling qualities, food quality, and nutritional value critically affect 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 likely to be lost. In addition, breeding grains that have superior quality traits will more probably give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum that is perceived by some to have comparably poor quality characteristics to other major cereals. 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

Couscous and High Quality Flour Processing

As an update on our activities geared to stimulate couscous and high quality flour production in the region, with a focus on Niger, a brief overview follows. As described in previous annual reports, PRF-212 and INRAN/Niger Food Technology Laboratory set up a cereal-processing unit at INRAN to conduct research, demonstration, and testing of sorghum and millet processed products. A central goal of the project has been to optimize the processing system and products, to generate information for entrepreneurial startups, and to work with interested individuals in the private sector. Products produced by the unit include high quality flours and grits, and agglomerated products including fine couscous (or *dambou*), medium couscous, and the coarse particle-size product *degue*. In 1995, the core of the sorghum/millet processing unit was installed at INRAN; consisting of a central mechanized agglomerator designed and fabricated at CIRAD, France by J. Faure, a mixer for flour wetting, a couscousierre (steamer), a small solar drier with through ventilation powered by a solar cell (fabricated in Niamey by ONERSOL), and a sealer for packaging. The initial unit was funded through the then functioning Niger InterCRSP project. Since that time, a much larger passive solar drying unit was built at INRAN to dry approximately 200 kg couscous every two days. As high quality flours are essential to make quality couscous, a commercial grain decorticator (dehuller) and hammer mill (Urpata Sahel, Dakar) were procured through PRF-212 to compete the unit. This last addition has also permitting INRAN cereal technologists to begin work on production of high quality sorghum and millet flours and other products made from them.

At INRAN/Niger, various market tests on couscous and flour produced at the unit have been completed that indicate high acceptability of the products. Current efforts, in collaboration with O. Botorou and economists, are geared towards contracting farmers for pure grain source which is critical to make consistent, acceptable products and assisting a local entrepreneur in setting up her own mechanized processing facility. A large recent achievement of the group is the fabrication of the agglomerator locally in Niamey.

In Senegal, much has been done with various donors towards stimulating domestic and some export millet processing businesses. Numerous successful partnerships between ITA (A. N'Doye) and entrepreneurs are cited. Purdue PRF-212 is now backstopping their INTSORMIL project by in-depth analysis of millet *cv.* Thialack which is superior as a composite flour for bread-making.

Fundamental Determinants of Sorghum Porridge Texture

Sorghum porridges and other foods, such as flat breads (e.g., injera and rotis) and composite baked foods (breads, crackers, cookies), tend to have functional properties that differ somewhat from like foods made from other cereal grains. Often sorghum porridges are characterized to be comparably thick pastes (this may be desirable) that form rather stiff gels that, depending on variety used, often do not have good keeping quality. Flat breads made from sorghum may be of initial high quality, but tend to go stale rather quickly when stored. We are interested in the fundamental nature of sorghum grain components that makes sorghum grain flour behave as it does, and accordingly how these traits can be manipulated through genetics or processing.

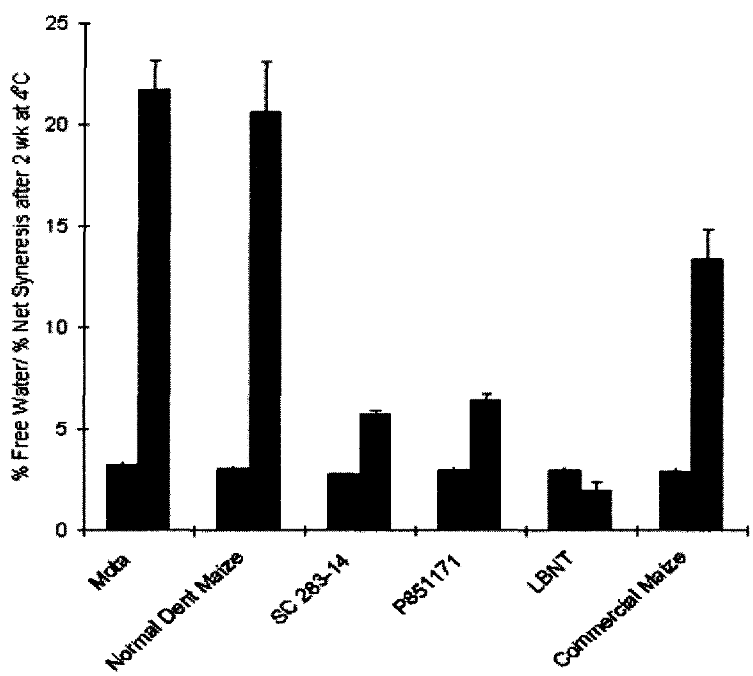
Studies conducted in the past year revealed that starch properties, particularly related to structure, largely affect properties of sorghum porridges related to paste viscosity or thickness, gel firmness, and storability (ability to retain thick paste/gel properties opposed to breaking apart and exuding water, termed syneresis). This research related sorghum starch properties to sorghum product functionality using rice and maize for comparison. In other work both in our laboratory and elsewhere, starch types and ratios, as well as structural characteristics, have been found to have a profound influence on food quality parameters. Amylose has been particularly implicated, as it is linear and smaller than amylopectin, and tends reassociate or retrograde rapidly on cooling of a cooked starchy food. Amylopectin, a much larger and highly branched molecule, also retrogrades; the rate of which depends on its structural aspects. The ultimate goal of this M.S. level project was to provide recommendations for the development and cultivation of sorghum cultivars that would produce desirable food products.

Specifically, this research focused on sorghum porridges, as porridge is a typical food product in parts of the world where sorghum is heavily consumed. Both isolated starch gels and flour pastes from sorghum, maize, and rice were evaluated for thermal (which in this case relates to reassociation of starch molecules following cooking) and textural changes during refrigerated storage. Analysis of starch properties including ratio of amylose to amylopectin, average molecular weights of amylose and amylopectin, and amylopectin fine structure were determined and related to textural and thermal properties of gels and pastes.

Significant differences in the rate and degree of starch retrogradation were found among starches from sorghum, maize, and rice, as well as among different sorghum cultivars. Initial starch gel texture differences were attributed to amylose retrogradation; long term changes in gel texture were attributed to amylopectin retrogradation with sorghum landrace cv. Mota Maradi showing very high retrogradation, as well as pasting properties. Likewise, syneresis, which is indicative of storability, related to amylopectin retrogradation and pasting properties. Syneresis after 2 weeks of storage at 4°C was highly positively correlated ($r=0.99$, $p<0.01$) with a viscosity measurement relating to amylopectin retrogradation (G') measured at 25°C after seven days of storage. Amylopectin fine structure, as represented by proportions and lengths of linear glucose-containing chains, appeared to provide the underlying basis for differences in porridge/paste properties. Proportion of the longest linear chain (100-120 glucose units long) from isoamylase debranched amylopectin was highly positively correlated with starch gel firmness (storage modulus) after 7 days at 4°C ($r=0.92$, $p<0.01$). Analysis of initial and stored *flour* paste texture implicated starch and starch properties as the primary contributor to paste texture; native flour lipids retarded paste firming during storage.

The above results specifically showed that sorghum cultivars that have and amylopectin fine structures with a higher proportion of the longest linear chains (fraction I), as well as high amylose contents, have a much increased tendency to retrograde, which would be desirable for initial and overnight stored porridge texture. Longer-term storage of these porridges causes deterioration due to syneresis. (Figure 1)

Figure 1. Syneresis of porridges immediately after cooling (blue) and 7 days of storage at 4°C show wide variation among sorghum cultivars (Mota, SC283, P851171 (high digestibility mutant)) with cv. Mota exhibiting poor storability.



Sorghum with High Protein Digestibility

Work has again picked up on the high protein digestibility/ high lysine sorghum mutant identified in the mid-1990's with two aims: 1) to improve grain quality (hardness) in lines that show stability over environment and consistency in panicles, and 2) to identify fundamental biochemical changes due to the mutation, and to compile information on the mutant gene responsible for the enhanced digestibility and protein quality. As described in previous reports and publications, this mutant genotype contains protein bodies with altered morphology consisting of a deeply folded structure that results in a high rate of digestion of the kafirin storage proteins. The protein body mutation also apparently causes over expression of certain cytoplasmic proteins that concurrently result in elevated lysine content. Practical advantages of the high protein digestibility trait are for improved protein nutritional value for people who have margin protein intake and for livestock where high protein feed meals are expensive relative to sorghum. Perhaps even more useful, is a relationship reported last year where the high protein digestibility trait additionally increased starch digestibility of cooked sorghum porridges. Increasing energy utilization of staple cereals, particularly of sorghum with somewhat poor digestibility characteristics, is critical for subpopulations who have chronically low caloric intake.

Grain Quality

Aim #1 was a research focus during the latter 1990's as collaboration between our laboratory and the program of Dr. John Axtell. Upon his unexpected and sad passing in 2000, this project was not active for about three years and was again revived last year with the hiring of a post-doc (T. Tesso) shared between Drs. Ejeta and Hamaker. In the fall of 2003, Dr. Tesso was required to return to Ethiopia, however a good deal was accomplished in the nine months he was here. As shown in the 2001 INTSORMIL report, a vitreous normal-appearing kernel with mutant high digestibility protein bodies is possible, however consistency within the panicle was lacking and stability of this combination is still uncertain. In India, Drs. Murty and Chandrashekar have made progress on the grain quality question through the collaborative project (finished in 2001) funded by Mahyco Research Foundation. Their similar results showed improved quality mutant grain from crosses made with elite Indian germplasm.

In this collaborative project with Dr. Ejeta, high protein digestibility lines (screened for this trait), derived from crosses of modified mutant lines with highly vitreous parents, were first identified with well modified kernel type and seemingly good consistency within panicles. These modified endosperm types have been previously described as containing a vitreous (hard) endosperm section originating out of the interior of the kernel rather than the typical phenotype where vitreous endosperm is found at the kernel periphery radiating toward the center. In the lines chosen, the vitreous endosperm section accounted for approximately 50% or more of total area and opaque endosperm appeared encircling it with only a thin region at the kernel periphery. Stability tests are underway. In another study, genotypes were developed to understand whether a dosage effect would be present regarding the high protein digestibility trait. Results show that, in fact, when copies of the mutant genome are reduced from 3 to 2 to 1, digestibility decreases concomitantly. This may offer a strategy to obtain a compromise in improved digestibility with good grain quality.

Biochemical Changes in the High Protein Digestibility Mutant

Aim #2 is a research focus we have been longer-term undertaking in collaboration with A. Chandrashekar at CFTRI, Mysore, India. The following work is recent data from Purdue done by post-doctoral researcher, M. Benmoussa (partially funded through INTSORMIL), in the past year. Seed developmental studies have corroborated previous findings in India that expression of the BiP chaperone protein is much higher in the mutant grain than wild-type beginning at 20 days after pollination. This is the period that kafirin synthesis is at its highest. Moreover, two other chaperone-type proteins, heat-shock protein 70 (HSP70) and protein disulfide isomerase (PDI), were found to be present in higher amount at early stages of seed development for HSP70 and later stages of development for PDI. Taken together, this indicates that misfolding of the protein body in the high protein digestibility mutant causes repair or chaperone protein expression to be enhanced, but at different times. While it is well known that a single point mutant can cause a plietrophic response affecting many proteins, it remains possible that the chaperones may be implicated. High-resolution 2-dimension gel electrophoresis was employed to separate both the kafirin and non-kafirin classes of sorghum proteins from mutant and wild-type lines. Identification of spots differing in the mutant is currently being done.

Starch Digestibility of Cooked Sorghum Pastes

In cooked sorghum foods, as it is particularly known for porridges, starch digestibility is low compared to like foods made from other cereals and additionally appears to have a slow digesting property. We reported in the last two-year's annual reports that:

1) Starch digestibility was improved in the high protein digestibility mutant sorghum due to the fast digesting protein component. This is potentially useful, as high digestibility sorghums would be valuable in in weaning foods and other foods where high availability of macronutrients is critical. Such sorghums could find a place in diets of the marginally malnourished who do not meet UN-set requirements for protein and energy intake.

2) Sorghum proteins form web- and sheet-like structures that appear to constrain swelling of the gelatinized granules and, in a manner that is yet clear, reduces starch digestion rate and overall digestibility. As is the cause for the relatively low

protein digestibility of sorghum, intermolecular disulfide bonding among proteins that is promoted by the cooking process seems to be responsible for formation of large polymeric web-like protein structures. As shown in Figure 2, large web-like protein structures form on normal cooking of sorghum flour to porridge that are related to the lower starch digestibility of sorghum. Addition of reducing agent prevents formation of the large polymeric structures resulting in protein aggregates and higher starch digestibility.

Further work showed the actual effect of the protein web- and sheet-like structures in sorghum porridge on starch digestibility. An experiment was designed to determine the relative degree of starch-protein associated structures in cooked samples after 30 min of a-amylase digestion to digest away free, highly susceptible starch. If starch-protein associated structures were truly less digestible, then a concentration of such structures would appear in sorghum digests compared to maize or rice. Rice, maize, and normal sorghum samples were used. Confocal micrographs showed that the microstructure of cooked sorghum and maize pastes were more similar than that of rice showing a protein structure embedded in the mass of gelatinized starch. In cooked rice, the proteins aggregated away from the gelatinizing starch. After 30 min a-amylase digestion, sorghum still had a lot of gelatinized starch associated with the protein structures and some of it still encapsulated, while in maize most of the starch was digested and in rice almost all the starch was digested. Clearly the formation of the starch-protein structures caused retarded digestion of the associated starch.

Betty Bugusu completed her Ph.D. thesis on this topic in 2004. Overall, it was concluded that the transformation that sorghum proteins undergo during cooking have a dramatic effect on starch digestibility, although it is unclear exactly how such protein-starch associated structures affect amylase digestion. a-Amylase inhibitors present in the cereals samples were heat-labile and, thus, are not a major concern in cooked porridges. We believe that sorghum protein forms resilient web-like and sheet-like structures that encapsulate starch, resulting in reduced accessibility of starch by amylases. Maize and rice protein form aggregates and collapsed web-like structures that allow release of gelatinized starch. The protein component does not seem to affect the degree of gelatinization of starch granules. The greater increase in starch digestibility for the high protein digestibility mutant sorghums (compared to normal sorghum cultivars) after pepsin treatment could be attributed to the high protein digestion rates that result in the destruction of the protein microstructure, and hence the exposure or release of starch for amylase digestion. Practical aspects of this work center on increasing or decreasing digestion rate of sorghum starch through processing treatments. Long-term, this work should lead to knowledge of how to genetically manipulate starch digestion properties of cooked sorghum foods.

Starch Digestibility in Animal Feed Grain

For animal feed usage, low tannin or tannin-free sorghum grain is competitive with other feed grains, though in most studies is somewhat low in starch and protein digestibilities, with the former more pronounced. In fact, in other feed grains, such as maize, there is also interest in ways to improve starch digestibility for increased feed efficiency. In the U.S., sorghum grain is often, and in some cases always, processed to improve starch availability. Therefore, investigations into finding ways to increase starch digestibility are pertinent to the sorghum industry both in the U.S. and abroad. In our studies on how to improve starch digestibility of sorghum grain for animal feed, we have investigated the effect of endosperm protein matrix, starch molecular fine structure, and starch granule structures on digestibility. Our previously reported *in vitro* study on the effect of the fast protein-digesting mutant on starch digestibility showed no obvious relationship between protein and starch digestibilities. Last year we reported on a study that suggests that fine structure of sorghum amylopectin, specifically the comparably longer length of the short chains of the molecule, leads to a lower digestion property of the starch, hypothetically through greater starch crystallinity. Our initial work on granule structure and digestibility follows.

Implication of Starch Granule Structure - morphology and channels

Sorghum and maize starch granules are similar in the respect that they both have interior channels leading from pores on the granule surface to the central cavity of the granule. Accordingly, in animal digestion starch granules are corroded from the inside out, as amylases travel down the channels and digest the less crystalline central parts of the granule preferentially. A hypothesis pursued was that sorghum cultivars with higher amounts of channels may have somewhat higher starch digestibility. In a screening of different sorghum lines, mutant high protein digestibility/high lysine lines showed starch granules with high degree of channelization (Figure 3, arrows show pores, native and digested, leading to interior channels). *In vitro* digestibility testing showed that isolated starch from the mutant was digested at a somewhat faster rate than its wild-type relative. While a more extensive study is needed to confirm this trend over a wider range of genotypes, this approach appears to hold promise as a way to enhance starch digestion rate.

Other studies in our laboratory revealed that sorghum and maize starch granule channels are lined with proteins and a subsequent effort has been made to identify the proteins both to better understand the nature of the channels and to give clues on how to manipulate amount of channels to affect digestibility. Protein in channels was shown using a dye, 3-(4-carboxybenzoyl)quinoline-2-carboxaldehyde (CBQCA), that only fluoresces when covalently attached to protein and confocal laser scanning microscopy. Using a proteomic approach, maize channel proteins were separated on by 2-D gel electrophoresis and major proteins identified by MALDI-TOF mass spectrometry and identified as actin, tubulin, enzymes important in starch synthesis (ADP-glucose pyrophosphorylase, granule bound starch synthase), and brittle-1protein (a membrane

Figure 2. Confocal micrographs showing protein (labeled with CBQCA) in cooked sorghum flour pastes in water (left) and water + reducing agent (right). Web-structures in normal pastes are implicated in lower starch digestibility while reduction of disulfide bonds breaks up webs and increases digestibility.

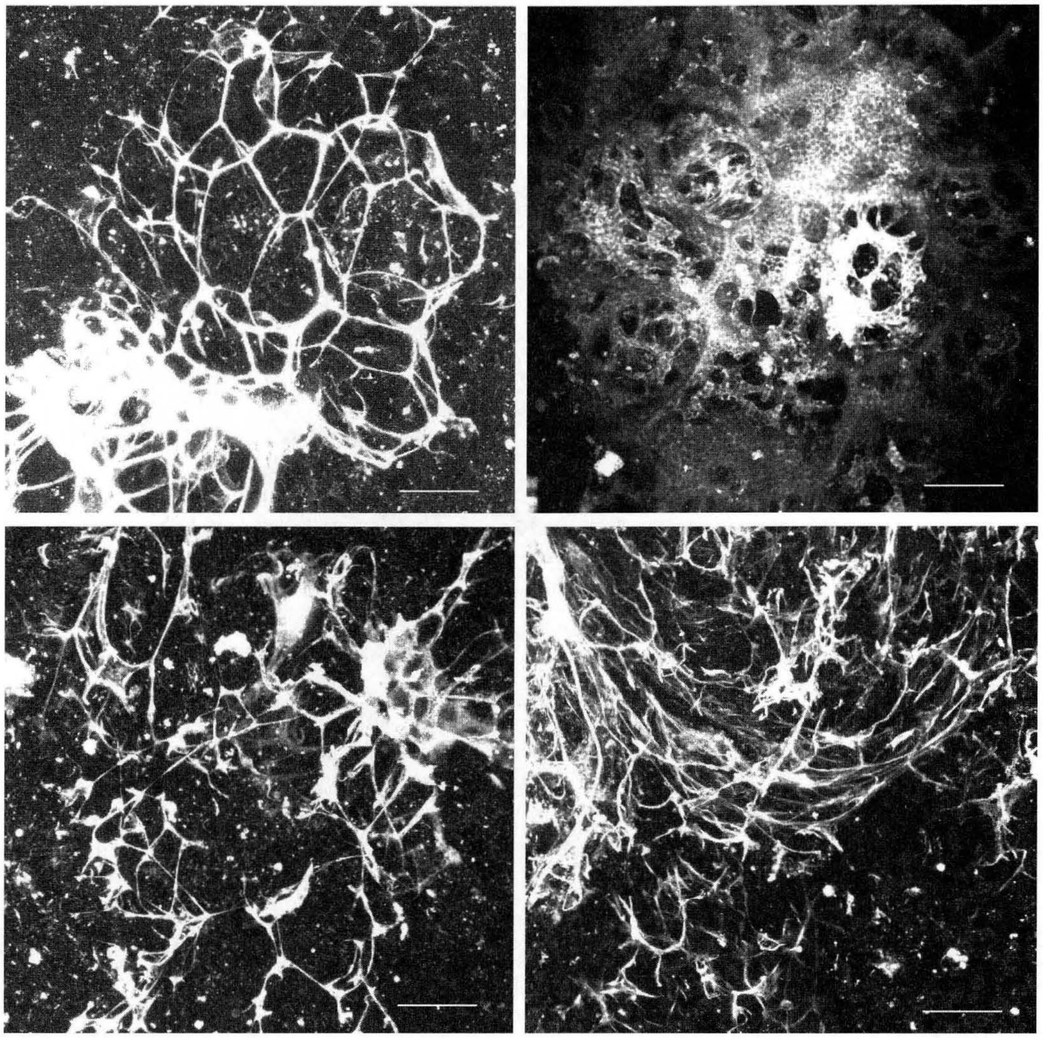


Figure 3. Scanning electron micrographs of starch granules from a high protein digestibility/high lysine mutant sorghum line showing surface pores that reveal interior channels leading to the central cavity (right – native granules, left – amylase-treated granules). High degree of channelization of mutant lines suggests faster starch digestion rate.

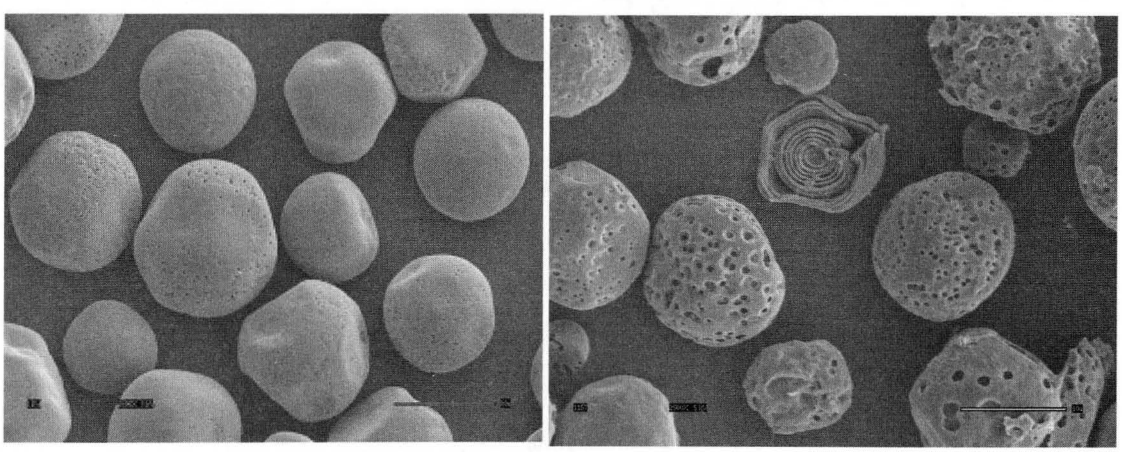
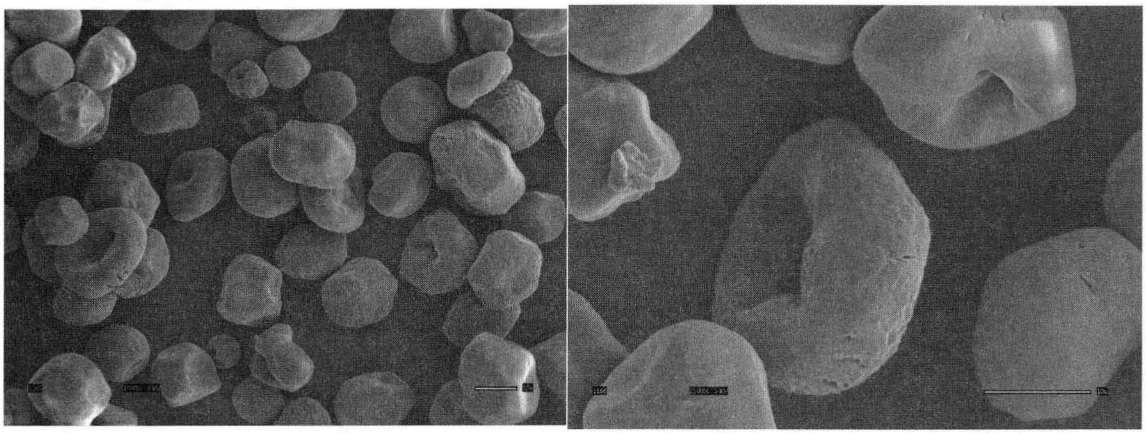


Figure 4. Sorghum *cv.* IS6986 containing a subpopulation of starch granules with abnormal "doughnut" shapes that are highly digestible.



protein involved in transport of ADP-glucose). The finding, in particular, of actin and tubulin residing in the channels implies that they are microtubules and that manipulation at the genetic level might be possible for digestibility improvement.

In a related study on relationship between sorghum starch granule structure and digestibility, a line, IS6986, was identified containing a subpopulation of starch granules that are abnormal in shape (doughnut-shaped) with a highly digestible characteristic (Figure 4). I was unclear what internal properties of the granule lead to faster digestion.

Networking Activities

In August 2003, Dr. Hamaker traveled to Burkina Faso and Niger to meet with INERA and IRSAT staff in Ouagadougou, and INRAN staff in Niamey to discuss ongoing research.

In September 2003, Dr. Hamaker traveled to West Africa for the External Evaluation Panel review of the eastern and western regional programs. Because of the proposed change to merge the programs into one West Africa regional program and the likelihood that Dr. Hamaker would take the role of U.S. coordinator, he accompanied the panel in Senegal, Niger, and Mali. In Niamey, Nigerian PIs attended the meetings.

Dr. Hamaker traveled to Ouagadougou in April 2004 for the West Africa Regional Planning meeting; a three and one half day meeting and workshop for strategic planning for the merged six country regional program, workplan development and submission, and new project development. There were 60 participants, 48 African PIs and 12 U.S. PIs and administrative personnel.

Publications and Presentations

Abstracts

Aboubacar, A. and Hamaker, B. Investigation of the structures of cereal starches attacked by alpha-amylase, American Association of Cereal Chemists annual meeting, Portland, October.

Bugusu, B.A. and Hamaker, B.R. Role of the protein component in low starch digestibility of cooked sorghum porridges, American Association of Cereal Chemists annual meeting, Portland, October.

Choi, S.J., Kim, H.J., Jung, S.H., Hamaker, B.R. and Moon, T.W. The relationship between sorghum digestibilities and their protein-starch interaction, Institute of Food Technologists annual meeting, Chicago, July.

Hamaker, B.R. and Rooney, L.W. INTSORMIL activities on grain-source preserved value-added sorghum/millet urban foods, Institute of Food Technologists annual meeting, Chicago, July.

Journal Articles

Miklus, M.B. and Hamaker, B.R. 2003. Isolation and characterization of a soluble branched starch fraction from corn masa associated with adhesiveness. *Cereal Chem.* 80:693-698.

Shin, S.I., Choi, H.J., Chung, K.M., Hamaker, B.R., Park, K.H. and Moon, T.W. 2004. Slowly digestible starch from debranched waxy sorghum starch: preparation and properties. *Cereal Chem.* 81:404-408.

Dissertations and Theses

Bugusu, B.A. 2004. Understanding the basis of the slow digestion characteristic of sorghum porridges and how to manipulate starch digestion rate. Ph.D.

Food and Nutritional Quality of Sorghum and Millet

Project TAM 226
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Ms. Etienne Palacios, Seed Technologist, INTA, Nicaragua (English language training and potential M.S. in FSTC)

Summary

New more efficient higher yielding white tan varieties are near release from the IER breeding program in Mali. The photosensitive types escape significant weathering/molding that adversely affects earlier insensitive white tan sorghums and led to their failure. These photosensitive value-enhanced sorghums provide improved grain quality for identity-preserved (IP) marketing of sorghums. The grain produced excellent food products because it was not discolored by insects and molds. Farmers were very excited with these white tan plant sorghum varieties because they liked the agronomics and grain yields. They were pleased with the grain quality for their own food consumption and appreciated the opportunity to sell the grain at a potential premium. This was especially significant in view of the fact that some of them had a bad experience the previous year with a grain trader who defaulted on a promised premium price. The principle of supply chain management from seed to food products has been demonstrated; however, a great deal of work to obtain widespread participation is required.

Similar situations exist in El Salvador where small farmers have vertically integrated and sell their own white tan sorghums in the form of baked products containing sorghum flour. There are some significant successes in this area.

Dakar, Senegal has a significant and growing number of small processors producing packaged pearl millet products ranging from yogurt containing pearled millet to extruded snacks, flours, meals and various couscous products. There is a growing interest in securing improved quality grains for processing. This project has collaborated with Dr. Sander's project to further the marketing of these grains. A position paper was authored with other INTSORMIL PIs and Dr. Ouendeba Botorou regarding the development of a supply chain management system in targeted areas such as Senegal, Mali, Burkina and Niger.

United States value-enhanced white food sorghums developed in part by this project and promoted by the U.S. Grains Council in Japan are used by the Japanese food industry to market snacks and several other products. The white sorghums are color sorted, pearled to a very white color, and used as an ingredient in a wide variety of foods including brewing. The cost of value-added white sorghums is competitive with domestic Japanese rice. More production of white food sorghum is needed.

Several small mills in the U.S. are producing sorghum flour for niche markets. The operations are small, but produce sorghum flour and other products that have been made into foods for Celiac-Sprue patients and ethnic groups.

Special sorghums with high levels of phenols and antioxidants were extruded to produce snacks with high levels of anti-

oxidants. The extruder is a low-cost, short-barrel friction type that could be used by small companies in targeted countries, i.e., Central America. The extrudates are high in dietary fiber as well as antioxidants. We found that whole, cracked and decorticated sorghums produced a wide variety of extrudates. The extruded whole grain products would have significant appeal as health foods. Bread machine mixes with sorghum bran, gluten, flax and barley flour produced good quality bread with a natural dark color and improved nutritional value.

The high antioxidant sorghums had effective antioxidant properties in processed meat systems. A patent disclosure was developed on the use of sorghum bran in processed meats.

We continue to monitor the quality of new food-type sorghums in special sorghum nurseries grown in the sorghum belt by collaboration with Drs. Tuinstra, Rooney, Peterson and others. The IFSAT trials consisting of advanced food sorghums of potential value in host countries are evaluated for quality annually in several locations. Several parental sorghum lines released from our program are used in commercial food hybrids. New commercial sorghum hybrids with tan plant white pericarp color were released by commercial hybrid seed companies. ATx635 hybrids have outstanding milling and food properties. Red tan plant hybrid sorghums have excellent milling properties compared to red purple plant sorghums.

Antifungal proteins (AFP) are related to grain mold resistance in sorghum. An improved faster assay for antifungal protein detection was developed. When exposed to warm, humid environments and mold attack, sorghums that have higher levels of AFP have the highest resistance to molds. It is not really the level, but the ability of the sorghum to retain the AFP.

One Ph.D. and two M.S. students completed their degrees with thesis or dissertations on sorghum. In addition, two M.S. students had experience with sorghum but their theses were on QPM maize and tortilla quality. They are employed in the food industry in Mexico, the U.S. and by EARO in Ethiopia. The Ph.D. was Ms. Senayit Yetneberk who worked with Dr. John Taylor at the University of Pretoria.

Objectives, Production, and Utilization Constraints

Objectives

- Develop new food products from sorghum and millet using technology appropriate for use in less developed areas.
- Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum; seek ways of modifying its properties or improving methods of processing.
- Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.
- Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

The major constraint to development of profitable sorghum and millet foods remains the lack of a consistent supply of good quality grain at affordable prices. Until a source of IP good quality grain can be produced, sorghum and millet products will be of inferior quality. Systems for marketing IP grains as value-added products for urban consumers are critically important. These systems start with the seed or even before the seed and must be profitable for all parties through to the consumer. Slowly the concept of supply chain management is being adapted by National Research Leaders.

This project relates quality to measurable characteristics that can be used to select sorghum and millets with acceptable traditional and industrial utilization attributes. It defines quality attributes and collaborates with breeders to incorporate desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptability that can generate income for farmers and entrepreneurs.

Grain molds 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

The acquisition of good quality grain for value-added processing is absolutely essential to produce acceptable food products from sorghum and millet. That is why we have pushed hard for new improved varieties with good processing quality even if grain yield is not significantly increased. In most cases, systems to produce the new varieties and deliver the grain to processors are lacking and are difficult to put in place. More people are beginning to understand the need to develop supply chain management schemes to secure grain for processing. Many small entrepreneurs demanding improved quality grain appear willing to pay more because grain quality is critically important for their continued success and expansion of markets. This has proven to be true in Dakar, Senegal where processors are willing to pay for improved quality grain. Profit for all from the seed to the processor is necessary.

Significant Accomplishments

Applications of Technology in Mali

Work in Mali continues to demonstrate the value of new white, tan-plant photosensitive sorghum varieties in food systems. During the past few years, progress to develop an effective IP production scheme to produce sorghum of good quality for processing into value-added flour and meal was demonstrated.

New second generation value-enhanced food sorghum cultivars from the Malian sorghum-breeding program have improved productivity and profitability as indicated by farmers who planted them. They like the grain yields, agronomics and the grain quality for their own food processing. In addition, they appreciated the potential to secure a premium price for processing. Some of these farmers had contracted to grow N'Tenemissa last year (2002) but the grain trader defaulted on the contract. Nevertheless, the farmers still were willing to grow the newer photosensitive white tan cultivars from IER since they thought that they had high yields and improved quality. It is fairly impressive and the concept of growing improved quality sorghums has been demonstrated provided the agronomics and grain yields are competitive with the best locals and that is apparently true.

Another positive development is that farmers growing the white tan sorghums prefer the porridge and other foods made from these grains. This is similar to farmers in Honduras and El Salvador who prefer tortillas made from white tan plant sorghum varieties instead of the native Criollos, which have purple glumes. This project (TAM 226) has interacted with the Malian program since 1979. We believe that significantly faster progress will continue now that the principles have been demonstrated quite well and Malian business people are involved.

We believe strongly that supply chain management is the way to improve adoption of new technologies from new cultivars to other management practices provided there is a profitable market for the grain produced. This is an emerging situation that will occur only when sufficient margins are available to support all parties in the supply chain by sharing the profits. Successful development of this system is difficult and requires patience and practical programs to educate key managers, farmers and processors.

New Markets for Food Sorghums

Several extruded salty snacks and milled products based on IP U.S. white food sorghums continue to be sold by Japanese food companies. South Korea and other countries are interested in using white food sorghums. Utilization of sorghum in these highly developed countries helps our efforts to convince food companies in other countries that sorghum is a good food ingredient. Similar findings in Mali, Central America, Mexico and other countries of West Africa demonstrate that sorghum of good quality is necessary for value-added products. The products are acceptable and purchased by consumers provided convenience, good taste, appearance and consistent quality is available at competitive prices.

In South Africa, significant quantities of Mabella meal are consumed even though the price is significantly higher than mealy meal (maize) because a 14% value-added tax is assessed to sorghum-processed products. Botswana is an example where maize consumption is decreasing while sorghum consumption is increasing even though red or brown sorghum must be imported from South Africa. Professor Taylor and L.W. Rooney are chairing a white food sorghum workshop in Pretoria for the Southern African area in October 2004. White food sorghums may find significant niche markets in South Africa.

Applications in Honduras and El Salvador

Our research on sorghum has been applied in Honduras and El Salvador. The variety Sureño, and others with white tan plant color are used in Central America for tortillas, rosquillos, rosquettes and other products. In El Salvador, sorghum flours from white tan plant varieties are used in small bakeries to produce pan dulce, muffins, bread, rosquettes, rosquillos and other variations of these products. There is significant interest in use of sorghum flour in blends and alone for baked products. There is a lack of milling equipment to secure flour although there appears to be sufficient production of food-type sorghums. The ability to IP food sorghums for processing must be developed for consistent success. The opportunities exist to stimulate use of white food sorghums in Central America since a source of grain is available, but technologies that can be used to decorticate sorghum and mill it into flour or meal are required along with production of a consistent supply of IP grain.

Some producers process their own sorghum into flour and sell baked products in local village markets. These operators plant Dorado, harvest, store and process the grain into baked products. These activities apparently support the family since two or three daughters are involved along with the father who produces the sorghum. According to CENTA personnel there are many examples of these small processors marketing sorghums in food products. There is significant interest in the formal baking industry to use white sorghum flour but a large quantity of flour is unavailable to test the market. The costs of sorghum flour are reduced in the country while it would be higher in San Salvador due to transport into San Salvador.

Ms. R. Vilma Calderon, food technologist, CENTA, has been working with a large rice miller to process white food sorghum into flour and decorticated products. These are being supplied to bakers. A large snack food company in El Salvador is interested in using white food sorghum in extrusion because they saw our pilot plant sorghum extrusion results.

Health Foods from Special Sorghums

The HPLC analysis of procyanidins (condensed tannins) indicated that tannin or brown sorghums had a large number of oligomers that comprised the condensed tannins. The processing of tannin sorghums using extrusion significantly reduced the polymer size of the procyanidins. The increased percentages of oligomers with less than 10 units may positively affect the biological significance of the antioxidants. The type of processing is important since similar changes did not occur when the brans were mixed into cookie and breads. The potential to produce healthy foods from sorghum is quite high.

The bran is high in dietary fiber, phytates and natural brown or black pigments that impart attractive colors to baked products such as cookies and multigrain breads. A bread that contains modest levels of high tannin sorghums as a source of antioxidants is currently being sold by a commercial bakery.

Ms. Crystal Rudiger completed her M.S. thesis and developed a bread mix containing brown or black sorghum bran with flax seed, gluten, barley and wheat flour. The bread has excellent flavor, texture and outstanding levels of dietary fiber, antioxidants, ligans and omega 3 fatty acids with a natural brown color. Black sorghum bran in breads resulted in appearance, texture, color and specific volume (cm3/g) similar to commercial specialty or dark rye breads without the use of caramel coloring. Ms. Lindsey Wortham, M.S. student, has developed combinations of sorghum bran, wheat gluten, flax and beta-glucans into mixes for bread machines in some follow up research.

Ms. Linda Dykes, Ph.D. student, continues to characterize sorghum phenols and tannins using HPLC and other techniques. She is specifically evaluating the effect of different combinations of B1B2S and pericarp colors on tannin and anthocyanin contents. She is also studying the changes that occur in the tannins during maturation of the sorghum kernel. The levels of antioxidants and phenols are measured as well to determine the best combinations of genes to secure the highest levels of antioxidants. Ms. Lisha Xu, M.S. student, is evaluating the effect of extrusion on changes in the tannins using HPLC and also in the levels of antioxidants. The extrusion includes whole grain special sorghums and addition of up to 30 % bran to the whole or cracked grains. This research is to confirm what Turner found during extrusion of high bran levels. It may be possible to change the antioxidant activities and biological value by processing these special sorghums. Some of this work uses USDA funds. We are working with Dr. S. Bean at the Grain Marketing Lab in Manhattan, KS. His group will provide mass spectrometer data to aid in identifying the compounds.

Extrusion

It is possible to produce expanded sorghums directly from whole ground undecorticated white or brown sorghum grains using low-cost friction extruders. More research will be done to demonstrate the utility of sorghums of various kinds in low-cost extrusion of snacks. These smaller extruders are used in areas where infrastructure does not permit use of more costly sophisticated extruders and processes. Low-cost friction extruders can be used to produce an array of products. Thus, the ability to produce snacks directly from whole clean grain is a distinct advantage for sorghum. Extrudates of 100% whole brown or tannin sorghums would have excellent nutritional properties. More work is needed to document their properties.

The evaluation of sorghum as an ingredient in extrusion of snacks and breakfast foods was initiated to compare their properties with corn and rice. This information is of interest to potential users of sorghum around the world. Rice produces extrudates with white, bland flavor and excellent crispness. The goal of these experiments is to test the extrudate properties of sorghum directly against corn and rice ingredients. The white food sorghums have a bland flavor, light color and produce acceptable food products of various kinds.

White sorghum samples prepared by combining four decortication levels (0, 10, 20 and 30%) and three particle sizes were extruded in a Maddox single screw friction-type extruder. A commercial yellow cornmeal and polished rice were extruded as controls. The extrusion conditions were held constant for all samples. The expansion ratio, bulk density, color and texture of the extrudates were significantly affected by both particle size and decortication level. As the decortication level increased, the extrudates were whiter, more expanded, less dense, crisper and more thoroughly cooked. The extrudates made from coarse particle size materials had the most desirable characteristics compared to the other particle sizes used. Some sorghum products had a higher expansion ratio than both rice and corn, and had similar bulk density and texture characteristics. With increasing decortication level, whiter, more expanded, stronger and crispier, bland flavored extrudates were produced. The decortication level and particle size can be used to vary expansion ratio, crispiness and bulk density.

The Japanese use sorghum because it has a bland flavor, light color, can carry mild flavors and seasonings similar to rice, has good extrusion properties similar to rice, and is potentially less expensive. Participants in our snack foods short course from Central America are interested in using sorghum but finding a consistent supply of good quality grain is a significant problem.

Sorghum Flour in Specialty Products

Sorghum flour (SF) can be substituted for 100% of the wheat flour in a variety of products that are used in gluten free diets for Celiac-Sprue patients who are intolerant of wheat and other cool weather cereals. Sorghum flour produces acceptable baked products with additives to substitute for its lack of gluten. Various prepared mixes, flours and other products containing sorghum have been introduced into specialty markets recently. The National Sorghum Producers Association is promoting sorghum as a healthy food ingredient and it has ethnic appeal to many immigrants.

Sorghum Starch, Malting and Brewing Studies

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to collaborate on sorghum research, especially with graduate students working on sorghum for brewing, industrial films and as a source of antioxidants. His group has conducted significant research on wet milling of sorghum and evaluated its use as brewing adjuncts. Dr. Serna has provided assistance to our projects in El Salvador and Nicaragua. He has consented to participate in seminars we are planning to have in Central America this next year. We hope to utilize his expertise.

Central American Use of Sorghum

Ms. R. Vilma Calderon, working with CENTA in El Salvador, has conducted trials in local bakeries showing that sorghum can be used effectively in baking of rosquettes, sweet breads and many other products as well. She and others are working with a large rice milling company to decorticated white sorghum for use in foods. The product appears to be acceptable and is being tried by some of the local bakeries. Technically the project will be successful but the economics must be determined and higher value products developed. There is real potential for use of the meal and other components in snacks via extrusion where a light color, bland flavor would be desirable. The concepts proven to be successful in Japan apply directly to use of the white sorghums in Central America. Bland flavor sorghum flour has an advantage over corn flour as a substitute for wheat flour. This affords an opportunity to utilize sorghum in popular food items. As we work to enhance utilization at the entrepreneur level, the combination of cereals and legumes to produce value-added foods is critically important.

The price of rice is such that locally grown sorghums could compete for markets in certain snacks, ready-to-eat breakfast cereals and composite flours for baking. In rural non-rice producing areas, a decorticated sorghum could serve as a cost effective substitute or diluent for rice in many households. Success could lead to significant economic activity by small producers in the Hillsides.

Tan Plant Food-type Hybrid Performance and Quality Trials

Attributes of sorghums that produce light colored meals, flour and grits with bland flavors were evaluated under different environments in uniform yield trials with 40 entries. This work was in collaboration with Drs. Tuinstra and William Rooney, who conducted the evaluation trials. Red and white sorghum varieties grown at locations in Texas, Kansas and Nebraska from 1999-2003 were evaluated for hardness using a SKHT (single kernel hardness tester), decortication properties using TADD (tangential abrasive dehulling device), TKW (thousand kernel weight), color (L, a, b), test weight, density, proximate composition and relative mold damage. Environment and hybrids significantly affected composition, physical and processing properties. White tan sorghum (WT) hybrids were harder, more dense and lighter in color than white purple (WP) hybrids or red hybrids (Figure 1). WP hybrids were more adversely affected by weathering and molds than WT hybrids. All of the ATx635 hybrids had significantly improved physical properties and higher milling yields than the other white hybrids. This grain also has a thin pericarp that is particularly suited to whole grain extrusion.

White sorghums had better milling performance than red hybrids. A significant correlation ($r=0.69$, $n=105$) was found between SKHT and TADD hardness values, suggesting SKHT could be used to predict decortication properties. However, the TADD or barley pearler would more effectively predict commercial decorticating since the principles are similar to those used in large-scale decorticators. Efforts by breeders, agronomists and food technologists have produced tan white food-type sorghums with significantly improved food quality attributes.

The red tan hybrid sorghums could be grown in areas where molds and weathering are serious problems, such as in the coastal bend of Texas, in areas where the Kharif sorghums are grown in India and in many African countries where the sorghums mature during moist conditions. The problem of molding and staining is decreased with tan plant sorghums that have straw colored glumes. For example, the Kharif sorghums of India become black with mold damage and sell for 50-60% discount. This is rapidly reducing sorghum production in India during the rainy season. The red tans might be useful for decortication and produce better food and poultry feed than the white sorghums currently being grown. The Kharif hybrids sell for significantly less money than the rabbi or dry, post rainy season sorghum called maldandi. Similar problems occur in much of Africa except the Sudan, Ethiopia and others where sorghum matures in the very dry season.

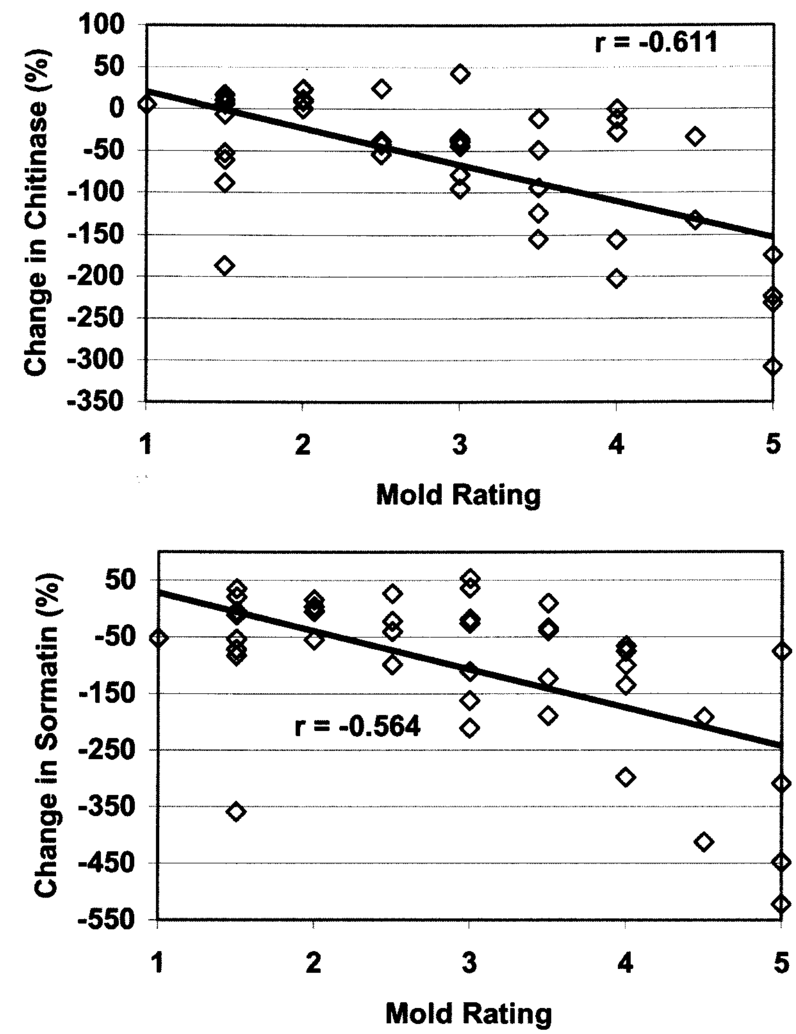
Improved Methods of Analysis

NIR equipment to analyze for protein, moisture and starch in whole grains was calibrated. The use of NIR to analyze for starch, protein and moisture is successful but continuous improvements in the calibrations are needed. A large number of samples were analyzed with good repeatability. Numerous factors like color, cracked and broken kernels, glume content and degree of molding appear to affect the analytical values obtained.

In our previous reports, we have shown that when considerable mold infection occurs, there were statistically significant correlations between the severity of mold infection and the amount of AFP in sorghums. Higher levels (at 50 DAA) and greater retention (% change from 30 to 50 DAA) of AFP reduced molding of sorghums (Figure 1). Sorghums are likely to be more resistant to fungal invasion if they are able to retain good amounts of AFP from physiological to combine harvest maturity. In contrast, if they lose a lot of AFP during that period, they become more susceptible to molds. This indicates that AFP provides sorghums with an effective defense mechanism against fungal infection.

Another set of samples was collected and analyzed in 2003 and results of this study will be presented in the 2004 annual meeting of the American Association of Cereal Chemists (AACC) in September. All sorghums were grown at the Texas A&M University Farm, College Station, Texas. It comprised

Figure 1. Effect of AFP retention on grain mold rating of 2002 sorghums: Chitinase (top); Sormatin (bottom).



of 31 red and 13 white sorghum cultivars. Grain mold ratings at 50 DAA were assessed in the field by visually estimating severity, based on a 1 to 5 scale. Other grain quality attributes such as seed density, seed color, germination rate and total phenols were measured. Sorghum AFP (chitinase and sormatin) at 30 and 50 DAA were determined using the dot-blot immunoassay. The percentage change in AFP content from 30 to 50 DAA was calculated and used to measure degree AFP retention for each cultivar.

In order to determine the factors that influence sorghum's response against mold invasion, considerable molding should occur in the field as in 2002. The average mold rating for the 2003 sorghums was 2.1 which were less than that in 2002 (mold rating = 3.0). Nevertheless, differences in mold response among the cultivars were still observed. In the 2002 experiment, only AFP contents and mold ratings were measured. In the 2003 collection, sorghums were also analyzed for other physical and chemical properties in order to know if such attributes play some role in grain mold resistance.

Correlations between different sorghum variables for all the 44 cultivars of varying seed colors were determined. Mold rating score (MS) and germination rate (GR) were significantly correlated with each other. Visual assessment of molding in colored-seeded sorghums can be difficult. Hence, although not a direct measure of mold infection, the germination rate test was used to compliment the mold rating scores.

Consistent with our previous findings, the results prove that AFP is a significant factor that determines the resistance of sorghums against fungal invasion. Chitinase retention was significantly correlated with MS and GR, while sormatin retention was correlated to GR only. Seed color measurements (L, a and b values) were consistent with total phenols, showing that colored seeded sorghums contain more phenolic compounds than white sorghums. Total phenols were significantly correlated with MS but not with GR. Seed density was not correlated with MS or GR.

Previous studies have explained the role of phenolic compounds against molds which may be consistent with the results of this study. However, while total phenols were significantly correlated with MS, it was not with GR. It appears that the amount of phenolic compounds in sorghum alone does not guarantee mold resistance, as there are mold susceptible red sorghums and mold resistant white varieties. However, mold resistance attributed to AFP retention is more consistent and applies to both red and white sorghums.

We previously mentioned the possibility of AFP as mechanism for mold resistance in sorghums being an inherited trait. Thus, seven sorghum hybrids and their parents were measured of their mold response as well as the various factors that may have contributed to such response. Traits from parents were compared to those of the hybrids. The degree of chitinase retention in hybrids appears to be inherited from their parents. Most hybrids showed improved chitinase retention and consequently, higher mold resistance than their parents. Among the attributes being linked to mold resistance, chitinase retention appears to be more consistent than the others. However, this is only a preliminary study and did not strictly follow the inheritance study methodology used by plant geneticists. Thus, we will be asking the help of plant geneticists to come up with a better experimental design that would test this hypothesis.

We are currently in the processes of collecting samples from this year's crop. We have chosen to collect from 87 cultivars of which 46 are red and 41 are white sorghums. As in 2003, we will analyze for AFP as well as other physical and chemical grain attributes that are implicated in grain mold resistance. This will validate the conclusions we came up in the 2003 study. (Figure 1)

Networking Activities

Southern Africa

The PI, Lloyd Rooney, made three trips to Central America, one trip to Mexico and one trip to Mali to develop collaboration and present information on sorghum food and feed quality

INTSORMIL's interaction with the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. Graduate students in the Food Science Department at University of Pretoria are from many African countries. Many participate in the Regional Master of Science program, which consists of joint programs between CSIR and University of Pretoria. INTSORMIL is providing significant assistance to the region by involvement in these key programs.

Dr. S. Yetneberk from Ethiopia completed her Ph.D. program at University of Pretoria under Dr. John Taylor. She made excellent progress to determine major factors affecting the quality of injera from sorghum cultivars grown in Ethiopia. She found the addition of emulsifying agents appears to improve quality and prolong shelf life of injera from sorghum. Some hard white cultivars have acceptable injera quality. She has returned to the Ethiopian National Sorghum Improvement Program where she is developing improved sorghums for injera.

Mr. Steve Barrion, M.S. candidate, University of Pretoria, is working on milling of pearl millet from Namibia. Commercial milled products from a major millet variety were produced and analyzed for components and physical properties. This project will provide useful information relative to commercial milling of pearl millet compared to traditional milling.

Ms. Nomusa Ngwenya-Dlamini, Bulawayo, Zimbabwe, is working on a Ph.D. in food science at the University of Pretoria, involving antioxidants from sorghum. She teaches food science courses at the National University of Zimbabwe in Bulawayo. She was granted a Fulbright Fellowship to complete a Ph.D. program which will be done at Texas A&M University and the University of Pretoria where she has already made progress on antioxidants from sorghum and the effect of processing on them. Professor Taylor and Dr. L.W. Rooney will work together to co-advise her on her Ph.D. program.

Honduras, Salvador, Mexico and South America

Dr. Rooney traveled to San Salvador, El Salvador and Managua, Nicaragua to develop collaborative research plans and to evaluate the current status of value-added sorghum in food processing. A one day seminar on Sorghum Utilization in Feeds and factors affecting its value especially tannins was presented in Nicaragua and El Salvador. Dr. J Bueso, Associate Professor, EAP, Zamarano Honduras was the interpreter for Professors Joe Hancock (KSU 220) and Lloyd Rooney. In April, Dr. Lloyd Rooney participated in the PCCMCA conference in San Salvador by giving a presentation to the sorghum and rice sessions. While there, meetings with potential processors and CENTA personnel furthered the use of white food sorghums in snacks and other products. Dr Bueso just completed his Ph.D. at TAMU as part of the TAM 226 INTSORMIL project.

Experience obtained in Japan applies quite well to the situation in Salvador and elsewhere in Central America. A small Central American food company has initiated use of modest amounts of sorghum in their extruded snacks as the result of participation in our snack foods short course.

Dr. Lloyd Rooney has long term cooperative projects 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 new improved food sorghum hybrids in wet and dry milling and as adjuncts in brewing. His Ph.D. and subsequent post doctorate experience in our laboratory was partially funded from INTSORMIL.

We currently have three graduate students from Mexico partially funded on TAM 226. We are able to leverage our

INTSORMIL funds by using additional research funds from private industry and other agencies to conduct joint research activities. The practical short course on Snack Foods provides opportunities to conduct proprietary research projects for participants. These short courses generate funds that are used to partially support graduate students.

We are actively recruiting a graduate student from El Salvador (Ruth Vilma Calderon) and Nicaragua (E. Palacio) to develop skilled personnel for those programs in Central America where food science personnel related to crop improvement programs are unavailable. Ms. Palacios is in language training using World Bank Funds. Ms. Calderon is a food scientist at CENTA who is conducting research on the milling of sorghum into flour using a large rice mill. This appears promising.

Mali and West Africa

Dr. A. Touré, IER, Mali, and his associates have made progress in utilization and breeding research to develop IP production and use of the new white tan plant photosensitive sorghum varieties for value-added production. It is clear that many scientists and others understand that acquisition of good quality sorghum and millet grains for processing is necessary to produce profitable, competitive food products for urban markets. This is a continuous painstakingly slow process but progress is occurring. This same concept has been demonstrated in Niger and other places where poor quality grain produced unacceptable products that consumers will not buy.

The products were of excellent quality overall; processors realize they need improved quality and consistency of grain and are willing to pay more for it. The organization of farmers to produce higher quality grain and supply chain management and sharing in profits by all parties are the next steps toward more efficiency. These developments are the results of long-term efforts on the part of numerous international agencies that assisted ITA and other organizations to lay the groundwork for these entrepreneurs. The time is ripe to develop a supply chain to provide value-enhanced grain for increased profits for all participants from seed producers through to the consumer. A supply chain for improved quality grain will make delivery and adoption of new cultivars much easier and will permit processors to expand production to meet market demands that appear to exist.

North America

Several papers were presented at the annual American Association of Cereal Chemists Conference, Portland, Oregon. Dr. Lloyd Rooney presented sorghum quality/utilization discussions to Texas Sorghum Producers Board Members and panels and U.S. Grains Council sponsored trade teams.

Visitors and collaborators from Southern Africa, Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador, Korea, Japan, Venezuela, Colombia, and China were presented information.

Practical Snack Foods Short Course

Our laboratory conducts an annual one-week short course on practical snack foods production for private industry in which sorghum utilization is part of the program. A book on Snack Food Processing co-edited by Dr. Lloyd Rooney contains information on food sorghum. Participants (48) from all over the world (18 countries represented) enrolled in the short course, including several from Central America and Mexico. This short course produces a profit, which is used to partially support our research activities, another example of leveraging of resources.

Training, Education and Human Resource Development

Two M.S. theses were completed. Five graduate students currently work on INTSORMIL related research in our laboratory, with partial financial support while several others are supported from non-INTSORMIL funds. Inflation continues to significantly reduce the number of graduate students that can be supported.

Our collaboration with Dr. Serna-Saldivar, Head, Food Science Dept., ITESM, Monterey, Mexico has led to completion of six M.S. degrees. These young scientists have positions in the Mexican food industry, which transfers the technology directly to industry.

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Host Country Program Enhancement

Central America (El Salvador, Nicaragua)

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Collaborative Program

Vision Statement

The following vision statement was developed to guide regional program activities. "INTSORMIL collaboration will support national research programs' efforts to develop dynamic, competent institutional research programs which contribute to productivity, economic growth, natural resource conservation and improved diets for grain sorghum producers, processors and consumers. Scientists in the region will work as regional, multi-institutional, multi-disciplinary teams collaborating with extension services, NGOs, international research centers, PCCMCA, the private sector and scientists from U.S. land grant universities to increase productivity, profitability, economic growth, conservation of natural resources, and food security for producers, processors and consumers of sorghum".

Institutions

Active INTSORMIL collaboration in Central America is occurring primarily among the following institutions: Centro Nacional de Technología de Agropecuaria y Forestal (CENTA), El Salvador; Instituto Nicaragüense de Tecnología Agropecuaria (INTA), Nicaragua; Universidad Nacional Agraría (UNA), Managua, Nicaragua; Kansas State University, Mississippi State University, Texas A&M University; and the University of Nebraska. In addition, INTSORMIL has a current MOU with the Universidad Nacional Autónoma de Nicaragua (UNAN), Leon, Nicaragua, and maintains ties with the Escuela Agrícola Panamericana (EAP), Honduras based upon past collaboration. During 2003 a new Memorandum of Understanding was signed with the Dirección de Ciencia y Tecnología Agropecuaria (DICTA) in Honduras, and program activities were initiated in Jan. 2004. INTSORMIL has developed linkages with the regional seed companies Cristiani Burkart and Productores de Semillas, allowing new activities in Guatemala, testing of hybrids/varieties and support of the sorghum industry in Central America. Also informal collaboration with the Universidad José Matías Delgado (in food science) and the Universidad de El Salvador (entomology) has been established during the past two years.

Organization and Management

In 1999, INTSORMIL shifted program emphasis in Central America to El Salvador and Nicaragua. Scientists from collaborating institutions met and developed a research plan for the 2000-2001 years with collaborative projects in plant breeding, utilization, plant protection (entomology and plant pathology), and agronomy. In Feb. 2002 scientists met to present two-year research results and develop priorities for collaborative research for 2002-2006. In Oct. 2002, the research directors of collaborating institutions met to develop a regional training priorities for sorghum programs which is being implemented. These research and training priorities are the focus of regional efforts.

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America Regional Program budget, which was $130,000 during the past year. The four collaborative research projects (plant breeding, utilization, plant protection, and agronomy) were budgeted at $8,000 to $25,000 for activities 2003 - 2004. In addition, regional funds were used to support English study and costs of taking the TOEFL and GRE tests in preparation for graduate study, with the balance maintained at the INTSORMIL Management Entity to cover regional expenses. These regional expenses included expenses associated with short-term training, equipment purchases and administrative travel.

Collaboration

INTSORMIL's Central America program has collaboration with many non-governmental organizations mainly in validation of new sorghum varieties on-farm (see form for complete list), and formal collaboration with national extension services, and it has served as a catalyst for Central American grain sorghum research and technology transfer. Collaborative relationships have been established with a number of universities in El Salvador and Nicaragua, and undergraduate students often complete thesis research on INTSORMIL-supported experiments. In addition, René Clará Valencia coordinated the regional grain sorghum yield trials conducted by the PCCMCA, and provided technical assistance for seed production to the private seed company Productoras de Semillas in Guatemala. A strong collaborative relationship has been developed between INTSORMIL's regional sorghum research program and ANPROSOR, the Nicaraguan grain sorghum producers association, which has assisted in identifying research priorities and has collaborated with a number of research studies since 2002. Regional scientists have collaboration with the CIRAD-CIAT project on participatory plant breeding for sorghum (and upland rice), and ICRISAT provides germplasm for breeding use as requested.

Sorghum Production/Utilization Constraints

Grain sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to grain sorghum in 2003 was 225,897 ha^{-1} with an average grain yield of 1.5 Mg ha^{-1} (FAO, 2004). During the last decade sorghum grain yield in Central America increased due to improved technology (including improved cultivars and hybrids, herbicides, insecticides, planting date, minimum tillage, seed treatments and fertilizer) available to producers.

Small-scale Central American farmers are burdened with low productivity and limited land resources. Intercropping provides a means to increase total productivity per unit land area and reduce the risk of dependence on one crop. The dominant cropping system is maize intercropped with maicillos criollos (called millón in Nicaragua). These tropical grain sorghums are three to four meters tall, drought tolerant, and photoperiod sensitive. The grain is used as human food and a feed grain for livestock, and the stover is used for livestock forage. Although maicillos criollos produce low yields, they are planted on approximately 67% of the grain sorghum area in Central America.

The limited grain yield response of traditional maicillo criollo varieties to management practices is a primary constraint to increased production. Soil and water conservation, improved production practices and soil fertility management, and increased genetic potential of both maicillos criollos and other sorghum varieties is essential to obtain economical yield increases. To date, increased grain sorghum production, yield and area are due primarily to utilization of improved cultivars (hybrids and varieties) other than maicillos criollos.

Alternative uses for sorghum grain need to be developed to encourage sustainable economic growth in semi-arid areas in Central America. White-grain, tan-plant colored grain sorghum cultivars are well adapted to Central American human food and livestock feed systems. Innovative processing systems, like extrusion and flaking, are needed to increase starch digestibility and maximize net energy intake for livestock feed. A lack of milling equipment for production of grain sorghum flour limits adoption of the use of grain sorghum flour for baked products. Human consumption needs to be promoted, especially in tortilla products, extruded snacks and flour substitution through use of superior grain-quality sorghum cultivars. Use of grain sorghum cultivars for forage, or dual use for both grain and forage are important to small producers.

Research Accomplishments and Planning

Sorghum Utilization for Feed Workshops

One-day workshops were held Jan. 12, 2004 in Managua, Nicaragua and Jan. 14 in San Salvador, El Salvador with presentations on sorghum use as livestock feed by Drs. Lloyd Rooney and Joe Hancock. The workshops were attended by 30 to 45 participants per workshop largely from the private livestock feed sector, but also included sorghum scientists from national programs and the national sorghum producers association in Nicaragua. The workshop in El Salvador was sponsored by AVES (Asociación de Avicultores de El Salvador). ANPROSOR in collaboration with INTA scientists and Drs. Lloyd Rooney and Sergio Serna-Saldivar are making plans for a broader sorghum utilization workshop to be held in Managua in early 2005.

Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales (PCCMCA) [Cooperative Central American Program for Crop and Animal Improvement] Annual Meeting

Regional coordinator René Clará; Drs. Larry Claflin, Lloyd Rooney and Bill Rooney; and 10 collaborating scientists participated in this annual meeting April 16 -20, 2004. Most oral papers on grain sorghum were presented by INTSORMIL collaborators, and Orlando Téllez Obregón won the award for outstanding paper in the sorghum and rice section. Dr. Lloyd Rooney gave an invited presentation on grain utilization to the sorghum/rice section. The meeting provided a forum for broadening contacts with programs in other countries and with the private sector. In addition, it was useful for regional planning of the 2004 growing season research and technology transfer plans.

External Evaluation Panel (EEP) Review

The EEP visited El Salvador and Nicaragua Dec. 8-12, 2003. Collaborators from Honduras assisted the review in El Salvador. The review team met with regional scientists and administrators, NGOs involved in technology transfer, producers and utilizers of sorghum grain.

Undergraduate Research Theses at the Universidad Nacional Agraría, Nicaragua

Undergraduate students are required to complete a research thesis as part of the Bachelor of Science degree. During 2003-2004, 14 students completed thesis research at the Universidad Nacional Agraría on grain sorghum with support from agronomy projects. These included the following:

Chepita Garcia y Yolanda Herrera.2004. Evaluacion de 16 lineas de sorgo en Zambrano, Masaya (Evaluation of 16 sorghum lines for nitrogen use efficiency at Zambrano, Masaya).

Ajax Fonseca, Lenin Lopez, Eliezer Manzanares y Francisco Calero. 2004. Evaluacion de 25 lineas de sorgo en San Ramon, Matagalpa (Evaluation of 25 sorghum lines for nitrogen use efficiency at San Ramon, Matagalpa).

Ruby Altamirano y Mario Gadea..2004. Evaluacion del uso de frijol Mungo como fuente alternativa de N en sorgo en San Ramon, Matagalpa (Evaluation of mungbean as an alternate N source for sorghum at San Ramon, Matagalpa).

Ramiro Manzanares y Roberto Hernadez. 2004. Evaluacion del uso de frijol Mungo como fuente alternativa de N en sorgo en Tisma, Masaya [Evaluation of mungbean as an alternate N source for sorghum at Tisma, Masaya].

Alex Gonzalez y Willar Green. 2004. Evaluacion de 25 lineas de sorgo en Posoltega, Leon. [Evaluation of 25 sorghum lines for nitrogen use efficiency at Posoltega, Leon].

Maury Gurdian. 2004. Evaluacion de 16 lineas de sorgo en Posoltega, Leon. [Evaluation of 16 sorghum lines for nitrogen use efficiency at Posoltega, Leon].

Plant Breeding

Research Methods

The plant breeding programs in both El Salvador and Nicaragua are striving to identify adapted grain sorghum lines with good agronomic and utilization characteristics for development either as photoperiod-sensitive (for relay intercropping systems with sorghum planted into the existing maize crop) or insensitive varieties for grain production or dual use as grain and forage. Photoperiod-insensitive lines may also serve as parents for hybrids. During 2002 - 2003, the Nicaraguan program took regional leadership for the hybrid development program, while El Salvador took regional leadership for the photoperiod sensitive variety program. Once potentially superior lines are identified, then preliminary yield trials are conducted followed by on-farm verification trials and ultimate release. The breeding programs are constantly evaluating new sources of germplasm identified in the region, from INTSORMIL breeding programs in the United States, and from ICRISAT. In 2003-2004 varieties from CENTA were evaluated in Honduras. Each year, grain sorghum hybrid tests have been conducted in three to seven countries in Central America. Collaborative ties have been made with Dr. Gille Trouché, CIRAD-CIAT project, with focus on a participatory sorghum breeding program in Nicaragua. Technical support is provided to regional sorghum seed companies headquartered in Guatemala, who are also assisting with the PCCMCA hybrid trials and evaluation of grain/forage sorghum hybrid/varieties for future release.

Research Results

Regional PCCMCA trials were conducted for sorghum hybrid entries from Christiani Burkart, Sefloarca and Prosemillas, a common check hybrid and a local check hybrid at 6 locations in El Salvador, Guatemala and Nicaragua. No hybrid differences in grain yield, plant height or days to flowering were found. Grain from all hybrids were tested for tannin level, which were all low with no potential to reduce feed efficiency for monogastric animals.

Plant breeding programs in El Salvador and Nicaragua are evaluating photoperiod sensitive sorghum varieties (maicillos criollos and millón) for intercropping systems with maize, and in some cases, with dry beans. In El Salvador the varieties 85-SCP-805 and ES-790 were promoted through 430 on-farm validation trials in cooperations with various NGOs. A set of these photoperiod sensitive varieties was sent to Honduras for testing and seed increase. On photoperiod sensitive populations was intercropped with maize, and 49 new uniform F8 lines were selected for future use. Fifty-two new crosses between nine photoperiod sensitive varieties and nine three-dwarf elite photoperiod sensitive elite lines for selection and evaluation in the future.

Evaluations of photoperiod-insensitive varieties continues in both countries. Several evaluation trials for white and red grain were conducted to select lines for potential release as varieties. The white grain varieties Macía (locally called 'Africana'), CENTA-RCV (El Salvador) and (TXP)-12, and the red grain varieties (SR17)-10-2-2-2, (SR-16)-10-1-1-3 and (SR-6)-1-5-1-1 were grown in on-farm validation trials.

Seed production of the four best forage hybrids selected in 2002 plus the check ATX623 was determined to select the female with best seed production. The lines ICSA275 and ICSA264 were 100% or more better than the check for seed production in El Salvador and Nicaragua with yields of 2597 to 3247 kg ha^{-1}.

In Nicaragua, the forage hybrid ATX623(BMR)*WRAY had the best green-chop forage yield, and shows potential for future use.

Four male-sterile populations from Texas A&M and ICRISAT were evaluated. The lines K82 and TX288 were found to have the highest potential to generate new varieties or lines for making hybrids.

For hybrid grain sorghum development the A and B lines AES-1, BES-1, AES-2, BES-2 were generated from Texas A&M germplasm. All lines have red grain color, light brown plant color, tropical adaptation and three-dwarf characteristics. In addition 15 new B lines and nine new R lines were selected from Texas A&M germplasm for developing new hybrids with tropical adaptation.

In Honduras, the varieties Sureño, RCV and Soberano were evaluated at La Lujosa Experiment Station near Choluteca. All three produced grain yields between 5.2 and 5.5 Mg ha-1. RCV and Soberano were earlier maturing and had shorter plants with less lodging, but produced less forage. All three are being tested on farm, and show potential to increase sorghum production in Honduras.

Broom production is an important enterprise in Honduras with a potential annual market of three million dollars, but local production of broomcorn is inadequate to meet demand. The broomcorn varieties 162474-1-8-2-8, 18137NSS228, 18132NSS222, and 22025INDIA were tested on-farm using sustainable production practices of minimum tillage, using crop residues for mulch, no burning, and soil conservation practices. The variety 18132NSS222 showed good potential based upon plant height, lodging and panicle size. The large panicle size is particularly beneficial since larger brooms can be produced which have higher market value.

Plant Protection Research

Research Methods

Efforts to move beyond disease identification to determining the economic loss and control methods has been an objective. Meetings organized by UNA, INTA, CIRAD-CIAT and ANPROSOR were held in 2003 with 70 farmers from the Pacific Region of Nicaragua to learn about the main sorghum production constraints in Nicaragua. ADIN nurseries are planted to identify host-plant resistant germplasm, and insecticide fungicide application studied to determine economic loss and potential use for control of pests. The effects of chemical application (diazinon), non-chemical controls (Neem spray and the fungal biological agent *Beauveria bassiana*), and cultural planting system using pigeon pea barriers on insect and disease pests was conducted in Nicaragua.

Research Results

In Nicaragua, farmer meetings identified the need for training in integrated pest management of grain sorghum, especially with diseases, and agronomic management. In addition, fertilizer management (particularly rates and application timing), weed control and additional utilization options beyond being a poultry feed. They indicated a need for a simple grain sorghum production manual. Technical training workshops are being planned. Many of the farmers offered their farms to be used for research studies.

Evaluations in the ADIN in two farmer fields and on the CENTA experiment station at San Andrés in El Salvador and indicate that the most prevalent diseases were rust *(Puccinia* species), *Helmintosporium*, zonal spot (*Gloeocercospora*) ergot (*Clavcep*),*fuscarium, gray leaf spot (Cercsopora)*. The lines MB198B, 96GCPDB172, D2CA4624, Sureño, BTx635, Tegemeo, 86EON361, GR108-90M-24, 90EON328, and 99GW092 exhibited the best resistance to diseases.

Studies in El Salvador using improved (RCV and Soberano) and traditional (leche) varieties for with fungicide (Daconil) and without fungicide showed the fungicide increased yield of the susceptible local variety from 500 to 4400 kg ha^{-1}, but had little influence on the improved varieties which produced similar yield to the traditional variety with fungicide applied. This shows that these improved varieties have disease resistance, making fungicide application unnecessary. Improved variety use without fungicide application was the most economic alternative.

Insecticides were applied to the varieties RCV and SOBERANO to control stalk borers and sorghum webworm in El Salvador. The sorghum variety RCV had higher yield than SOBERANO, but insecticide application had little effect on grain yield or quality since infestation levels were low. Insecticide application had little effect on sorghum webworm infestation. Planting RCV without insecticide application gave the highest economic return.

A chemical, non-chemical and barrier crop study in Nicaragua produced inconclusive results. Treatments had no effect on insect larvae, thus no influence on grain yield. Plot sizes were too small, Neem and *Beauveria bassiana* were not effective on sorghum midge, and the pigeon pea barrier was not used in practical manner on the small plots.

Grain Utilization (Quality) Research

Research Methods

The Central America program has historically concentrated on improving the grain yield and processing characteristics of sorghum for use in tortillas and related products with research conducted at the Escuela Agrícola Panamericana in Honduras. In recent years the research has broadened to include grain sorghum flour substitution in yeast and sweet breads in El Salvador. This research has included market surveys, and research on specific grain quality/food utilization issues by CENTA, with undergraduate students from the Escuela Agrícola Panamericana, or graduate students at Texas A & M University or the Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico. In 2002, CENTA established collaboration with the Universidad José Matías Delgado in El Salvador, and conducted research on decortification of sorghum grain, development of new sweet bread recipes, and determination of shelf life of sweet breads made with whole sorghum grain.

Availability of milling equipment, especially for decortification, for production of sorghum flour continues to be a limiting factor. Five rice milling units were tested during the year for production of decorticated sorghum flour, and the resulting particle size, grain breakage and nutritional content were determined.

Research Results

The rice mill Suzuki MT-99 used by the GUMARSAL company was found to be the best equipment available, producing 84% decortication with 2.4% breakage by abrading for 30 seconds. This produced slightly smaller particle size and nutritional value than whole-grain flour, but should produce superior baked products with a longer shelf-life. We have also determined that a small mill produced in Senegal would likely be appropriate technology for producing sorghum flour, and proposals are being prepared for funding to set up a mill in collaboration with ASOPAN, the association of bread bakers. Contacts have been made concerning mills for decortication and grinding of sorghum grain available in Senegal, South Africa and India. Project proposals are being written in hopes of obtaining additional funds to obtain the processing equipment made in Senegal.

Agronomy Research

Research Methods

A three-year study was conducted at two locations in El Salvador and two locations in 2002 - 2003 in Nicaragua in 2002 - 2003, and three locations in Nicaragua and one in El Salvador in 2003 - 2004 with the objective to determine if NUE differences exist among photoperiod insensitive sorghum varieties, determine optimal N fertilizer rates for grain sorghum in a randomized complete block design with four replications. Grain and stover yield, and N concentration of grain and stover at harvest were collected, and agronomic characteristics.

Previous research in El Salvador indicated that the photoperiod sensitive variety 85SCP805 was high yield and had high NUE. Validation trials versus a local check variety and with

(47 kg ha^{-1}) and no N fertilizer was conducted on 40 farms. In addition, technology transfer trials for the varieties RCV, SOBERANO, 85SCP805 were conducted with collaborating NGOs on 430 farms.

Research Results

The El Salvador location in 2003 provided little useful information due to site selection of a soil with relatively high nutrient level. In Nicaragua, large differences among sorghum lines and locations were present, but a line by N level interaction was only present for one-out-of three locations. It appears likely that a wider range of germplasm will be needed to incorporate high nitrogen use efficiency into photoperiod insensitive varieties in Central America.

In the Pacific Increasing N application from zero to 194 kg ha^{-1} increased sorghum grain yield quadratically from 2.1 to 3.9 Mg ha^{-1}, and the response would suggest that yields would be further increased with higher application rates. This yield response to N fertilizer application was consistent across varieties, except Tortillero Precoz had a smaller yield increase than other varieties between the highest N rates of 129 and 194 kg ha^{-1}. Economic marginal return analysis indicated that the optimal rate to recommend to producers is 129 kg ha^{-1}.

In on-farm validation trials, the improved variety 85SCP805 produced 130 kg ha^{-1} more grain than the local check without N application. Nitrogen application increased grain yield of 85SCP805 by approximately 700 kg ha^{-1}, and of the local check by approximately 300 kg ha^{-1}. In spite of the clear yield advantage of using the improved variety 85SCP805 with N application, the economic analysis indicated that the improved variety without N fertilizer application had the greatest net return due to the high local cost of N fertilizer. In the improved variety transfer plots (Table 1), all improved varieties produced higher yields than the local check variety, with the previously released RCV consistently yielding better than the local check.

Mutual Research Benefits

Many constraints to sorghum production are similar between Central America and the U.S. including drought, diseases, and insects. U.S. based scientists can provide germplasm that could at least partially alleviate the effects of some of these constraints. The maicillos criollos are a unique type of grain sorghum and can potentially contribute useful food quality traits to U.S. germplasm. Several maillos criollos lines are presently in the Texas A&M University/USDA-ARS Sorghum Conversion Program. Germplasm exchange will contribute to development of novel genetic combinations with multiple stress re-

Table 1. Technology transfer on-farm test results conducted in collaboration with NGOs in El Salvador.

NGO Responsible	Municipality	Community	85SCP 805	ES790	CENTA S3	RCV	Local Check
			Variety				
			kg ha^{-1}				
Ramírez Consultores S.A. de C.V.	Victoria	Rojitas	1948			3247	1234
		La Uvilla	1818			2597	1104
		Suburbano Victoria		1623			1169
		Caracol	1948			2922	1299
		Victoria Average	1905	1623		2922	1169
	San Isidro Guacotecti	Potrero Batres				2273	1104
		Agua Zarca				2922	1558
		Bañadero	2273		779	2597	1494
		Tempisque	1039		779		1558
		Guacotecti Average	1656		779	2760	1537
ESBESA	Sensuntepeque	Rojas	2597				974
		Tronalagua	1883	1888	3247	3506	1169
		Rio Grande	1883	1818	3247	1429	1234
		Llano Grande	2078		2597	1948	1429
		Sensuntepeque Average	2110	1853	3030	2294	961
Consorcio	Nuevo Eden de San Juan	Cucurucho	844				1039
		Jardin	974				909
		Nuevo Eden Average	900				974
PRODESO	Llobasco	San José				3377	1429
		Aqua Zarca				1688	1299
		Nanastepeque				1494	1299
		Llanitos				3247	1299
		Llobasco Average				2452	1332
FUMPROCOOP	Llobasco	San Benito			2403	2468	1299
		El Tule				2078	1429
		San Francisco			1234	2143	1299
		San Nicolas				1883	1169
		Llobasco Average			1819	2143	1299
	Average Across Locations		**1645**	**1738**	**1876**	**2330**	**1196**

sistance, wide adaptation, and improved food quality. INTSORMIL's collaborative research in entomology and plant pathology research includes pests that affect grain sorghum both in Central America and in the U.S., such as sorghum midge, fall armyworm, gray spot and ergot. Economic development of Central American countries will increase food security in the region, and potentially increase U.S. exports to the region.

Institution Building

Equipment and other support

INTSORMIL has provided pass-through funding and supplies for pathology laboratories in El Salvador and Nicaragua. INTSORMIL has facilitated donation of complete sets of Agronomy Journal and Crop Science to the library at CENTA.

Training and education

Johnson Zeledón (Nicaragua) completed a Ph.D. degree in entomology at Mississippi State University, Rafael Mateo (Honduras) is pursuing a Ph.D. in plant breeding at Texas A&M University and Sergio Pichardo Guido is pursuing a Ph.D. in plant pathology at Mississippi State University. Mario Parada Jaco (El Salvador) is in English language study in preparation for a Ph.D. program in entomology at Mississippi State University. In January 2005, Vilma Ruth Calderón (El Salvador) will start a M.S. degree in food science at Texas A&M University, and Otho Ludwig Argueta (El Salvador) will start a M.S. program in agricultural economics at Purdue University. Eliette Palacio (Nicaragua) is being funded for English language study by World Bank/INTA in hopes that she can enter a graduate degree program in food science at Texas A&M University. Short-term training on experimental design, data analysis and scientific communication was provided to 30 participants (primarily INTSORMIL collaborators) in October 2003.

Networking

Institutions/Organizations

INTSORMIL support has contributed to increased collaboration among CENTA, INTA and UNA during the past four years. In El Salvador, increased collaboration with the non-governmental organizations Ramírez Consultores S.A. de C.V., Escobar-Betancourt S.A. (ESBESA), ESBESA-Ramírez Consultores (Consorcio), Profesionales de Desarrollo Sostenible (PRODESO), Asosición de Añileros de Cabañas (ASEÑICA), MAG/AVES, FUNPROCOOP, PRODAP (Proyecto de Desarrollo Rural en la Región Paracentral), and FUNDESYRAM (Fundación Para E Desarrollo Socio-Económico y Restauración Ambiental) primarily with validation testing of sorghum varieties to be released. A collaborative relationship has also been established with the Universidad José Matías Delgado. In Nicaragua, increased collaboration with the CIRAD-CIAT Watershed Project at San Dionisio has been strengthened, especially collaboration with Dr. Gilles Trouché, sorghum breeder. Also collaboration with the universities of Campesina (UNICAM), Centroamericana (CSA) and Católica del Tropico Seco de Estelí (UCATSE), and with the non-governmental organizations ADRA-Ocotal (Adventist Development & Relief Agency), CARITAS-Matagalpa and CARE-Estelí have been developed. National programs have strong linkages to private seed companies, and are developing closer ties with feed and food utilization companies. Particularly noteworthy is providing technical assistance to the seed company Productora de Semilla in Guatemala. C, and new initatives with Cristiani Burkart. Close working ties with the Asociacíon Salvadoreña de Panifacadores (ASPAN) in El Salvador continues. Improved networking with INTSORMIL universities and Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico is desired through graduate education and collaborative research efforts. INTSORMIL is actively working to promote and strengthen collaborative linkages.

Travel

Regional coordinator René Clará, U.S. Principal Investigators Bill Rooney, Lloyd Rooney and Larry Claflin, and 10 collaborating scientists attended the PCCMCA meeting Apr. 16-20, 2004 in San Salvador, El Salvador. Most papers in the sorghum session were presented by INTSORMIL Collaborators.

Drs. John Sanders and Lloyd Rooney, and graduate student Felix Baquedano traveled to El Salvador and Nicaragua in Aug. 2003 to study sorghum grain production, marketing and utilization.

Drs. Larry Claflin and Henry Pitre visited El Salvador and Nicaragua in Nov., 2003 to assist with collaborative research.

Drs. Lloyd Rooney and Joe Hancock gave seminars on sorghum utilization for livestock feed in Nicaragua (Jan. 12, 2004) and Nicaragua (Jan. 14, 2004).

Regional coordinator René Clará visited Nicaragua and Honduras several times to coordinate regional activities and assist with the plant breeding programs. He also visited Productora de Semillas in Guatemala to provide assistance on sorghum seed production.

The External Evaluation Panel (EEP) visited El Salvador and Nicaragua Dec. 8-12. 2003. Collaborators from Honduras participated in the El Salvador portion of this visit.

Dr. Stephen Mason, Regional Coordinator, made an administrative trip to El Salvador and Nicaragua in Dec. 2003.

Dr. John Yohe, Director, and Dr. Stephen Mason and Ing. René Clará traveled to Honduras to sign a new Memorandum of Understanding between INTSORMIL and DICTA in Oct. 2003.

Horn of Africa (Ethiopia, Eritrea, Kenya, Uganda)

Gebisa Ejeta
Purdue University

Coordinators

Gebisa Ejeta, Regional Coordinator, Purdue University, Dept. of Agronomy, West Lafayette, IN 47907
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Collaborative Program

INTSORMIL/Horn of Africa is a regional collaborative research program on sorghum and millets in Eastern Africa between INTSORMIL and national agricultural research centers (NARS) in the region. The program strives to develop fruitful collaborative engagements between and among a group of scientists to address sorghum and millet production and utilization problems of mutual interest. Before the start of the current regional effort, INTSORMIL had had a productive collaborative program with the Agricultural Research Corporation (ARC) in Sudan. Collaboration resulted in an array of technical developments that have impacted on sorghum agriculture in Sudan and the region. Technologies have been generated as a result of the collaborative effort that has significantly impacted sorghum and millet production and utilization in Sudan. The long-term collaborative association has also resulted in several Sudanese scientists being trained in INTSORMIL institutions. U.S. scientists 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, memoranda of agreements were signed with NARS in Ethiopia, Eritrea, Kenya, Tanzania, and Uganda. With these MOA, INTSORMIL now has collaborative relationships with five countries in the Horn of Africa region. A two-tier program has been developed in the Horn of Africa. With each national program, we have a traditional bilateral 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, and are then disbursed in country to each collaborating scientist to carry out the research project. 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, initially to catalyze exchange of information and ideas among member NARS and INTSORMIL scientists, and currently, to work through the regional sorghum and millet network, ECARSAM. A major initiative that has been implemented as a regional effort has been the integrated *Striga* management (ISM) project for effective control of *Striga* at the farm level. We focused on *Striga* because it is a major regional constraint upon which considerable research has been undertaken by one or more of the NARS in the region. The ISM program has been implemented first in Ethiopia, and since expanded into Tanzania and Eritrea. In each country, we combined three proven technologies (*Striga* resistant cultivars, nitrogen fertilization, and water conservation measure of tied ridges) for a synergistic effect in the control of *Striga*. The ISM project has been widely accepted as a major regional initiative. Other similar regional initiative may also be identified. Once agreed upon, collaborative research projects among NARS in the region will be developed, in consultance with appropriate INTSORMIL scientists, on a priority research agenda of regional importance. Inputs from concerned scientists in the region will be solicited in developing the research agenda as well as in refining the research protocol on a timely basis. Collaborative scientists will be encouraged to meet regularly (preferably once a year) to exchange ideas and to sharpen the focus of the regional research agenda.

Annual field/laboratory touring workshops will be organized alternately at a site in one of the host countries in the region. Participation in the tour will be based on interest and the topic of the workshop for that year. These tours will provide INTSORMIL PIs opportunities for interaction with very many scientists in the region. Scientists from the region will also have opportunity to pick up useful germplasm, research techniques, or potentially transferable technologies that they may come across during these tours.

Opportunities for collaboration with other organizations in the region, such as ASARECA, ICRISAT/East Africa, World Vision International, Sasakawa Global 2000, and the IPM CRSP have been good with some joint activity underway with each of these organizations. Discussions have also been underway to determine possibilities of buy-ins from USAID Missions in the various countries in the Horn of Africa. A major agreement was developed, a few years ago, between INTSORMIL, USAID/REDSO/East, and the Inter-Governmental Agency for Development (IGAD) with funds allocated through the Greater Horn of Africa Program. Through this initiative INTSORMIL spearheaded a study on availability and use of technologies that alleviate problems associated with dryland agriculture. This comprehensive study is expected to provide direction for future agricultural research and transfer of technologies for drought prone environments of the Horn of Africa.

Research Disciplines and Collaborators

Ethiopia:

Agronomy –Tewodros Mesfin Abebe/Gebreyesus Brhane Tesfahunegn, EARO; Charles Wortmann/ Martha Mamo, INTSORMIL.

Striga Management – Tesfaye Tesso/Fasil Redda, EARO; Gebisa Ejeta, INTSORMIL.

Entomology – Tsedeke Abate, EARO; Henry Pitre, INTSORMIL.

Agricultural Economics – Yeshi Chiche, EARO; John Sanders, INTSORMIL.

Sorghum Utilization – Senait Yetneberk, EARO; Bruce Hamaker and Gebisa Ejeta, INTSORMIL.

Research Extension – Aberra Deressa, EARO; Gebisa Ejeta, INTSORMIL.

Pathology – Girma Tegegne, EARO

Kenya:

Sorghum Breeding – C. K. Kamau, KARI; Gebisa Ejeta, INTSORMIL.

Food Quality – Betty Bugusu, KARI; Bruce Hamaker, INTSORMIL.

Striga – C. Mburu, KARI; Gebisa Ejeta, INTSORMIL

Uganda:

Sorghum and Millet Pathology – Peter Esele, NARO; Gebisa Ejeta, INTSORMIL.

Sorghum Agronomy – Kayuki Kayyizzi, NARO; Charles Wortmann, INTSORMIL.

Eritrea:

Sorghum Breeding – Tesfamichael Abraha, NARI; Gebisa Ejeta, INTSORMIL.

Millet Breeding – Neguse Abraha, NARI; Gebisa Ejeta, INTSORMIL

Entomology – Asmelash Woldai, NARI; Henry Pitre, INTSORMIL.

Striga Management – Goitom Ghobezai, NARI; Gebisa Ejeta, INTSORMIL.

Tanzania:

Sorghum Breeding: Hamis Saadan, DRD; Gebisa Ejeta, INTSORMIL

Striga Management: Ambonesigwe Mbwaga, DRD; Gebisa Ejeta, INTSORMIL

Agronomy: E.A. Letayo, DRD/ARI

Sorghum/Millet Constraints Researched

Sorghum and millet are important crops in all of the countries in the Horn of Africa, 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 1 and 2)

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 has 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

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	785	2386	1150	192	221
Uganda	255	1498	382	407	1602	652

Table 2. Production Constraints of Sorghum and Millet Across Eastern Africa Countries

	Eritrea	Ethiopia	Kenya	Uganda
Varietal Development	X	X		X
Striga	X	X	X	X
Crop Protection				
Pest	X	X	X	X
Diseases	X	X	X	X
Drought	X	X	X	X
Production	X	X	X	X
Technology Transfer	X	X	X	X
Training – Long-term	X	X	X	X
- Short-term	X	X	X	X
Socio-economics				
Utilization	X	X	X	X
Information Exchange				X
Germplasm Introduction	X	X	X	X
Soil/Water Conservation	X		X	
Seed Production & Marketing	X	X	X	X

are limited by lack of a field screening procedure and lack of knowledge of sources of appropriate germplasm with useful traits. The lack of absolute definition of good food quality parameters and good screening methods for food quality to some extent also limit the utilization of high yielding sorghum and millet varieties. Very little research has also gone in developing germplasm with resistance to the major insect pests and diseases. *Striga*, a major parasitic weed of sorghum and millet, constitutes a major constraint to the production of these crops. There is very little sorghum and millet germplasm with resistance to *Striga* and the mechanisms that render resistance to *Striga* are not well understood. Knowledge about inheritance of many of these traits is also lacking. In many of these areas, the crop/bush fallow system of production has traditionally been used to provide enough nutrients and possibly some moisture for a period of crop years (5-10 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.

Progress Report

Integrated *Striga* Management on Sorghum in Tanzania

Mbwaga, H. Saadan, E. Letayo

Striga is one of the major constraints to crop production in Tanzania. *Striga* species of economic importance in Tanzania include *S. asiatica*, the most widely spread species, *S. hermonthica* which is found in the Northwest of the country around Lake Victoria and *S. forbesii* found mainly in the eastern part of Tanzania. Cereal crops affected by *Striga* include sorghum, maize, upland rice and finger millet. It has been observed that pearl millet is not attacked by any of the *Striga* species found in Tanzania. Though several control methods have been suggested, none has been effective in eradicating *Striga*. Recently, an integrated approach to *Striga* control, bringing in multiple control options to systematically address the issue of control and reduction of the parasite, appear to be successful.

In Tanzania, *Striga* resistant sorghum varieties have been identified, verified on farmers' fields, and released for commercial use in the country in 2002. We have found that resistance alone is not a 100% solution to the problem of *Striga*; it needs integration with other *Striga* control options. Other options of *Striga* control include hand weeding, intercropping with legumes, improving soil fertility through application of inorganic/animal manure, green manure and improvement of available soil moisture to the plants by using tied-ridges. In this project we had demonstration on the use of inorganic fertilizer/animal manure, tied-ridges and resistant sorghum varieties for control of *Striga* and increase sorghum grain yield under farmers' field management.

In collaboration with INTSORMIL, we conducted during the 2003 and 2004 crop seasons an integrated *Striga* management (ISM) in three districts, namely, Singida, Kongwa, and Lake Zone.

In the Singida district, two locations were identified for carrying out this project. The first location was Sepuka ward, where two villages, Musungua and Musimi, were selected. Each village formed a farmer research group of 12 farmers for conducting the evaluation.

Sepuka Ward:

Treatment included the following demonstrations:

- Local sorghum variety plus their local cultivation practice
- Sorghum variety Hakika plus tied-ridges,
- Sorghum variety Hakika plus tied-ridges plus animal manure,
- Sorghum variety Hakika plus tied-ridges plus inorganic fertilizer (urea).

Farmers were provided each with 1kg of sorghum variety Hakika (*Striga* resistant) per treatment.

Mtinko Ward:

In the Mtinko ward two villages were also selected with the same number of farmer research groups as from the Sepuka ward. The villages were Mpipiti and Malolo; these villages lie in a relative moist area. Farmers in the Mtinko ward plant sorghum on flat land, hence ridging was a new technology for them. They were given each 1kg of sorghum variety Wahi (*Striga* tolerant variety) and the following were the treatments:

- Farmer variety plus flat planting
- Wahi plus flat planting
- Wahi plus tied-ridges
- Wahi plus tied-ridges plus animal manure

The size of each demo plot for Sepuka and Mtinko wards was 10 x 35m and 10 x 70m respectively. Data was collected from an area of 5 x 5 m from each treatment. Farmers did the management and running of the demonstrations themselves through their group leadership and with assistance from the extension officer.

Farmers responded very well to growing the new varieties. From Sepuka out of 23 farmers 16 farmers had established the demo plots, while from Mtinko ward 20 farmers out of 22 established the demo plots. There was drought immediately after planting in February. This affected the crop establishment and effect of inorganic fertilizer. Some of the farmers had to replant the crop. Later, normal rain resumed and the performance of the crop was very attractive especially when we made a mid-season evaluation with farmers at milk dough stage of the crop. This year was a non- *Striga* year and very few *Striga* plants were observed on the plots hence those farmers did not even bother to count them.

From the treatments at the two villages of Sepuka ward tied-ridges plus animal manure produced the same grain yield as the demo plots applied with urea and the difference was not statistically significant. The difference was significant between the use of fertilizer and without fertilizer (Table 3). The question for further expansion of the best treatment should consider the cost and availability of fertilizer.

From the Mtinko ward the combination of sorghum variety Wahi, tied-ridges and animal manure/urea application had the highest grain yield. Flat planting for both local and improved variety did not differ from each other in terms of grain yields (Table 4).

Tentative conclusions are as follows: farmers have liked the improved varieties because of the short texture, early maturity, bold white grains, easier to scare birds, they also stay green hence good for animal fodder.

From crop management practices, most of the farmers are convinced in using the new varieties, tied-ridges and animal manure. Farmers in this area are said to have enough animal manure; meanwhile urea is very expensive and not readily available at the village level. The urea we used for demonstrations cost 30 US$ of 50kg bag and it was only available at the district level. (Figure 1)

Plans made for future efforts in the ISM project in Singida district will include the following:

- Many farmers have asked for seed in the coming season and from the available seed we expect to reach up to 400 farmers.
- From the participating villages 100kg seed of each of the sorghum varieties have been harvested from isolated fields, bought by the project and treated for distribution to more farmers in the coming season.
- In the district there is a seed farm, which has agreed to produce seed of the two sorghum varieties Wahi and Hakika. We have promised to provide the seed farm with 100 kg and 50 kg of Hakika and Wahi respectively to multiply for the coming season.
- We expect to hold a stake holder's workshop late September on the marketing and utilization of sorghum for the two districts, Singida and Kongwa districts. We hope this

Table 3. Performance of Sorghum Variety Hakika against local variety under different crop management: Sepuka-Singida 2004.

Treatment	**VILLAGES**	
	Msungua	**Musimi**
Farmer variety and flat planting	1.7B	1.4B
Hakika flat planting	1.8B	1.4B
Hakika + tied-ridges + animal manure	2.7A	2.0A
Hakika + tied-ridges + Urea	3.0A	1.9A
Grand mean	**2.3**	**1.7**
CV	**25.0**	**19.2**

Numbers followed by the same letter did not differ significantly from each other at $p \leq 0.05$. NB I bag (50kg) of Urea cost 30 US $

Table 4. Performance of Sorghum Variety Wahi under different crop management: Mtinko-Sngida 2004

Treatment	**VILLAGES**	
	Malolo	**Mpipiti**
Farmer variety and flat planting	1.4B	0.8B
Wahi + flat planting	1.4B	1.3B
Wahi + tied-ridges	2.6A	2.2A
Wahi + tied-ridges + Animal manure	2.9A	2.9A
Grand mean	**1.7**	**1.44**
CV	**45.55**	**34.74**

Numbers followed by the same letter did not differ significantly from each other at $p \leq 0.05$

Figure 1. A farm family in Sepuka Ward in a plot of *Striga* resistant variety, Hakika, Singida 2004

will motivate farmers to produce more sorghum in the area because the major bottleneck of growing sorghum has been the availability of markets for sorghum. The participants will include those from the brewing industry, animal feed, food processors, traders, stockists, farmer research groups NGOs as well as policy makers.

Table 5. Amount of seed produced at the research station for on-farm demonstrations 2004-05

Variety	Quantity kg
Hakika	586
Wahi	338

Figure 2. A farmer in the Mtinko Ward , Singida in a plot of *Striga* resistant sorghum variety, Wahi, just prior to harvest, Singida, 2004.

- Amount of seed produced at the station during the 2004 season to be used for on-farm demonstration at the three sights Singida (Figure 2), Kongwa and Missungwi-Mwanza for 2004/2005 season as shown in Table 5.

In Kongwa district, a total of 16 farmers were recruited to participate in the ISM on-farm trials, but only 15 farmers eventually succeeded in implementing the project as agreed. The season was not a normal one because rainfall was below the mean annual rainfall normally received for the area. Urea fertilization was used on all plots with *Striga* resistant cultivar, but because of the severe drought the biggest performance was shown due to use of flat versus ridge plots. The following data were collected from 15 farmer plots in three villages (five farmers from each village), and samples were collected from a plot area of $20m^2$:

Village	Tied-ridges (Kg)/plot	Flat (Kg)/plot
Sejeli	4.24	3.24
Manuugu	5.22	3.69
Vilundilo	5.00	3.84

In the Lake Zone area, demonstration of the ISM package involving the *Striga* resistant sorghum cultivar (Hakika), nitrogen fertilization (urea), and a water conservation measure (tied ridges) was conducted in the Misungwi district and it started with 20 volunteer farmers from the division of Usagara.

The Division Extension staff and the office of the Executive Division in Usagara at their annual agriculture campaign motivated farmers in villages to volunteer in demonstrating technology packages where Hakika, a newly released sorghum variety, was selected. In this operation both researchers and extension staff were able to select only 20 farmers and were provided with seeds and fertilizers. These farmers came from Fela, Bujingwa, Kanyelele, Mwakalima, Nyamatala and Mwagala villages

Researchers and extension officers participated on enhancing the demonstration of technology packages through group seminars. Each farmer was advised to provide an area of about one acre but unfortunately we were late because most farmers had already prepared their land for planting during the short rains. Therefore farmers who prepared their land but not planted are the ones who participated in the demonstration and most of them had various sizes of land, which was less than one acre.

The inputs that were provided for each farmer were 2.5 kg of sorghum seeds, 7 kg of TSP and 20 kg of Urea. From land preparation till harvest extension staff, farmers and researchers all together supervised operations.

- Tied-ridges were among the package to be demonstrated to farmers; however few farmers were able to practice it because of the nature of their land/soil type selected for demonstration. For instance few farmers selected black *mbuga* or clay soils that are difficult to work in making ridges.
- Little knowledge of farmers on the actual area that covers 1 acre. Most of the volunteer farmers did not know what the actual size of an acre is. Areas they allocated were less than an acre. As a result, we decided that for uniformity, each participant would have half an acre. Other farmers planted their sorghum seeds in a very highly exhausted soil (poor sandy soils) coupled with poor management and received low or no yields at all.
- Severe drought this year affected grain yields.
- We had already organized one farmers meeting to share experience gained regarding demonstration of Technology Package
- Farmers had already sold sorghum grain they harvested as seeds to different stakeholders amounting to a total of about 1.5 metric tons at a price of T Shs 600 ($ 0.6) per kilogram

The Regional Commission of the Mara requested 10 tons of sorghum seed (Hakika) to be distributed to farmers in Mara region following similar procedure used in Usagara division-Mwanza region. In Usagara division where demonstration was conducted, farmers sold each kilo of sorghum at 600/= ($0.6) as seed a condition which motivated other farmers to join to be as a group for production of Hakika. So it showed that the price was the driving force to increase the number of farmers in the coming season.

Future plan

We need to promote sorghum utilization (products) to different stakeholders as we realize that many people are not aware of the white sorghum variety products in the Lake Zone. Many people perceive sorghum is 'brown' in color and produce brown hard porridge "Ugali". The Agricultural Research Institute at Ukiriguru will prepare different white sorghum varieties and some food products to be displayed during the Zonal Agricultural Show which will take place August 8th 2004 known as Nane nane show.

Since we know that in the lake zone there are two cropping seasons, the first season-short rains, starts mid October to mid November while the second season starts late January to early February. In our planning we concentrated with the short rains and took the crop calendar which goes along with the season.

Integrated *Striga* Management (ISM) Pilot Project in Eritrea

Tesfamichael Abraha, Goitom Ghobezai, and Tewolde Gebreselassie

Sorghum [*Sorghum bicolor* (L.) Moench] is the most important cereal crop in Eritrea. It is the staple food for the majority of the people in the country. The parasitic weeds *Striga hermonthica* (Del.) Benth. are a major biotic constraint to cereal production in general and sorghum production in particular, especially in the potential sorghum growing areas where continuous cropping as a result of increasing population density and mono-cropping has led to widespread soil infertility. The *Striga* problem is more aggravated by stress condition where the country faces moisture stress once in every three years. Yield losses due to *Striga* can be up to 100%. *Striga*-resistant sorghums would be an important component of integrated *Striga* Management.

Adoption of the improved *Striga*-resistant sorghum varieties by farmers in each target region and their cultivation using integrated *Striga* control practices will improve household food security and income stability.

Based on these aspects the following *Striga* control measures were suggested and proposed by the INTSORMIL-NARI collaboration programs.

- Advanced sorghum varieties that show better resistance to *Striga* (P-9401, P9405, P9406 and P 9407)
- Water conservation methods (tied ridges or other alternative conservation techniques)
- Fertility improvement through fertilizer application (DAP and Urea)

The overall objectives of the program are:

- To minimize yield loss due to *Striga*
- To maximize sorghum production and thereby enhance food security.

This *Striga* project is purely participatory approach, which will be sustainable and demonstrate to the farmers whose field is severely affected by *Striga*. In the year 2003 rainy season it was planned initially to start the project with 100 farmers to be selected from different sub zones of Gash Barka and the Southern zones. After this initial popularization of the program many farmers are expected to be involved in the project. The following considerations were taken while selecting farmers' field:

- The selected farmer's field should be a *Striga* infested site
- The site selected should have an access to transport for supervision and observation by the farmers community
- The selected farmer will cooperate in implementing the

project successfully in his ½ hectare of land

- Selected farmers will receive different packages for *Striga* control measures, and be fully involved in all the management and popularization of the practice

The Pilot Project was started late in July and planting at farmers field was done between the end of July and the first week of August. The main reasons for the late planting were:

- Budget for the project implementation was delayed
- The additional advanced sorghum varieties for *Striga* resistance were sent in mid-July
- Farmers' and site selections for *Striga* infested plots were carried out later than the normal planting time

Because of these reasons most of the farmers, particularly in the *Striga* -infested sites, planted before the project was started. Though we were late it was decided to minimize the number of farmers to be 50-60 in Gash Barka (Sub zoba Goluj and Shambuko) but to postpone the Southern zone program. (Tables 6, 7 and 8)

Conclusion:

The project is at its starting point and much work still remains to be done. From the preliminary observation of the 2003 cropping season the integrated *Striga* management packages as well as the *Striga* resistant varieties are well accepted by the farmers who were involved in the pilot project. It is recommended therefore to further push the project among additional farmers.

For the coming 2004 rainy season we have collected from specially selected farmers' fields for all the agronomic and isolation practices about ten quintals of the four Purdue *Striga* resistant varieties. Much of the seed collected was for the variety P9407 that performed better in the previous ISM pilot project program.

For the sustainable continuation of the project we strongly recommend the following points:

- In the cropping season of 2003 only four members of the task force actively participated in implementing all the ac-

Table 6. Farmers Involvement in Integrated *Striga* Management in Zoba Gash-Barka, Variety by area planted, 2003 rainy season

Sub Zoba	Variety Type given	Villages	Farmers involved	Area covered (hectares)
Goluj	P-9401	1. Tebeldia 2. Omhajer 3. Goluj	3	1.5
Goluj	P-9405	1. Tebeldia 2. Gergef 3. Omhajer 4. Goluj 5. Sabunite	12	8.5
Goluj	***P-9406***	1. Tebeldia 2. Gergef 3. Omhajer 4. Goluj	10	7.0
Goluj	***P-9407***	1. Tebeldia 2. Gergef 3. Omhajer 4. Goluj	11	8
Shambuko	*P-9401* P-9405 P-9406 P-9407	Dembe Asmara	10	5
	Total		46	30

Table 7. Farmers Involvement and input Distribution in Integrated *Striga* Management in Zoba Gash-Barka

Zobas	Sub Zoba	Area Covered (hectares)	No. of farmers involved	Seed distributed (quintals)	Fertilizer (DAP and Urea distributed (quintals)
Gash Barka	Goluj	25	36	3.0	25 (DAP) and 12.5 (Urea)
	Shambuko	5	10	0.7	5 (DAP) and 2.5 (Urea)
	Total	**30**	**46**	**3.7**	**30 (DAP) and 15 (Urea)**

Remark: Seven farmers in sub zoba Goluj were given inputs for one hectare.

Table 8. Demonstration ISM in Zoba Gash Barka 2003 Cropping Season

Sub Zoba	Varieties	No. of sorghum plants/plot ($2m^2$)	*Striga* count/plot ($2m^2$)	Yield ranges Quintal/hectare
Goluj	P-9406	20	8	0.3 – 3.3
	Local	20	68	0.0 – 1.2
	P-9407	30	9	2.0 – 13.0
	Local	34	88	0.0 – 3.0
	P-9405	21	2	1.0 – 2.0
	Local	26	127	0.0 – 1.5
	P-9401	25	43	1.0 – 5.0
	Local	30	249	0.0 – 1.5
Shambuko	P-9407	NA	NA	3.0 – 8.0
	Local			0.0 – 2.0

N.B

1. The low yield levels are not only due to *Striga* infestation but also because of moisture stress, late planting and low population density that was damaged by grasshopper at the seedling stage.
2. About 15 hectares failed completely due to moisture stress and grasshoppers.

tivities. Hence all the task force members for this project should participate.

- We recommend that the Ministry of Agriculture to declare the ISM packages to be applied as a national campaign and all concerned Zoba heads, Administrators, Extension workers and NGO's to be aware and participate in this pilot project.
- Budgeting, project activities and logistics to be implemented as per the project planned.

Pearl Millet Breeding Activities 2003

Negussie Abraha

Pearl millet (Pennistum glaucum) has protogynous nature of flowering and is grown mainly for grain in the tropical and sub-tropical areas of Africa and in the Indian sub-continent. It is an indispensable food for millions inhabiting the semi-arid and arid tropics and is more important in the diet of the poor (Harinarayana, 1987).

Pearl millet is the second largest food crop in Eritrea, grown mainly by small farmers in lowlands and midlands. Landraces currently grown by the farmers contain the traits that farmers have selected for centuries, and thus represent a very valuable resource for the breeding program. However, because of the cross-pollinated nature of the crop, such desirable traits may not exist in a high frequency in landrace populations and may be accompanied by various undesirable traits, such as susceptibility to downy mildew.

Pearl millet downy mildew, caused by the fungus, *Sclerospora graminicola,* is one of the major production constraints in pearl millet in most of the semi-arid tropics (Singh et al., 1993). Downy mildew is widely spread in Eritrea and occurs in epidemic form on farmer landraces, making it the major millet disease in Eritrea. Surveys conducted in 1999 and 2000 showed high levels of downy mildew incidence ranging from 30% to as high as 70% in farmers' fields.

The Eritrean pearl millet breeding program, which started its research and breeding activities in early 2000, seeks to produce adapted, disease resistant pearl millet varieties, acceptable to farmers, that will help to increase and stabilize millet productivity in Eritrea. In this effort, local landraces and exotic cultivars were tested for their disease resistance and yield capabilities. Crosses were made between the exotic and local landraces to increase disease resistance and productivity of the landraces.

In the rainy season of 2003, landraces, exotic varieties, new population crosses and top-cross hybrids were tested on-station and on-farm trials for their adaptability, disease resistance, yield potential and to assess the farmers' perception of the positive and negative aspects of the new crosses.

The on-farm trials were conducted at 13 sites in Zoba Anseba (four in sub-Zoba Hagaz, three in sub-zoba Hamelmalo, three in sub-zoba Keren and three in sub-Zoba Elabered) and eight sites in Gash Barka (two sites in Mogollo, Gogne, Barentu, Shambiko sub-zobas). Plot size was 50 meters square (5m x 10m) and the plots were laid side by side. Extension personnel from the Ministry of Agriculture from these sub-zobas were entrusted with the responsibility of identifying farmers and conducting the trials.

The Hagaz Research site is located at an altitude of 850 m.a.s.l. with minimum and maximum temperatures of about 12°c and 42°c respectively. The average rainfall ranges from 300 – 400 mm/annum. The site has a typical arid and semi-arid climatic conditions, which is conducive for pearl millet research work. During the growing period (July 1- September 10, 2002) a total of more than 333 mm was recorded. Two hand weeding and cultivation were also done. Analysis of variance was computed using Gen-stat 5 software in all the trials.

The pearl millet breeding program in Eritrea conducts off-season nursery activities during the dry season with irrigation to initiate new experimental crosses and increase seed of breeding materials selected in nurseries during the main crop season.

Advanced Yield Trial of Exotic Varieties

The objective of this experiment was to identify genetic material that may be suitable for direct use as an introduction in some agro-ecological zones or to identify parental material with candidate traits for use in crosses with local landraces or other selections. Twenty-two experimental varieties were tested in this experiment. The design used was a RCBD with three replications. Spacing was 4m x 0.75m xs 4 rows. At the time of planting basal application of DAP at a rate of 100 kg ha^{-1} was applied. Thinning and transplanting were accomplished two weeks after planting. Top dressing of urea was applied at a rate of 100 kg per ha three weeks after planting. Observations were taken on the center two rows for days to 75% flowering, plant height, plant count, head count, head yield, ear length, and grain yield.

The results are reported in Table 9. In the analysis of variance for days to 75% flowering ($P < 0.001$) and agronomic scoring ($P < 0.001$), genotypes showed highly significant differences indicating that genetic variation influenced the maturity date and agronomic performance. Moreover, there was significant difference between genotypes for the trait grain yield ($P = 0.012$). However, there was no significant difference between the genotypes for the character plant height ($P = 0.09$).

Table 9: Result of Advanced Yield Trial of Exotic Varieties, Rainy Season, 2003.

Ent.	Entry Name	Flower Day (75%)	Plant Ht	Grain Yld Qt/ha	Agro. Score	Remark
1	ICMP 95490	48	207	25	4.7	*
2	ICMP 97754	49	207	18	5.3	
3	ICMP 98107	48	187	18	6.3	
4	EERC CO	44	161	20	6.5	
5	IAC ISC ICP 4	49	213	24	5.0	*
6	IAC ISC ICP 6	53	205	18	6.0	
7	Sudan Pop II	49	202	18	5.7	
8	EC 89 CO x MC 88 CO	45	188	28	5.5	
9	MC 89 CO x AIMP 92901	47	176	21	6.0	*
10	MC 89 CO x RCB IC 912	47	198	23	6.0	*
11	AIMP 92901 x SDMV 96063	47	200	24	5.5	*
12	SDMV 96063 x SDMV 95017	47	208	18	5.3	*
13	ICMV 97802	57	200	12	6.3	
14	ICMV 96601	48	211	24	5.0	*
15	ICMP 96611	48	200	22	5.0	*
16	ICMV 95846	43	193	13	7.3	
17	CZ IC 922	45	205	20	6.7	
18	ICMV 97801	60	220	15	7.0	
19	ICMV 91170	44	197	25	6.3	*
20	AIMP 92901	46	189	21	6.0	*
21	GICKV 93191	45	192	18	6.7	
22	ICMP 97774	46	200	22	5.7	*
	Grand Mean	48	198	20.32	5.9	
	LSD	3.183	28.77	7.9	1.13	
	Se					
	CV (%)					
	F. Prob (5%)	***	NS	*	***	

The variety EERC CO was the earliest to flower. However, it was the shortest in plant height and resulted in less biomass. This variety can be used as a source of genes for early maturity and future breeding efforts. The varieties ICMV 95846 and ICMV 91170 followed EERC CO in earliness and these materials can be used as source of genes for earliness.

When the trait grain yield was considered, the crosses EC 89 CO x MC 88 CO attained the highest grain yield. It was followed by the varieties IAC ISC ICMP 4, ICMV 96601 AND AIMP 92901 x SDMV 96063.

By considering the different traits, the following varieties were selected to advance to the coming rainy season for further evaluations. These are ICMP 95490, IAC ISC TCP 4, ICMV 96601, ICMP 96611, ICMV 91170, AIMP 92901, ICMP 97774, EC 89 CO x MC 88 CO, MC 89 CO x AIMP 92901, MC 89 CO x RCB IC 912, AIMP 92901 x SDMV 96063 and SDMV 96063 x SDMV 95017

Advanced Yield Trials of Population Crosses

The objective of this experiment was to identify the most promising population cross that can be grown in different millet growing environments. The experimental materials used were 26 with 4 landraces as checks. The experimental design used was RCBD with 3 replications. They were planted with spacing of 4m x 0.75m x 4 rows. Observations were recorded on the central 2 rows of each plot with the following characteristics: days to 75% flowering, plant height, plant count, head count, panicle count, panicle yield, panicle size, 100 seed weight and grain yield. To maintain soil fertility, 100kg ha^{-2} DAP before planting and 100 kg ha^{-2} urea three weeks after planting were applied. Thinning and transplanting were done two weeks after planting. It was cultivated once and hand weeded twice.

The analysis of variance (Table 10) or days to 75% to flowering, plant height showed highly significant difference between genotypes ($P < 0.001$) indicating that plants reach 75% flowering date at a different time and the genetic makeup had influenced the biomass production. Moreover, the trait of agronomic scoring also showed significant difference ($P = 0.025$) between the genotypes. However, there was no significant difference for grain yield ($P = 0.122$).

Comparisons between the genotypes were made. When days to 75% flowering were considered, the earliest varieties

Table 10: Result of Advanced Yield Trial of Population Crosses, Rainy Season, 2003.

Ent.	Entry Name	Flower Day (75%)	Plant ht (cm)	Grain Yld Qt/ha	Agro. Score	Remark
1	Tosho x IAC ISC TCP 1	49	218	14	6.3	
2	Tosho x MC SRC	48	225	18	6.0	*
3	Tosho x Sudan pop I	51	225	12	6.0	
4	Tosho x SOS AT C88	51	210	9	6.5	
5	Mebred x IAC ISC TCP 1	53	233	15	5.7	
6	Mebred x MC SRC	52	240	17	5.0	*
7	Mebred x Sudan pop I	52	222	17	6.0	*
8	Mebred x SOS AT C88	54	229	21	6.0	*
9	Ashera x ICMP 91170	47	218	20	5.3	*
10	Ashera x AIMP 92901	48	214	22	6.0	*
11	Ashera x GICKV 93191	48	215	16	6.3	
12	Ashera x ICMP 97774	48	219	17	6.3	*
13	Libana x ICMP 91170	48	210	21	5.7	*
14	Libana x AIMP 92901	48	199	23	5.7	*
15	Libana x GICKV 93191	48	207	19	5.0	*
16	Libana x ICMP 97774	52	212	15	5.5	
17	Jengeren x ICMP 91170	48	228	19	6.7	*
18	Jengeren x AIMP 92901	48	212	19	5.3	*
19	Jengeren x GICKV 93191	48	225	16	6.7	
20	Jengeren x ICMP 97774	49	208	18	6.0	*
21	Mogollo II x ICMP 91170	46	191	15	7.0	
22	Mogollo II x AIMP 92901	43	187	16	6.7	*
23	Mogollo II x GICKV 93191	45	192	16	6.7	
24	Mogollo II x ICMP 97774	45	204	14	6.7	
25	Mebred x Kona (C2)	49	214	13	6.5	
26	Zibedi x Kona (C2)	49	206	16	5.3	
27	Ashera (LD)	51	220	17	6.0	
28	Libana (LD)	55	238	22	5.0	
29	Jengeren (LD)	51	234	13	6.7	
30	Mogollo II (LD)	47	181	13	7.3	
	Grand Mean	49	215	16.8	6.1	
	LSD	2.6	24.2	7.8	1.3	
	Se					
	CV (%)					
	F. Prob (5%)	***	***	NS	*	

Table 11: Results of Advanced Yield Trial with New Pearl Millet Top-Cross Hybrids, 2003, RS.

Ent. No.	Entry Name	Flower Day (75%)	Plant Ht (cm)	Grain Yld Qt/ha	Agro. Score Rank	Remark
1	Tosho x ICMA 89111	49	217	31	5.3	*
2	Tosho x ICMA 95333	48	216	26	5.7	*
3	Tosho x ICMA 97333	50	227	36	4.7	*
4	Tosho x ICMA 91222	49	214	24	5.7	
5	Tosho x ICMA 97111	52	225	25	6.0	
6	Mebred x ICMA 89111	52	223	24	6.3	
7	Mebred x ICMA 95333	55	205	29	5.7	*
8	Mebred x ICMA 97333	50	221	31	6.0	*
9	Mebred x ICMA 91222	50	215	31	6.0	*
10	Mebred x ICMA 97111	53	229	23	6.3	
11	Zibedi S x ICMA 97111	45	201	26	6.0	*
12	Zibedi S x ICMA 92444	48	202	24	6.0	
13	Kona x ICMA 95333	48	218	23	6.0	
14	Kona x ICMA 97333	54	223	21	5.0	
	Grand Mean	50	217	27	5.8	
	LSD	8.9	20.79	7.5	1.2	
	Se					
	CV (%)					
	F. Prob (5%)	***	NS	*	NS	

was Mogollo II x AIMP 92901. The latest and the tallest population cross was Libana which is one of the parents.

When the grain yield was considered the population cross Libana x AIMP 92901 attained the maximum yield (23 qt/ha) followed by Ashera x AIMP 92901 (22 qt/ha) and Libana (22qt/ha).

By considering all the characters, 15 population crosses were selected for the coming rainy season to be tested as advanced yield trial. These are: Tosho x MC SRC, Mebred x MC SRC, Mebred x Sudan pop 1, Mebred x SOS AT C88, Ashera x ICMP 91170, Ashera x AIMP 92901, Ashera x ICMP 97774, Libana x ICMP 91170, Libana x AIMP 92901, Libana x GICKV 93191, Jengeren x ICMP 91170, Jengeren x AIMP 92901, Jengeren x ICMP 97774, Mogollo II x AIMP 92901.

Advance Yield Trial of New Top-Cross Hybrids

The objective of this experiment was:

- To combine the stress-adaptive traits of farmers' own landraces with improved grain yield and disease resistance that landraces often lack.
- To develop landrace-based Topcross hybrid which exploits heterosis between adapted, dual-purpose male-sterile lines and pollinators derived from local landraces.

The experimental materials used were 10 + 8 (checks) which were developed from crosses of two selected landraces and five male-sterile lines. The experimental design used was RCBD with three replications. Spacing was 4m x 0.75m x 4 rows. At the time of planting basal application of DAP at a rate of 100 kg ha^{-2} was applied and after two weeks thinning and transplanting were done. Top-dressing at a rate of 100kg ha^{-2} urea was given three weeks after planting.

Results showed days to 75% flowering ($P < 0.001$) with highly significant difference and grain yield showed significant ($P = 0.015$) difference between the genotypes indicating that genetic variation had influenced maturity date and grain yield. However, there were no significant differences between the genotypes for the traits plant height ($P = 0.156$) and agronomic scoring ($P = 0.262$).

The earliest top-cross hybrid was Zibedi S x ICMA 97333 which attained a medium plant height with satisfactory grain yield as compared to other hybrids. It was followed by the hybrids Tosho x ICMA 95333, Zibedi S x ICMA 92444 and Kona x ICMA 9533. These hybrids had reasonable grain yield. These four hybrids can be considered as early hybrids and can be recommended during the short season.

When grain yield was considered, the hybrid Tosho x ICMA 97333 attained the highest performance (36 qt/ha). It was followed by Tosho x ICMA 89111, Mebred x ICMA 97333 and Mebred x ICMA 91222.

We can conclude that the male sterile lines (MS-Lines) ICMA 97333, ICMA 89111, ICMA 97333 and ICMA 91222 can be used as best materials for the development of Top-cross hybrids. They could be crossed with adaptable varieties from the region. This type of approach could be applied in the developing countries of Africa. Single cross hybrid development could be difficult and costly (John Withcombe and Tom Hash, personal com, Bangor Uni. ICRISAT respectively). Two rows for days to 75% flowering, plant height, plant count, head count, head yield, ear length and grain yield. The materials used in this trial are listed in Table 11.

Seed Multiplication

The pearl millet breeding program assists with multiplication of foundation seed for the Ministry of Agriculture (MOA). The MOA receives foundation seed from NARI to produce certified seed, which is produced by farmers on contract. The MOA purchases seed from farmers at the market price rate +25% premium price. Based on such an arrangement, the pearl millet improvement program produced foundation seed in three stations during the 2003 cropping season.

At the Hagaz Station, the improved variety Hagaz had wide acceptance by farmers in the region.

At Shambiko Research Station, the varieties Hagaz and Kona were sown on 6 ha for foundation seed production. At the end of the season, about 15 qt Hagaz variety and 4.5 qt Kona variety seed was produced. At Golij Research Station, the Hagaz variety was sown on 10 ha for foundation seed production. In spite of the moisture stress during the season in the area, about 60qt of foundation seed was produced.

Southern Africa (Botswana, Namibia, South Africa, Zambia, Zimbabwe)

Gary C. Peterson
Texas A&M University

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Collaborative Program

Organization, Management, Implementation and Financial Inputs

The INTSORMIL Southern Africa regional program involves five projects:

Pearl Millet Breeding: Development of pearl millet cultivars for dryland production, commercialization and industrial development in Southern Africa

Pathology: Disease management research, identification and use of resistance

Food Quality: Cultivar food quality, milling technologies, sorghum and pearl millet food nutritional value

Entomology: Genetic resistance to sugarcane aphid and integrated pest management in Botswana and South Africa

Sorghum Breeding: Development of improved sorghum varieties and hybrids for Southern Africa

The INTSORMIL Southern Africa program has been organized to be fully integrated with, and operate in conjunction with, SADC/ICRISAT/SMIP activities located at the ICRISAT Center, Matopos, Zimbabwe. Work plans for each INTSORMIL project are developed based on regional needs and the expertise of the scientists involved. Through the SMINET regional coordinator (located at Matopos) the SMIP Technology Transfer Program (SMINET) Steering Committee reviewed each work plan to ensure it was responsive to regional pearl millet and sorghum research needs. Through a Memorandum of Agreement INTSORMIL funds were disbursed through ICRISAT/Matopos to 10 collaborating scientists affiliated with seven research agencies in four countries. Since ICRISAT has no core funded pearl millet or sorghum scientists in the SADC region and SMIP Phase IV focused entirely on technology transfer. INTSORMIL participation in Southern Africa is critical to maintaining and improving the knowledge base of pearl millet and sorghum in the region. With the formal end of SMIP activities in December 2003, INTSORMIL will provide additional leadership to regional pearl millet and sorghum research and technology transfer. INTSORMIL will collaborate with ICRISAT regional activity as appropriate and mutually beneficial, and will continue to develop linkages with other agencies to strengthen regional research and technology transfer.

Through integration with SMINET complementary with existing regional pearl millet and sorghum programs was achieved. This complementary enabled both organizations to capitalize on their relative strengths for greater benefit to the region. Collaborating organizations for each regional project are:

Pearl millet breeding - Ministry of Agriculture, Water and Rural Development, Omahenene Research Station, Outapi, Omusati Region, Namibia; Department of Agricultural Research, Botswana;Ministry of Agriculture, Kaoma Research Station, Kaoma, Zambia

Pathology - ARC-Summer Grain Crops Institute, Potchefstroom; South Africa (SA) Crops and Soil Research, Mt. Makulu Research Station, Chilanga, Zambia; Department of Agricultural Research, Gaborone, Botswana; Medical Research Council, Tygerberg, SA

Food quality - University of Pretoria CSIR (SA); ARC-Summer Grain Crops Institute

Entomology - ARC-Summer Grains Crop Institute; Botswana College of Agriculture, Gaborone, Botswana; North West University, Potchefstroom

Sorghum breeding - Ministry of Agriculture/Golden Valley Research Trust, Zambia; Department of Agricultural Research, Botswana

With the dissolution of SMIP and SMINET work plans are now reviewed by the regional coordinators. Fund transferred through ICRISAT/Bulawayo ended on June 30, 2004.

Institution Building

Equipment

- INTSORMIL purchased a MaxiMil Roller mill and Auger for the Food Quality program at the University of Pretoria.
- INTSORMIL purchased a trailer to transport equipment, supplies, and grain for the Zambia breeding program.

Visits

- Dr. John Taylor (University of Pretoria) attended the American Association of Cereal Chemists annual meeting in Portland, Oregon in September 2003. He also visited with Dr. Bruce Hamaker and Dr. Gebisa Ejeta at Purdue University to discuss collaborative work, particularly on protein quality and injera-making quality of sorghum.
- Dr. Gary Peterson (Texas A&M University) visited Zambia, Botswana, Namibia, and South Africa to review research progress and plan the EEP review, November 2003. Dr. Medson Chisi (Zambia) participated in the meetings in Botswana, Namibia, and South Africa.
- Dr. John Leslie visited South Africa in November 2003 to review current research and plan future research with collaborators at the ARC-Grain Crops Institute at Potchefstroom and the Medical Research Council at Tygerberg.
- Dr. Tom Crawford (University of Nebraska Management Entity) participated in the closing meeting of SMINET (Sorghum and Millet Improvement Network) at Bulawayo, Zimbabwe, November 2004.
- Dr. Medson Chisi (Zambia), Dr. Gary Peterson (Texas A&M Univ.), and Dr. Tom Crawford (Univ. of Nebraska Management Entity) evaluated the Mozambique sorghum-breeding program and presented results of the evaluation to Dr. Calisto Bias, INIA Director, in February 2004. Dr. Chisi participated in the EEP review in Zambia and South Africa.
- Mr. S.A. Ipinge (Namibia) and Mr. Michael Mogorosi (Botswana) participated in the INTSORMIL External Evaluation Panel (EEP) review of their collaborative activities during the EEP visit to Zambia, March 2004.
- Dr. John Taylor (Univ. of Pretoria), Mrs. Janet Taylor (University of Pretoria), Dr. Stephen Chite (Botswana), Dr. David Munthali (Botswana), Ms. Phoebe Ditshipi (Botswana/Univ. of the Free State), Dr. Neal McLaren (ARC), Ms. H. du Plessis (ARC), and Dr. J. v.d. Berg (North West Univ.) participated in the EEP review at the Cedara Experimental Station in KwaZulu-Natal, South Africa in March 2004. The University of Pretoria hosted the EEP and INTSORMIL scientists and staff at the University of Pretoria where Dr Taylor's INTSORMIL research was re-

view. The EEP was also hosted by the Medical Research Council, Tygerberg, SA, where the research of Dr. Wally Marasas and associated was review.

- Dr. Jeff Wilson (USDA-ARS) participated in the EEP review in Zambia of regional pearl millet breeding activity. Following the review Dr. Wilson, Mr. Ipinge (Namibia), Mr. Muuka (Zambia), and Mr. Mogorosi (Botswana) toured the Nambia pearl millet growing research and research stations, March 2004. Dr. Wilson met with Mr. Simon Awala, the new Namabian pearl millet breeder, to establish collaboration and plan a short-term training assignment.
- Dr. Bonnie Pendleton (West Texas A&M University) and Dr. John Leslie (Kansas State University) participated in the EEP review at Cedara and Tygerberg, respectively. Dr. Pendleton also conferred with collaborators at Potchefstroom and Gaborone. Dr. Leslie also conferred with collaborators at the Univ. of Pretoria.

Short-term Training

- Twenty students from sorghum beer brewing companies in five SADC countries took the Certificate Course in Opaque Beer Brewing conducted by the University of Pretoria.
- Eduardo Aizequi Lameque Joaquim, Rodrigues Joã Mambonhe, and Flemming Nielsen (all from Mozambique) visited the Zambia sorghum breeding program 2-8 May 2004. A number of sorghum lines that may be useful in Mozambique were identified and will be sent to Mozambique before the next growing season. The Zambia sorghum breeding program will continue to share germplasm, trial results, and expertise with any program in the region.
- The Zambia sorghum-breeding program in cooperation with World Vision International (WVI) conducted a workshop on "Sorghum Seed Production and Managing On-farm Research Trials". There were 17 participants (including three females) in the workshop. The main objective was to assist WVI with their outreach program in seed production and seed availability to small farmers. Advanced pre-released lines from the breeding program will be evaluated by WVI in on-farm trials.

Long-term Training

- Students are in graduate degree programs (either M.S. or Ph.D.) at institutions in the region (University of Zambia, University of the Free State (South Africa), University of Pretoria (South Africa) and in the U.S. (Texas A&M University). The students are supported either fully or partially by INTSORMIL, or work on sorghum and pearl millet research problems of direct benefit to the INTSORMIL program. Students from Mozambique are in USAID Mission (Maputo) training program. The students begin returning to Maputo in August 2004 and will initiate programs as INTSORMIL collaborators.

Seed Increase

- Availability of high quality seed for distribution to farmers continues to hinder adoption of improved varieties and is a major challenge to breeding programs. Local seed companies cite low demand as the reason to not produce seed. The Zambia breeding programs work with INTSORMIL to increase and distribute seed of improved varieties. With INTSORMIL support a Revolving Seed Fund has been established to support the cost of increasing seed. Following harvest the seed is cleaned, packaged, and sold to NGO's with proceeds going back into the Revolving Fund to support future increases. In 2003/04 season NGO's such as WVI, GTZ and Oxfam were involved in seed production of released open pollinated varieties. The following varieties were increased at Golden Valley: Kuyuma (2750 kg available), Sima (850 kg), ZSV-15 (1250 kg), ZSV-35 (1100 kg), and WP-13. Additionally, Zamseed produced seed of a hybrid MMSH-375 on six hectares but the quantity of seed available was not known at the time this report was prepared. For pearl millet three tons of the variety Lubasi was produced with INTSORMIL support.

Sorghum and Pearl Millet Constraints Researched

Production and Utilization Constraints

Sorghum and pearl millet are major food crops in the SADC region, and sorghum is used to make opaque beer. Sorghum is also used to a certain extent as a livestock feed. Sorghum is the major cereal in Botswana and parts of Zambia, Mozambique, Malawi, and Tanzania, while pearl millet is the major cereal in Namibia and parts of Tanzania, Mozambique, Zambia, and Zimbabwe.

Many constraints associated with low resource agriculture are present including low grain yield potential, infertile soils, variable moisture availability, numerous insect pests and diseases, poor grain quality, lack of improved seed, and poor distribution and market structures. Genetic improvement and better disease or insect management can economically address some constraints by increasing grain yield potential and stress resistance and by improving grain quality to meet end-use requirements. However, market channels need to be improved since sorghum varieties with the required quality to meet commercial consumer requirements frequently have inconsistent production and supply. The inconsistent supply of quality grain is frequently cited as a major factor in deciding to use maize as opposed to sorghum. Availability of a consistent supply of improved quality sorghum and pearl millet for processing into value added urban products is a major problem limiting utilization. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. A strong need exists for developing a system of identity preservation for production, marketing, and processing.

New varieties and hybrids with increased grain yield potential, improved environmental adaptation, increased resistance to abiotic (drought tolerance) or biotic (disease and insect) stress, improved end-use traits (for food, feed and forage), and other desirable traits are in development by national programs. Exotic sorghums and pearl millets are continually introduced into the SADC region as sources of needed traits. Identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will assist the NARS teams in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and in similar SADC environments. Research is on-going to improve disease and insect pest management and to improve sorghum and pearl millet processing techniques to improve use in value added foods.

Constraints Addressed by Project Objectives

Pearl Millet Breeding: Develop topcross grain and forage hybrids adapted to low rainfall regimes in Southern Africa with the potential to transform the crop from subsistence to commercial status through commercialization and stimulating industrial development, test prototype cultivars in commercial and industrial ventures, and develop appropriate populations for sustaining the program. Important traits are yield, early maturity, and grain size.

Pathology: Identify adapted, agronomically desirable sources of resistance to major foliar pathogens and charcoal rot, including drought tolerance and resistance to sugarcane aphid where feasible. Determine disease vulnerability of recently released sorghums and the need for better sources of resistance. Determine mycotoxin production capabilities of new *Fusarium* species, and the presence of *Fusarium* mycotoxins in molded grain. Develop appropriate control measures for economically important diseases.

Food Quality: Determine the physical, chemical and processing properties of local and improved sorghum and millets. Improve the quality of food products by modification of processes to reduce or eliminate anti-nutritional components. Summarize existing information on quality and utilization, and transfer the information on utilization quality to potential users.

Entomology: Reduce yield losses by identifying, evaluating, and incorporating sugarcane aphid resistance into adapted sorghum varieties and hybrids. Assess the response of sorghum varieties and segregating populations to other insect pests as appropriate. Develop integrated pest management strategies for sorghum insect pests in Southern Africa.

Sorghum Breeding: Develop high grain yield sorghum varieties and hybrids with improved stress resistance (disease, insect, drought), improved environmental adaptation, and improved end-use quality traits for food, forage and feed for drought prone areas. Maintain pre-basic and basic seeds of all released and pre-released varieties, hybrids and their parents, and assist with seed production and distribution systems at a community level. Develop appropriate agronomic management practices based on the farming system and assist in technology transfer.

Mutuality of Benefits

The collaborative Southern Africa regional program provides reciprocal mutual benefits in breeding, plant pathology, entomology, and food science. The benefits strengthen both the host country and U.S. based programs. In plant breeding a free and unhindered exchange of germplasm occurs. The U.S. based programs have access to germplasm with biotic and abiotic stress resistance sources and well as the opportunity to evaluate germplasm in a diverse set of environments. The host country programs gain access to a wide-array of new technology, germplasm, and gene combinations not present within the country. Much of the research knowledge used in the U.S. for ergot is a direct result of INTSORMIL collaboration with scientists in South Africa. Their expertise assisted the U.S. industry in managing the disease. Collaborating scientists benefit through access to new research technology, germplasm, and reciprocal visits. Entomology research in integrated pest management and host plant resistance uses methodology developed in the U.S. and modified for the pests of Southern Africa. Knowledge gained through the research will benefit the U.S. should the insect pests be introduced into the U.S. The excellent working relationships between the entomologists enable them to exchange research ideas, methodology, and knowledge. The food quality program provides training and expertise at a level not found in the U.S. Students conduct research, supervised by local and U.S. scientists, to understand how to improve the processing of sorghum and pearl millet and to develop new uses for both crops. The information gathered in the program is potentially beneficial wherever sorghum and pearl millet are grown.

Research Progress

The collaborative research program goal is to develop the technology for increased production and use of pearl millet and sorghum. Component projects conduct research specific to the project goals but which has implications to research in other projects. Projects interact to develop new technology and the interaction should increase as additional opportunities and funding become available. The local scientists are encouraged to collaborate across country boundaries.

The Texas A&M University/Texas Agricultural Experiment Station sorghum-breeding program distributes tests and nurseries based on requests from individual collaborators. Multilocation testing establishes base-line data for performance response of introduced germplasm throughout the region. Germplasm suitable for direct use or use as parental lines in a breeding program is identified. Disease pathogen race and insect biotype distribution can be established as well as identification of resistance sources. Regional research is conducted under rain-fed conditions with little if any supplemental irrigation. Thus reporting of results is frequently contingent on timely rainfall sufficient to produce the environment necessary for evaluation.

Pearl Millet Breeding

Zambia

Pearl millet is the third most important traditional cereal food crop after sorghum and finger millet. It is cultivated in low input farming systems and in communities experiencing high poverty levels (more than 80%), endemic malnutrition, and poor agricultural services and delivery systems. Abiotic constraints include poor soil fertility; low soil pH and erratic rainfall while the major biotic constraints are downy mildew, ergot, and smut. The lack of improved seed which affects productivity and production. The breeding strategy involves developing suitable topcross R_4 (cytoplasm) restorer parents from adapted Zambian genetic stocks which can then be crossed with suitable exotic A_4 CMS seed parents to produce hybrids.

The A_4 CMS seed parents 79-2068 A_4, 1163 A_4, 88006 A_4, and 8401 A_4were used in making all possible hybrid combinations with ten diverse potential topcross pollinators (NEC, Lubasi, ZPMBC, ZPMDC-C_2, NLC, Tuso, NLoC, Sepo, ZPMV 92008, and Oksahans-1). In addition, two A_1 CMS seed parents 79-2068 A_1 and 1163 A_1 were also used. The hybrids were evaluated in two trials to assess the combining ability of the parental lines and identify superior hybrid combinations.

In the first hybrid trial for seed parents hybrids based on 1163 A_4 were generally superior (3962 kg/ha^{-1}) to those from 79-2068 A_4 (3588 kg/ha^{-1}), 8401 A_4 (3437 kg/ha^{-1}), and 888006 A_4. In the second hybrid trial parental performance was inconsistent compared to the first trial. Performance of the A_1 CMS system was also inconsistent within and between trials as well as in comparison with the A_4 CMS system. The results generally conform with those from the previous season. For pollen parents in the A_4 CMS-based trial hybrids derived from ZPMDC-C_2 (4638 kg/ha^{-1}) were superior to those derived from Tuso (4414 kg/ha^{-1}) and Sepo (3990 kg/ha^{-1}). In the second trial the best pollinators were NEC (3747 kg/ha^{-1}), ZPMBC (3348 kg/ha^{-1}) and ZPMDC-C_2. There was no consistent superiority for grain yield across pollinators and trials for the A_4 CMS system over the A_1 CMS system. Male parent heterosis for grain yield ranged from -39 to 212%. Ergot was prevalent mainly on late tillers with incidences of up to 60%. A few hybrids showed incidences of smut up to 16%. These preliminary findings highlight the possibility of the existence of superior specific hybrid combinations in both the A_1 and A_4 CMS systems but do not take into consideration the established merits of the A_4 over the A_1 system.

Namibia

The program has three major objectives: develop top-cross hybrids by breeding A_4 restorer versions of the best Namibian varieties for use with selected A_4 seed parents, develop and test prototype hybrids using SMIP A_4 seed parents, and identify the best A_4 F_1 male sterile seed parents. The program is in transition between breeders but working to achieve its research objectives. Mr. S.A. Ipinge has been reassigned as Deputy Director, Ministry of Agriculture, Water and Rural Development. Mr. Simon Awala, previously a technician in the breeding program, completed his B.Sc. degree and is now the pearl millet breeder. Mr. Awala has established collaboration with Dr. Jeff Wilson and will participate in a short-term training assignment with Dr. Wilson.

During the 2003/04 cropping season several crosses were made to develop test varieties. Additionally, test varieties from the 2001/02 cropping season were increased so that all varieties could be entered in multi-location variety trials during the 2004/05 cropping season. The new entries will be tested at three major sites - Omahenene, Okashana, and Mashare to compare grain yield performance and adaptability against the standard checks.

Botswana

A major objective of the program is to identify hybrids with high grain yield potential and adaptation to the areas of Botswana where pearl millet is an important crop. A pearl millet hybrid trial consisting of 25 hybrids obtained from SADC/ ICRISAT at Matopos, Zimbabwe was planted and data collected on days to 50% anthesis, plant height, and grain yield. Significant differences were identified for the traits studied. Grain yield ranged from 1600 kg/ha^{-1} to 4440 kg/ha^{-1}. Three hybrids produced over 3,000 kg/ha^{-1} of grain - SDMH 99001 at 4,440 kg/ha^{-1}, SDMH 90005 at 3,381 kg/ha^{-1}, and SDMH 91008 at 3,141 kg/ha^{-1} and were significantly better than the farmer's local check and the experimental entries SDMH 99004, and Okashana-1 at 1,600, 1,600, and 1,627 kg/ha^{-1} respectively. The hybrid SDMH 99001 produced significantly more grain than all but one other entry (SDMH 90005 at 3381 kg/ha^{-1}). The hybrids SDMH 99001 and SDMH 90005 produced significantly more grain that the local farmer's produced the lowest grain yield (kg/ha^{-1}), was the tallest, and was one of the latest entries in the test. Hybrids have the capability of significantly increasing the production of pearl millet grain in Botswana.

Pathology

Research on diseases affecting sorghum and pearl millet is conducted throughout Southern Africa. The pathology program has active research programs in Zambia and South Africa. The primary Botswana collaborator is currently in a Ph.D. program at the University of the Free State, Bloemfontain, South Africa. Field pathology research is supported by Texas A&M University through planting standard replicated nurseries or tests such as the ADIN (All Disease and Insect Nursery), GWT (Grain Weathering Test), and the ARGN (Anthracnose Resistance Germplasm Nursery). The replicated tests are usually planted at more than one location and data compiled to study germplasm environmental response and pathogen distribution. Major activity on fusarium research is conducted in South Africa (Medical Research Council) and through collaboration with Kansas State University.

Zambia

Primary emphasis of the program is to evaluate standard nurseries to determine the disease(s) present and the response of elite germplasm to the disease and the agronomic desirability in the local environment. Four nurseries were planted: the Anthracnose Resistance Germplasm Nursery (ARGN), the All Disease and Insect Nursery (ADIN), the Sugarcane Aphid Resistance Nursery (SCA), and the International Sorghum Virus Nursery (ISVN). Nurseries planted at the Mansa Technical Assessment Site all failed due to abnormally high rainfall. Plant stand at Mt. Kakulu was poor due to excessive rainfall after planting.

The ADIN, planted at Mt. Makulu, was scored for disease and agronomic desirability. Table 1 shows data collect on the ADIN at Mt. Makulu, Zambia and Cedara, South Africa. At Mt. Makulu anthracnose was the only disease present during

Table 1. Disease scores, agronomic information, and plant traits for the ADIN grown at Cedara, South Africa and Mt. Makulu, Zambia, 2003-2004.

Designation/Pedigree	Leaf blight†	Anthracnose†		Ergot‡	Grain mold§	Desirability¶	Grain Color#	Plant Color††	Plant Height
		Cedara	Mt. Makulu	%					cm
92BD1982-4_(PL2120*87EO366)-BD6-	3.2	0.0	2.5	0.0	0.5	3.0	R	T	50-70
98BRON122_(GR127-90M37*GR107-90M18)-LG2	1.5	1.0	1.0	3.0	1.5	2.5	R	T	50-70
B.9715_(B.8201-2*IS9530)-C1-C3	3.0	0.0	1.0	0.0	4.2	3.5	R	R	70-90
BTx635_B.Var,B.Var1,BVG1	0.8	1.0	2.0	6.0	2.2	3.5	W	T	70-90
B35_IS12555 der./SC35-6/Durra	2.2	1.5	3.0	0.5	5.0	4.0	W	R	50-70
LG70_(Tx2862*(Tx2868*PI55607))-LG70	2.0	3.0	3.0	5.5	2.0	4.0	R	R	50-70
96GCPOB172_(88CC445*Tx2862)-HG62-BG2-CG3-CG3	2.5	3.0	3.0	3.5	3.5	3.5	R	T	50-70
TAM428_IS110 der.,IS12610 der.,Zerazera	2.2	1.0	2.5	0.0	3.5	3.5	W	R	50-70
Tx2880_(MR63/(Tx430*MR6)*Tx2766)	3.2	0.0	3.5	13.5	4.2	3.5	R	R	50-70
86EON361_(R5646*SC326-6)	1.5	2.8	1.0	17.0	2.8	2.5	W	T	50-70
R.9528_((SC120*Tx7000)*Tx7000)-10-4-6*(Tx430*77CS1)-1-1-B2	1.0	1.8	2.5	33.5	4.0	3.0	W	T	50-70
9BRON125_(2241*(R5646*SC326-6)*GR107-90M18)-LG94	0.5	0.0	1.0	9.0	3.0	2.5	W	T	50-70
BTx623_(BTx3197*SC170-6)	4.0	0.0	3.5	1.0	3.5	3.5	W	R	90-110
B.LD6(wxy)_(B.BON34*B9502)-LD6wxy	2.0	0.0	3.0	0.0	1.2	4.0	W	T	50-70
B8PR1045_(Tx2783 der.*(BTx623*(BTx625*B35)))	3.0	0.0	1.5	0.0	2.5	2.0	R	R	70-90
B.9955_(IS9530*B8110)-B7	0.0	2.2	1.5	39.5	2.5	3.5	R	R	50-70
98CD187_(87EON366*99EON328)-HF6-ED1	2.0	1.8	5.0	0.0	3.0	4.0	W	T	90-110
SC326-6_IS3758 der./Nigricans	0.0	0.0	1.0	0.0	3.0	2.0	W	R	50-70
Sureno_((SC423*CS3541)*E35-1)-1-2/M62650/VG146	1.8	0.0	1.5	0.0	1.8	3.5	W	T	110-130
LG35_(Tx2862*(Tx2868*PI55607))-LG35	0.8	3.0	3.0	4.0	3.5	3.5	R	T	50-70
SRN39_Striga Res.	3.2	0.0	1.5	0.0	2.8	3.5	W	T	70-90
BTx378_IS413,Redlan	0.0	1.8	1.0	0.0	3.0	4.0	R	R	70-90
95BRON155_(87BH8606-4*GR127-90M48)-HF30-BG1	0.8	0.5	1.5	25.0	1.8	4.0	R	T	50-70
99GWO92_(86EO361*90EON343)-HD12-	2.8	1.0	1.5	0.0	3.2	4.0	R	T	50-70
Tx2911_(SC719-11E*SC630-11E)-1-3/92B1941	0.5	3.0	4.0	21.0	3.0	4.0	R	R	50-70
96GCPOB160_5BRO147/(B.Var*GB102-39-3-1)-LG5-CG3-CG3	1.0	0.0	1.5	0.0	0.5	3.5	R	T	50-70
R.9732_(ADN55*Tx430)-B10	1.0	2.2	2.0	3.5	3.5	4.0	W	T	50-70
RTx2919_R.9603/((SC120*Tx7000)*Tx7000)-10-4-6-1-1-1	0.2	0.0	2.0	10.0	3.0	2.5	R	T	50-70
Tegemeo_Sooty,Stripe Res.	2.8	0.0	3.0	0.0	0.8	3.0	W	T	90-110
96GCPOB143_(86EO361*GR107-36-3)-LG7-BG1-LG1-	1.0	0.2	1.0	10.5	1.2	2.5	R	T	50-70
B.9612_(B4R*B35)-B9	0.5	0.8	3.0	0.0	1.8	4.5	R	R	50-70
B8PR1059_(88B885*GB102B)	3.5	1.0	1.0	28.0	3.0	4.0	R	T	50-70
96CD635_(SRN39*90EON328)-HF4-ED2	2.0	1.0	1.0	31.0	3.2	3.0	W	T	90-110
B.9712_B.MF/RS4490-?64-74-C5	1.8	1.5	1.0	0.0	2.8	4.0	R	R	50-70
RTx2918_R.9317/(((SC120*Tx7000)*Tx7000)*Tx2894)			1.0			4.5			

Table 1. Cont'd - Disease scores, agronomic information, and plant traits for the ADIN grown at Cedara, South Africa and Mt. Makulu, Zambia, 2003-2004.

97BRON179_(89BE5398*GB112-29)-HG52-B1-CG2-CG1-CG4-CGBK-LBK	2.8	0.2	2.5	20.0	1.5	4.0	R	T	50-70
02CA4624_(Macia*Dorado)-HD12	1.5	1.0	1.5	0.0	1.5	2.5	W	T	70-90
Tx2783_(SC110 der.*Capbam)	3.2	1.8	5.0	15.0	1.5	3.8	R	R	50-70
BTx631_(BTx378*SC110-9)*BTx631)-4-3-4	2.0	0.0	1.0	0.0	2.2	3.0	W	T	90-110
SC630-11E(II)_IS1269 der./Caffrorum	0.8	1.5	2.5	0.0	0.8	3.0	R	R	90-110
B8PR1051_(BTx631*GB102)	1.0	0.8	1.0	0.0	4.5	3.2	W	T	50-70
R.8901_((SC120*Tx7000)*Tx7000)-10-4-6-	0.0	0.2	2.0	6.0	2.8	4.0	W	T	50-70
R.9529_(Tx2894*R8504)-B2-B3-	0.8	2.5	3.5	4.0	3.2	3.5	W	T	50-70
96GCPOB124_GR134B-LG56-BG1-L2-BG1-LGBK	0.5	1.2	2.5	0.0	2.2	3.0	R	T	50-70
B.HF14_(B1*BTx635)-HF14-	0.2	2.5	1.0	0.0	4.5	3.0	W	T	50-70
Malisor 84-7_Mali Pop der. Headbug Res.	2.5	0.0	1.0	7.5	1.0	3.0	W	T	70-90
SC414-12E_IS2508 der./CauKaf	2.5	0.0	1.0	52.5	4.2	2.5	W	R	50-70
02CA5053_(86EO361*88BE2668)-LL2	0.8	2.8	1.0	0.0	3.2	2.5	W	T	50-70
MB108B_MB108B-7-23/P. Grande	1.5	1.5	1.0	5.0	4.2	2.8	MIXED	R	70-90
R.9818_((Tx430*Tx2816-1*Tx435)-13*RTx436)-B2	0.0	1.2	1.0	55.0	LATE	4.0	LATE	T	50-70
RTx2917_R.9120/(Tx2894*Tx433)-F2-B13-B1-	1.0	0.5	2.0	58.5	0.8	4.0	R	T	50-70
Tx7078_IS415,Combine 7078	0.5	2.0	1.5	10.0	3.5	4.0	R	R	50-70
B8PR1013_MB120A-BM48	3.0	1.2	2.8	0.0	4.8	3.2	W	R	50-70
GR108-90M24_GR108-90M24/(BioE Tx430der*SC414-12E)	3.0	1.0	1.0	0.0	4.2	2.0	W	R	50-70
00CA4654_(Sureno*SRN39)-BE1-CW5-	2.8	0.0	1.0	12.5	3.5	2.5	R	T	70-90
R.9645_(RTx430*Sureno)-B12	1.2	0.0	1.0	1.5	4.5	3.5	W	T	50-70
90EON328_(Sureno*BDM499)-HD5-CW1	1.5	2.8	1.0	27.5	1.5	3.0	W	T	90-110
Tx436_((SC120*Tx7000)*Tx7000)-10-4-6/R8505	0.2	1.2	1.0	40.0	3.5	4.2	W	T	50-70
Tx430_(Tx2536*SC170-6)	0.0	4.0	1.5	58.5	4.5	4.0	W	R	50-70
B.9701_(BTx631*BTx626)-B11	1.0	0.0	1.5	0.0	2.2	3.5	R	T	50-70

† Rated on a scale of 0 = no disease expression to 5 = leaves killed by disease
‡ Percent of florets infected by ergot
§ Rated on a scale of 0 = no grain mold present to 5 = grain mold on all kernels with significant grain deterioration
¶ Rated on a scale of 1 = most desirable to 5 = least desirable
# W = White, R = Red.
†† T = Tan, R = Red

the growing season and entries were rated for disease severity. Thirty-five entries were rated 2.0 or less (24 at 1.0 and 11 at 1.5) indicating at least a low level of resistance. However, disease pressure in the nursery was low and there were no significant differences between treatments. For agronomic desirability most entries were average at best. Desirability ranged from 2.0 to 4.5 with only 13 entries rated below 3.0

South Africa

Susceptibility to the grain mold complex is the principle constraint to the introduction of white (food) sorghum to the South African market. Emphasis in the local program has thus shifted towards the identification of tan plant, white grain sorghums with an acceptable levels of grain mold resistance which also express resistance to the major diseases i.e. leaf blight, anthracnose, ergot and root rot. The ADIN (All Disease and Insect Nursery), SABN (South African Breeding Nursery), GWT (Grain Weathering Test) and a grain mold evaluation trial of six white grain tan plant U.S. (food) hybrids were planted at Cedara for disease evaluation. Delayed receipt of the nurseries due to shipping error resulted in late planting and relatively poor stands. Nonetheless, disease incidence was severe and a rating could be made in most trials for the primary diseases. A Head Smut Nursery was received but was too late to plant and is being used in a winter greenhouse evaluation to attempt to determine the local race(s) of the pathogen (head smut).

The SABN, ADIN, and GWT were scored for incidence of leaf blight, anthracnose, and ergot. In the ADIN 20 entries had leaf blight ratings less than 1 while 19 and 25 remained anthracnose and ergot free respectively (Table 1). Sixteen entries had grain mold ratings less than 2 of which 8 where white grained varieties. Individual panicle selections from entries in each nursery were made based on disease evaluation and agronomic desirability and will be incorporated into the larger local program. In the SABN 12 entries had leaf blight (mean = 1.6) ratings less than 1 while most were resistant to anthracnose (mean = 0.8) (partial results in Table 2). Twenty-seven entries were free of ergot although most were shorter season varieties that flowered during warmer conditions. The mean ergot severity was 8.3 % with a range of 0 to 51.5 %. Most entries were highly susceptible to grain molds although two entries were rated less than1 and 8 entries were rated less than 2. Disease severity was high in the GWT with mean leaf blight and anthracnose ratings of 1.96 and 0.56 respectively while ergot was severe in a number of entries (Table 3). Grain mold severity was generally high with a mean rating of 2.5 and only four entries were rated less than 2.

The grain mold hybrid evaluation trial was composed of six entries: Tuli, MK8828, Orbit, W902-W, DKS44-41C, and 14186-39104. Most entries were well adapted to local conditions. The hybrid 14186-39104 was susceptible (3.0) to leaf blight while the other entries were rated less than 1.5. All anthracnose ratings were less than 1 except for DKS44-41c which had a mean rating of 1.67. Grain mold severity was generally high. W902-W had a mean grain mold rating of 3.5 while remaining entries had ratings less than or equal to 2.5. Milling and seed quality tests are being conducted to determine the suitability of these hybrids for local markets.

Within the local commercial hybrid trials, most entries were highly susceptible to leaf blight with eight of the 16 entries having leaf blight ratings of 3 or higher while only four had ratings of # 1. Since all entries were red/brown seeded, grain molds were generally less severe although NK283 which makes up a large proportion of local production yielded a rating of 3. No white hybrids are currently on the commercial cultivar list due to susceptibility to grain molds. Ergot was also limited due to continuous screening of new releases for cold tolerance in relation to the production of viable pollen. Only MRBuster (imported) was susceptible to the disease (mean = 32.7 %). Within the local line screening test consisting of 68 entries, mean ratings of 1.1, 0.48 and 1.5 were recorded for leaf blight, anthracnose and grain mold respectively indicating improved levels of resistance within selections. A local seed company has expressed interest in evaluating a number of these for market potential.

Studies into the etiology and epidemiology of grain molds and root rots continued in collaboration with students from the University of the Free State from Eritrea (partly supported by INTSORMIL) and Botswana (fully supported by INTSORMIL) respectively. *Alternaria alternata* remains the primary isolate in grain from field trials at Cedara, Bethlehem and Potchefstroom. In greenhouse trials this pathogen reduced seed mass by 26.2 and 17.2 % in the test hybrids NK283 and PAN8706W respectively. *Fusarium graminearum* was commonly isolated from Cedara samples and reduced seed mass by 21.6 and 16.6 % in the two hybrids respectively while *F. proliferaturm* was most effective in reducing seed mass i.e. 31.6 and 36.1 % respectively. In field trials mean concentrations of fumonisin, zearalenone, aflotoxin and DON were 0.13, 29.7, 2.57, 1.64 and 0.15 ppm/b respectively. Highest concentrations were 0.48, 140.7, 6.1 and 0.26 ppm/b respectively and the potential of toxicity due to grain mold pathogens appears limited. Toxin production using artificial inoculation with pri-

Table 2. Evaluation of selected entries in the SABN for disease resistance at Cedara, South Africa, 2003-04

PEDIGREE	LEAF BLIGHT †	ANTHRACNOSE†	ERGOT‡	GRAIN MOLD§	GRAIN COLOR¶	PLANT COLOR#	PLANT HEIGHT
			%				cm
SURENO	2.0	0.3	7.0	4.3	W	T	90-110
ICSV 1089BF	0.8	1.0	10.0	3.0	W	T	110-130
MACIA	3.5	0.5	10.5	3.5	W	R	50-70
KUYUMA	1.5	0.3	0.0	2.5	W	T	70-90
ZSV 15	2.0	1.0	10.0	2.5	W	T	>150
CE 151-262-A1	1.8	0.0	19.0	3.5	W	T	70-90
TAM 428	1.8	2.5	2.5	3.0	W	T	50-70
86EO361	2.5	0.0	0.0	3.8	W	T	50-70
96CD 635	2.3	0.5	19.5	4.0	W	T	>150
02CA 4254	4.0	0.0	0.0	1.0	W	T	90-110
5EO 509	2.5	0.0	5.5	2.8	R	R	50-70
RCV(EL SALVADOR)	2.5	0.3	0.0	2.8	W	T	110-130
PINO/EM 1(NICARAGUA)	1.5	1.8	6.0	3.5	W	T	110-130
INTA 108/(TORT *PIN1) NICARAGUA	1.8	2.3	0.0	2.3	W	T	110-130
INTA LP-99 (NICARAGUA)	0.8	0.3	0.0	4.0	W	T	70-90
(87EO366 * WSV387)-HD27	2.8	0.5	2.5	2.5	W	T	90-110
(87EO366 * WSV387)-HF3	2.8	0.0	10.0	0.5	W	T	90-110
(87EO366 * WSV387)-HF14	2.8	0.8	11.5	1.3	W	T	90-110
(87EO361 * MACIA)-HD39	0.8	0.0	38.5	3.8	W	T	50-70
(ISCV 1089BF * MACIA)-HF112-CA2-	0.3	2.5	16.0	3.5	W	T	70-90
(ISCV 1089BF * MACIA)-HF2-CA2-AE	1.5	0.8	0.0	1.5	W	T	70-90
(86E0361 * BE2668)-LL2	0.8	0.8	0.0	2.5	W	T	50-70
(87EO366 * TAM 428)-HF2	1.5	2.0	0.0	2.3	W	T	50-70
(87EO366 * 90EO 328)-HD14	2.5	0.5	23.5	2.3	W	T	50-70
(98CD192/EO366*ED328)-HF6*KUYUMA)-BE22	1.8	0.8	0.0	3.3	W	T	130-150

Table 2. Cont'd - Evaluation of selected entries in the SABN for disease resistance at Cedara, South Africa, 2003-04

PEDIGREE	LEAF BLIGHT †	ANTHRACNOSE†	ERGOT‡	GRAIN MOLD§	GRAIN COLOR¶	PLANT COLOR#	PLANT HEIGHT
(90EO328 * CE151)-LA37	1.3	0.0	0.0	0.8	W	T	90-110
(CE151 * MP 531)-LD42	1.3	0.3	2.5	3.5	W	T	90-110
(CE151 * MP 531)-LD47	0.5	1.5	0.0	3.0	W	T	70-90
(MACIA * DORADO)-HD2-CA1	1.3	1.0	0.0	2.3	W	T	90-110
(MACIA * DORADO)-LL2	1.0	0.0	0.0	2.0	W	T	90-110
(MACIA * DORADO)-LL7	1.5	0.0	0.0	2.3	W	T	90-110
(MACIA * DORADO)-HD2---CA3	1.5	0.0	0.0	1.8	W	T	70-90
(MACIA * DORADO)-HD4	0.8	0.5	0.0	2.3	W	T	70-90
(MACIA * TAMU428)-LL7	0.3	2.0	1.5	3.8	W	T	70-90
(MACIA * TAMU428)-LL9	1.0	0.0	0.0	3.0	W	T	70-90
(MACIA * SURENO)-HF19	1.0	0.5	0.0	2.5	W	T	70-90
(MACIA * SURENO)-HF11-BE4	2.5	0.3	17.5	3.0	W	T	50-70
(MACIA * SURENO)-HF11-BE4	1.5	1.0	6.5	3.0	W	T	70-90
(CE151 * MACIA)-LD8	1.5	1.8	0.5	2.8	W	T	50-70
(SC56-14E * 86EO361)-HF1	0.8	1.5	0.0	2.8	W	T	50-70
Mean	1.28	1.30	15.85	1.93			

† Rated on a scale of 0 = no disease expression to 5 = leaves killed by disease
‡ Percent of florets infected by ergot
§ Rated on a scale of 0 = no grain mold present to 5 = grain mold on all kernels with significant grain deterioration
¶ W = White, R = Red
# T = Tan, R = Red

mary isolates is currently being determined. Grain molds significantly reduced milling and malt qualities. The latter was particularly affected and ranged from 17.15 to 38.57 dsu depending on the severity of grain molds and genotype. The past season was the final season for data accumulation for the development of a grain mold risk analysis model based on weather. Indications are that temperature and humidity are the principle variables with infection requiring RH>84% for the period 9-13 days post-anthesis. This model will be applied to predict high and low risk periods based on historic weather data for a specific locality.

The root rot study is directed to the development of an integrated root rot control strategy to optimize the utilization of limited moisture and nutrient reserves, particularly in low input agriculture. Initial emphasis has been on the etiology of root rots, concentrating on *Fusarium spp.* Isolates from 16 *Fusarium* spp. (based on provisional identifications) have been quantified in the field at Bethlehem, Cedara and Potchefstroom, purified and single-spored for the evaluation of pathogenicity and disease expression on a range of host genotypes. *F. solani*, *F. oxysporum* and *F. thapsinum* were the primary isolates. Emphasis will be on the identification of resistance and the components of resistance, extending to epidemiology as influenced by crop production systems and the potential that biocontrol agents may have in root rot control in small-scale production systems.

Mycotoxin

Investigations continued on toxigenic *Fusarium* species and mycotoxins associated with samples of sorghum (7) and pearl millet (7) collected from local markets and village granaries in Mali. *Fusarium* species were isolated from the samples and identified. The sorghum and millet samples were analyzed by high-performance liquid chromatography (HPLC) for fumonisins (FUM), i.e. fumonisin B_1 (FB_1), fumonisin B_2 (FB_2) and fumonisin B_3 (FB_3) and for moniliformin (MON). The presence of FUM in some of these samples was confirmed by liquid chromatography-mass spectrometry (LC-MS).

The identification of the *Fusarium* species isolated from these samples proved to be very difficult. Although staff members of PROMEC have been involved over many years in mycological studies on *Fusarium* species including the description of several new species of *Fusarium* from sorghum and millet, most of the *Fusarium* isolates from Mali could not be placed in any known *Fusarium* species on morphological grounds. Many of these unidentified *Fusarium* isolates probably belong in new species in the *Gibberella fujikuroi* complex and are currently being characterized molecularly by Dr. John Leslie at KSU.

The results of the chemical analyses for FUM (FB_1, FB_2, FB_3) and MON are given in Table 4. All the sorghum and millet samples contained FB_1 at levels ranging from 10-360 and 5-55 ng/g, respectively. None of the sorghum samples contained MON, but 4 of the 7 millet samples contained levels ranging from 65-524 ng/g. In addition to FB_1, 2 of the 7 sorghum samples contained FB_2 and one (sample 16) also contained FB_3. Sample 16 contained by far the highest levels of FB_1, FB_2, FB_3 and total FUM (1025 ng/g). The presence of FUM in Sample 16 and one other sorghum sample was confirmed by LC/MS and this is the first confirmed report of the presence of FUM in sorghum. None of the sorghum samples contained chemically detectable levels of MON (detection limit 30 ng/g).

Table 3. Evaluation of the Grain Weathering Test for disease resistance at Cedara, South Africa, 2003-04.

Pedigree	Leaf blight†	Anthracnose†	Ergot‡	Grain mold§	Plant color¶	Grain color#	Plant Height
			%				cm
97BRON30_(R4317*SC748-5)-C2-	2.3	0.0	8.0	2.5	R	R	50-70
Tx2911_92B1941/(SC719-11E*SC630-LLE)-1-3-	1.0	3.5	4.0	2.0	R	R	50-70
00CA4051_(M84-7*BH8606)-BE4-CWB'50-70-Z2-B2-	3.5	0.0	0.0	1.5	T	R	50-70
02CA4796_(ICSV1089BF*Macia)-HF9-CA1-BE2-CA3-CA2-C	2.0	0.0	34.0	3.0	T	W	70-90
00CA4254_(M84-7*VG153)-LB'50-70-PR7/19178-L4-L2	3.5	0.0	0.0	2.5	T	W	70-90
B.01336_((BTx631*BTx626)-B11*BTxARG1)-B7	1.8	0.0	0.0	2.0	T	R	50-70
SC650-11E(t)_IS2856 der.,Caffr('50-70afir)	0.5	2.0	0.0	2.3	R	R	90-110
Tx430_(Tx2536*SC170-6)	0.5	2.3	22.0	3.5	R	W	50-70
96CA5986_(Sureno*87EO366)-CW3-CW1-CW2-	0.0	1.5	25.0	2.5	T	W	50-70
01BD5689,62_(CE151*LG10-BE5-BE1,4(F7)	1.0	2.5	0.0	2.0	T	R	50-70
99L-GWO50_(5CBR765-2/(?*?)	2.0	1.0	46.0	3.0	T	R	70-90
R6078_(SC170-6-17*MR4-4671)-HL15(TM)	2.3	0.0	0.0	2.0	R	R	50-70
90L19178_(M84-7*VG153)/19178/-LB'50-70-PR7-L4-L2-	3.5	0.0	18.0	3.5	T	W	70-90
96GCPOB124_GR134B-LG56-BG1-L2-BG1-LGB'50-70	2.5	0.0	0.0	2.0	T	R	50-70
Sureno_((SC423*CS3541)*E36-1)-2/M62650/VG146	2.0	0.0	36.0	2.8	T	W	70-90
Tx2536_Y.E.Feterita Deriv.	1.8	0.0	58.0	3.5	R	W	50-70
00CA3936_(M84-7*VG153)-LB'50-70-PR7/19178-L4-L2	3.5	0.0	0.0	4.0	T	W	50-70
00CA4879_(87EO366*(CS3541*SC630))-F4-BE2	1.0	0.0	0.0	2.0	T	R	70-90
94BE6335_(Tx2891*R4317)-BD1-BC2-B'50-70	3.0	0.0	10.0	2.5	T	W	50-70
B.9904_((BTx3197*SC170-6)*SC748-5)	4.0	0.0	0.0	1.8	R	R	50-70
98CA4779/5EO509_(PL2120*BH8606)-BD19	4.0	0.5	0.0	2.5	R	R	50-70
90L19037_(M84-7*VG153)/19037/-L6-LB'50-70-PR2-1-1-	1.5	0.0	0.0	3.0	T	W	50-70
SC279-14E_IS7419C,Guinea/Conspic.	1.0	0.0	0.0	2.0	R	R	50-70
00CA3936_(M84-7*VG153)-LB'50-70-PR7/19178-L4-L2	3.0	0.0	0.0	3.0	T	W	50-70
R4317_(SC170-6-17*MR4-4671)-LEC	3.5	0.0	14.0	2.5	R	R	50-70
B.9818_(B155*BTx635)-CS3	2.3	0.0	0.0	2.5	T	W	50-70
02CA5226_(Macia*Sureno)-HF19-BE5-BD1-BD1-BD1	2.0	0.0	0.0	2.5	T	W	130-150
99CA3019_(VG153*(TAM428*SBIII))-23-BE2-BE2-BE1	2.0	0.0	44.0	3.5	T	W	90-110
90EON343_(Tx2895*(SC170*R4671))-BH7	2.0	0.0	0.0	1.5	T	R	70-90
01BD4966_(Macia*Sureno)-HF19-CCGWO193-1-BE5-BD2	0.5	0.0	0.0	2.5	T	W	90-110
95BRON155_(87BH8606-4*GR127-90M48)-HG30-BG1	1.0	0.0	0.0	2.0	T	R	50-70
ICSV1089BF_ICSV1089BF/ICRISAT	0.0	1.5	0.0	2.5	T	W	110-130
90CC549_(Sureno*VG153)/CC549/-HF42-BD2-CCB'50-70	0.5	0.0	0.0	3.5	T	W	90-110
SC630-11E(II)_IS1269 der.,Caffr('50-70afir)	0.0	2.5	0.0	2.0	R	R	70-90
99GWO92_6CA5466/(EO361*EO343)-HD12	1.5	0.5	0.0	2.5	T	R	70-110
02CA4801_(ICSV1089BF*Macia)-HF11-CA2-BE2-CA1-CA1-	1.0	1.0	0.0	3.0	T	W	90-110
SC170-6-17_IS12661 der,Zerazera,BC1 der.	4.5	0.0	0.0	2.5	R	W	50-70
01BD5546_(87EO366*(M84-7*Sureno)-Tx3-2)-BE7-BE1	2.5	0.0	0.0	3.0	T	W	70-90
VG153_(Wa1-1*IS9327)-1/M62676	3.5	0.0	0.0	2.5	T	W	90-110
SC719-11E_IS7013 der.,Caudatum	1.0	3.0	0.0	2.0	R	R	50-70
Mean	1.37	1.02	16.87	1.68			

† Rated on a scale of 0 = no disease expression to 5 = leaves killed by disease
‡ Percent of florets infected by ergot
§ Rated on a scale of 0 = no grain mold present to 5 = grain mold on all kernels with significant grain deterioration
¶ W = White, R = Red
# T = Tan, R = Red

In addition to FB_1, only one millet sample (Sample 4) contained FB_2 and FB_3 and this sample had the highest level of total FUM (70 ng/g) of the millet samples. The presence of FUM in Sample 4 and two other millet samples was confirmed by LC-MS and this is the first report of the natural occurrence of FUM in pearl millet. Sample 4 also contained the highest level of MON (524 ng/g) of the 4/7 positive millet samples. This is the first report of the natural occurrence of MON in pearl millet. The sorghum sample that contained the highest levels of FUM (Sample 16) and the millet sample that contained the highest levels of FUM as well as MON (Sample 4) were selected for detailed mycological investigations. *Fusarium* species were isolated from these two samples at KSU and at PROMEC, selected strains were cultured on corn patties and analyzed for FUM and MON at PROMEC.

Table 4. Fumonisin and moniliformin levels in sorghum and millet samples from Mali

Sample	Fumonisin (ng/g)[1]				Moniliformin (ng/g)[2]
	FB_1	FB_2	FB_3	Total	
Sorghum					
3	10	ND	ND	10	ND
5	35	5	ND	40[3]	ND
9	10	ND	ND	10	ND
10	20	ND	ND	20	ND
12	15	ND	ND	15	ND
14	25	ND	ND	25	ND
16	360	345	320	1025[3]	ND
Pearl Millet					
2	25	ND	ND	25[3]	65
4	55	10	5	70[3]	524
6	17	ND	ND	17[3]	ND
7	20	ND	ND	20	76
11	5	ND	ND	5	ND
13	15	ND	ND	15	ND
15	15	ND	ND	15	76

(1) ND = Not detected; Detection limit of fumonisins: 5 ng/g
(2) ND = Not detected; Detection limit of moniliformin: 30 ng/g
(3) Fumonisins confirmed by LC-MS

A total of 54 *Fusarium* isolates from sample 16 were obtained from KSU and classified in three morphological groups, i.e., 31 *F. andiyazi*-like (long microconidial chains, pseudochlamydospores), 11 F. *nygamai*-like (short microconidial chains, chlamydospores) and 12 others. Ten *F. andiyazi*-like strains and 5 *F. nygamai*-like strains were analyzed for FUM and MON. None of the isolates produced FB_1, FB_2 or FB_3. Consequently the *Fusarium* species that produced the high levels of FUM in sorghum Sample 16 remains unknown. All 15 *Fusarium* strains from sorghum produced MON at levels ranging from 2214 - 33080 mg/kg. The two highest producers (33080 and 18010 mg/kg) were both classified as *F. andiyazi*-like (MRC 8279 and 8281). The next three highest-producing strains (10280-14010 mg/kg) were classified as *F. nygamai*-like (MRC 8344, 8345, 8346). The identity of these high MON producing strains is unknown at present and it is also not known whether they are conspecific or not. They may belong in one or more new species of *Fusarium* that produce MON in sorghum in Africa.

A total of 27 *Fusarium* isolates that resemble the *G. fujikuroi* complex were isolated from pearl millet sample 4 and classified in three morphological groups i.e., seven *F. andiyazi-like* (long microconidial chains at the margin, shorter in the center of colonies, pseudochlamy-dospores), eight F. *nygamai*-like (short microconidial chains, polyphialides, chlamydospores) and 12 F. *pseudonygamai*-like (short microconidial chains, polyphialides, large, globose chlamydospores).

Five representative strains of each of the three morphological groups were analyzed for FUM and MON and the results are given in Table 5. All 15 strains produced FB_1 at levels ranging from 1 - 3895 mg/kg. The three highest producers of

Table 5. Production of fumonisin and moniliformin by *Fusarium* isolates from pearl millet sample 4 from Mali

Fusarium Species	Strain No MRC[3]	Fumonisin (mg/kg)[1]				Moniliformin (mg/kg)[2]
		FB_1	FB_2	FB_3	Total	
F. andiyazi-like	8192	1	ND	ND	1	17240
	8197	3772	900	155	4827	18
	8198	8	2	ND	10	1997
	8201	3469	909	185	4563	108
	8208	3895	1259	136	5290	98
F. nygamai-like	8193	13	4	ND	17	10080
	8194	3	ND	ND	3	11600
	8202	2	ND	ND	2	12790
	8205	1	ND	ND	1	13210
	8211	1	ND	ND	1	12710
F. pseudonygamai-like	8191	13	ND	ND	13	5886
	8200	2	ND	ND	2	13970
	8204	1	ND	ND	1	6709
	8209	4	ND	ND	4	15470
	8216	1	ND	ND	1	12880

(1) ND = Not detected; Detection limit: 1 mg/kg
(2) ND = Not detected; Detection limit: 1 mg/kg
(3) MRC numbers are accession numbers in the culture collection of the PROMEC Unit, Medical Research Council, Tygerberg, South Africa

FB_1 (3895, 3772 and 3469 mg/kg) were all in the *F. andiyazi*-like group. All three of these strains also produced FB_2 at levels ranging from 900 - 1259 mg/kg and FB_3 from 136-185 mg/kg. These three strains (MRC 8197, 8201 and 8208) were by far the highest FUM producers of the 15 tested and total FUM levels ranged from 4563 to 5290 mg/kg. The identity of these strains is not known but they are most probably not *F. andiyazi* which does not produce FUM. All 15 *Fusarium* strains from millet produced MON at levels ranging from 18-17240 mg/kg. The highest producer (17240 mg/kg) was classified as *F. andiyazi*-like (MRC 8192). Among the remaining eight high producers (>10 000 mg/kg), five were classified as *F. nygamai*-like (10080-13210 mg/kg) and three as *F. pseudonygamai*-like (12880-15470). With one exception (MRC 8193), all of these high MON producing strains were very low FUM producers (1-4 mg/kg). Conversely, the three highest FUM producers (4563-5290 mg/kg) were the lowest MON producers (18-108 mg/kg). The identity of these high MON producing strains is unknown at present and it is also not known whether they are conspecific or not. They may belong in one or more new species of *Fusarium* that produce MON in millet in Africa.

All of the sorghum and pearl millet samples from Mali contained FUM whereas only some millet samples contained MON as well. None of the *Fusarium* strains from sorghum produced FUM, whereas all produced MON, some at very high levels. The findings that *Fusarium* strains isolated from sorghum naturally contaminated with FUM but not MON, produced MON but not FUM in culture cannot be explained at present. *Fusarium* strains from sorghum that produce FUM remain to be found. Some *Fusarium* strains from millet produced high levels of FUM and others produced high levels of MON. Thus both FUM and MON producing *Fusarium* strains have been isolated from millet samples naturally contaminated with both mycotoxins.

Food Quality

The University of Pretoria is the SADC regional center for post-graduate training in Food Science and Technology. Research into the food and nutritional quality of sorghum and millet is focused on cultivar food quality, milling technologies and sorghum and millet food nutritional value. All of the research is conducted by University of Pretoria graduate students under the supervision of Dr. John Taylor and Dr. Lloyd Rooney. One post-doctoral student (from Nigeria), six doctoral students (from Botswana, Ethiopia, Cameroon, Mauritius, Uganda and Zimbabwe) and two masters students (from Namibia and South Africa) are conducting research projects in sorghum and pearl millet food science and technology.

The Ph.D. research of Dr. Senayit Yetneberk (Ethiopia) concerned cultivar quality with a goal of developing a simple system to objectively evaluate the injera making quality of sorghum cultivars. Injera, a fermented flatbread, is the staple food of Ethiopia. The system is to be applied in the Ethiopian sorghum-breeding program and should ultimately result in the cultivation of sorghum cultivars of improved injera making quality. Dr. Yetneberk completed the degree requirements in April 2004, and returned to Ethiopia.

The M.S. research of Mr. Stephen Barrion (Namibia) deals with the rolling technology of pearl millet. His research shows that the traditional Namibian milling process involves a lactic acid steep that does not improve the nutritional quality of the flour in comparison to dry abrasive decortication (dehulling). However, the flour sensory quality is altered by the lactic acid steep in terms of brightness and acidic taste, which the local Namibian consumer prefers.

In February 2004, the University of Pretoria took delivery of a Maximill roller mill provided by INTSORMIL. In March 2004, Mr. Martin Kebakile of the Botswana National Food Technology Research Centre began doctoral studies. The mill is used by Mr. Kebakile to investigate the effect of sorghum cultivar and milling process (roller milling, dehull-hammer mill and pounding) on the physico-chemical and sensory quality of sorghum porridge, the major staple food in Botswana.

Sorghum food nutritional quality is the focus of the PhD research conducted by Mrs. Nomusa Dlamini. Research into the anti-oxidant properties of southern African sorghum foods indicates it is possible through dehulling to substantially reduce the levels of the tannin anti-nutrients in tannin (brown) sorghum while retaining good antioxidant activity. Antioxidants in foods are generally considered to be beneficial to health and protective against a number of diseases including HIV/AIDS. Mrs. Dlamini has been awarded a Fullbright Scholarship and is to continue her research at Texas A&M University under the supervision of Dr. Lloyd Rooney with Dr. Taylor as co-supervisor.

Research, funded primarily by the European Union, on bioplastic films made from sorghum proteins has been initiated. Previous M.S. research by Mrs. Laura da Silva revealed that bioplastic films can be produced from kafirin (the major sorghum protein) extracted from bran, a by-product of sorghum dry milling. This value-added application for sorghum bran has the potential to improve the economics of sorghum milling. M.S. research by Mrs. Janet Taylor showed that glacial acetic acid can be used as an alternative to aqueous-alcohol as a solvent for kafirin protein. This finding is significant since the use of alcohol in manufacturing can pose religious and licensing problems. The Ph.D. research of Mr. Naushad Emmambux showed that the mechanical and oxygen-barrier properties of kafirin films can be improved by cross-linking them using tannins extracted from tannin sorghum. This finding is important since a major motivation for bioplastics is that they are natural. Thus, processes to improve their functional properties must also be "natural".

Entomology

South Africa

The sugarcane aphid (*Melanaphis sacchari*) is an insect pest of sorghum throughout Southern Africa. Research is directed at developing improved varieties with aphid resistance and other acceptable characteristics (maturity, height, grain yield, grain quality, disease resistance) for use in low input, small farmer areas of South Africa and the region. The sugarcane aphid resistance test contains 100 entries. In South Africa, spreader rows of susceptible sorghum were planted two weeks prior to the sugarcane aphid resistance test to ensure presence of aphids. Aphid damage was evaluated when the majority of entries were in the milk stage. Severity of infestation is evaluated using a 1 to 5 scale, where 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present of two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered to be resistant, while a rating of 3 indicated an intermediate level of resistance. Plants with a rating of 4 or 5 were considered susceptible. Additionally, the percent of plants infested with aphids is estimated as a measure of resistance.

Sugarcane aphid infestation levels at both South Africa locations were low. It was, however, higher at Burgershall than at Potchefstroom. Results from both trials indicated that 69 and 57 %, respectively for Potchefstroom and Burgershall, of the entries rated 1 on a scale of 1 to 5, indicating no to very slight damage. Ratings of 2 were scored for 18 % of the entries at both Potchefstroom and Burgershall. Since aphid infestation levels were low, a high level of damage was possible. One and 9 % of the entries at Potchefstroom and Burgershall respectively, died as a result of aphid infestation. In Botswana the abundance of sugarcane aphids on most of the sorghum lines was generally low. The abundance on 51 of the 100 lines was less than 10% infested plants per plot. Based upon the data collected 21 experimental entries were identified with a damage rating of 1 and fewer than 10% of the plants infested.

In Botswana the test was evaluated for the percent of plants infested by stem borers and termites. Ten lines were identified with fewer than 13.7% infested plants and therefore classified as expressing some level of resistance to stem borers. While the results show that some of the sorghum lines escaped stem borer and sugarcane aphid attack, termites infested all the 100 sorghum lines evaluated. Seven lines were identified with fewer than 9.2% infested plant and were classified as having a level of resistance to termites. From the data collected it was determined that while individual lines may be resistant to one insect (either sugarcane aphid, stem borers, or termites) none were resistant to all three insects. Additional breeding and selection will be necessary to develop improved varieties with resistance to multiple insects.

A late (January 2004) planting date of the sugarcane aphid test at Potchefstroom resulted in the test becoming infected with ergot. The test was therefore rate for severity of ergot as the percentage of ergot infection. It varied between 0 and 90 %, with 30 % of the entries showing less than 5 % infection. Thirteen entries were evaluated for sugarcane as very resistant (damage = 1) and possibly have some level of resistance to ergot (percent ergot infection less than 5%). Entries with less than 5% infection were classified, as possibly expressing some level of resistance to ergot but additional research is necessary.

In Botswana the abundance of sugarcane aphid, stem borer and termite infestation on each of 19 sorghum varieties developed in the SADC region was assessed at the Botswana College of Agriculture (Gaborone, Botswana). The sorghum varieties were: BSH1, ICSH93107, ICHR89028, LARSVYT46-85, Macia, Mahube, Mmabaitse, Marupantsi, Phofu, SDS6013, SDSH89009, SDSH98012, SDSR91014, SDSR91039, Segaolane, SV1, SV2, Tegemeo and Town. The field plots were examined every two weeks to monitor pests and their natural enemies, to determine periods of pest infestation and when the natural enemies such as coccinellid predators and ichneumonid parasites occurred. Abundance of sugarcane aphids, stem borers and termites was assessed by determining the percentage-attacked plants, using counts of total number of plants and numbers of infested plants per plot. Abundance of coccinellid predators was estimated using direct counts of the predators (including larvae, pupae and adults) found on all sorghum plants in each plot. Samples of adult coccinellids found on the sorghum plants were collected and processed for identification by coleopterists. Ichneumonid wasps found in the field were also collected for identification.

Analysis of the data led to the conclusion that the average abundance of sugarcane aphid infested plants and coccinellid predators per plot was not significantly affected by sorghum variety. Overall average abundance was 42.8% infested plants per plot. These results led to the conclusion that the 19 varieties were equally susceptible. The average abundance of coccinellid predators per plot was also not significantly affected by the sorghum variety. The average abundance of predators (including larvae, pupae and adults) was 18.3 per plant while the average number of coccinellid adults was 8.8 per plot. Comparison of the average abundance of sugarcane aphids and their coccinellid predators found during the 2002-2003 and 2003-2004 cropping seasons were similar. The overall abundance of sugarcane aphids was not affected by variety. Although the average abundance of coccinellid predators was not significantly affected by variety the overall average abundance of coccinellid predators found was considerably higher during the 2003-2004 than during the 2002-2003 cropping season. It is interesting to note that the high abundance of coccinellid predators recorded during the 2003-2004 cropping season corresponded with a high abundance of the sugarcane aphid infestation. Only one early season field assessment was possible during the 2003-2004 season. This might explain why the pest and predator numbers recorded were high. It is likely that a later assessment would have recorded a reduction in abundance of sugarcane aphids.

For plants attacked by stem borer data analysis led to the conclusion that the average abundance of stem borer attacked plants was not significantly ($P < 0.05$) affected by sorghum variety. The overall average was 78.3% attacked plants per plot. The results obtained during the 2002-2003 and the 2003-2004 cropping seasons led to the conclusion that the 19 varieties evaluated were equally susceptible to stem borer attack. The percent of sorghum plants with dead hearts was similar in the varieties with an overall average abundance of 17.3%.

Sorghum Breeding

Zambia

Sorghum research in Zambia is conducted on a collaborative basis with INTSORMIL and SMINET. Research goals are determined by the national program with input from the collaborators. The end of the SMIP/SMINET program increases the importance of INTSORMIL as a strategic collaborator. Collaboration between the Zambia sorghum-breeding programs has resulted in the reciprocal exchange of germplasm lines that are used in crosses in Zambia and the United States and evaluation of advanced lines and hybrids in replicated trials. INTSORMIL trials were evaluated at Golden Valley and Mansa, and evaluation of photoperiod sensitive material was done in Mansa. The overall program goal is to develop sorghum for areas that are marginal in the production of maize and frequently experience a food deficit. Government policy is now promoting crop diversification rather than maize dependency only. Increased production and use of sorghum is expected to benefit household food security and increase income for subsistence farming sector while providing commercial entities with increased production of a consistent supply of improved quality grain.

The major objective of the breeding nursery is to generate genetic variability through collections, introductions, and hybridization. Program activities are designed to target both small-scale farmers and commercial end users. A major emphasis of the program is the development of suitable hybrids for food (tan plant, white grain), brewing, feed and forage. This emphasis has been expanded to develop for the high rainfall region late maturity, white grain, tan plant genotypes. The pedigree breeding method is used with crosses made in the main season and F1's grown in an off-season nursery to obtain F2 seed. Promising lines are evaluated in multi-location trials for grain yield, quality traits, and other agronomic traits. Seed of released varieties is maintained and increased with evaluation conducted at Golden Valley and Mansa.

Three major replicated yield trials were grown at the Golden Valley Research Trust. The Sorghum Advanced Variety was composed of 20 entries (15 experimental entries and 5 standard checks). No significant differences were found for grain yield, days to 50% anthesis, or plant height (Table 6). The experimental variety [FRAM x SDS 3845] F6-5 produced the most grain at 7690 kg/ha^{-1}. Other varieties that produced over 7000 kg/ha^{-1} include had high mean yields were ZSV- 13, SDS 4345-2-1-4-3, ZSV – 15, and [ICSV 112 x WSV 187] 15-1-3-2. The White Sorghum Advanced Hybrid Trial contained 16 entries and included hybrids previously selected from preliminary yield trials. No significant differences were observed among the hybrids (Table 7). MMSH 1401 produced the most grain (6582 kg/ha^{-1}) and four additional hybrids MMSH 1391, ZSH 102, MMSH 1257, and MMSH 1038 produced over 6000 kg/ha^{-1} of grain. The brown sorghum advanced hybrid trial had 16 entries. Significant differences were observed among the entries for days to 50% flowering, plant height, and grain yield. The trail mean grain yield was 5746 kg/ha^{-1}. The check MMSH 375 had the highest mean of 7900 kg/ha^{-1} followed by MMSH 1194 with 7670 kg/ha^{-1}. The most promising varieties will be evaluated further at other locations for wider adaptation before on-farm activities are initiated.

To generate interest with the kind of products that can be made from sorghum and to distribute information from the research program that will benefit farmers or other interested participants from industry field days were organized at the Golden Valley Agricultural Research Trust and Mt. Makulu Research Station. Representatives of the program also attended and exhibited at locally and nationally organized agricultural shows. At the shows farmers and other participants were shown some of the promising improved varieties and products. Zambia Breweries (South African Breweries subsidiary) have indicated that their brewing plant in Ndola will exclusively utilize sorghum and a grower's scheme has been devised that will initially target 4,000 farmers to produce grain for the brewery.

Table 6. Grain yield, days to 50% anthesis, and plant height of entries in the Sorghum Advanced Variety Trial I & II, Golden Valley Agricultural Research Trust, 2003-04.

PEDIGREE	GRAIN YIELD	DAYS TO 50% ANTHESIS	PLANT HEIGHT
	kg/ha^{-1}		cm
(FRAM *SDS 3845)F6-5	7696	79	230
ZSV-13	7668	82	222
SDD 4345-2-1-4-3	7477	77	216
ZSV-15	7038	73	203
(ICSV 112 * WSV 187)15-1-3-2	7035	80	222
SARDIN 10-1-1	6904	75	222
(FRAM * SDS 3845)16-3	6821	75	210
Sima	6776	74	228
ICSV 93010-1	6765	79	225
Kuyuma	6715	76	205
(FRAM * SDS 3843)16-2-2	6640	77	227
(ICSV 112 * WSV 387)20-3-4	6615	72	212
SDS 1958-1-5-2	6607	74	203
ZSV-3	6507	75	213
SDS 3047	6487	75	217
90CC 651-655-1073-3	6343	78	238
CZADIN 1237-1	5970	73	197
SDS 4882-1	5807	75	225
SDS 3335-1	5601	74	195
(ICSV 112 * WSV 387)15-1-3	5221	78	197
Mean	6635	76	215

Table 7. Grain Yield, plant height, and days to 50% anthesis of entries in the White Sorghum Advanced Hybrid Trial, Golden Valley Agricultural Research Trust, 2003-04.

DESIGNATION	GRAIN YIELD	DAYS TO 50% ANTHESIS	PLANT HEIGHT
	kg/ha^{-1}		cm
MMSH - 1401	6582	63	220
MMSH - 1391	6557	67	173
ZSH - 102	6499	76	260
MMSH - 1257	6485	76	225
MMSH - 1038	6126	76	190
MMSH - 1338	5935	76	177
MMSH - 1399	5848	68	168
MMSH - 1287	5771	77	317
MMSH - 707	5437	80	237
MMSH - 1363	5289	69	205
MMSH - 1347	5257	69	167
MMSH - 1376	5215	68	158
MMSH - 1389	5020	67	170
MMSH - 1324	4900	66	192
MMSH - 1346	4759	67	155
MMSH - 1382	4325	68	175
Mean	5625	71	199

Botswana

The major objective of the breeding program is to provide small-scale farmer with seed of improved varieties and hybrids. The majority of sorghum production in Botswana is by small-scale farmer that using current technology cannot produce enough grain to satisfy national demand. The need exists to introduce and evaluate advanced improved lines for grain yield, adaptation, stress resistance, and agronomic traits. Based on the data superior lines will be identified for use in a crossing program to produce populations for selection and to elite adapted hybrid parental lines to produce hybrids for evaluation.

In 2003-2004 two INTSORMIL nurseries from Texas A&M University, the Drought Line Test (DLT) and the All Disease and Insect Nursery (ADIN), were evaluated at Maun. Unlike the previous cropping season timely rain was received, and there were no significant disease and insect problems. In the DLT significant differences were identified for the traits studies (grain yield, days to 50% flowering, plant height, panicle exsertion, and agronomic desirability. The test mean grain yield was 3122 kg ha^{-1}. Local checks were Segaolane (a Botswana developed variety with pre-flowering drought tolerance) and Macia (a Mozambique with excellent grain quality). Two entries produced more grain than Segaolane (4630 kg ha^{-1}) - 87EO366*WSV387 (5565 kg ha^{-1}) and CE151*MP531 (4769 kg ha^{-1}). WSV387 was developed in Southern Africa and CE 151 is an introduction from Senegal. Generally, entries with Macia, Dorado, or CE151 as one parent produced more grain than other entries.

The same traits were measured in the ADIN. Significant differences were identified for days to 50% flowering and plant height. The mean for days to 50% anthesis was 16 days later (86 vs 70) than for DLT entries. This was attributed to early season slow plant development. The mean grain yield (3023 kg ha^{-1}) was lower than that of the DLT. The lower ADIN grain yield could be attributed to parentage of the ADIN entries and less drought tolerance (either pre- or post-flowering). One local entry, the sooty stripe resistant local variety Tegemeo, produced 2960 kg ha^{-1} of grain. However, 17 entries produced more grain than Tegemeo.

Selections were made in promising lines in both nurseries. The selections will be evaluated in the next growing season at various locations. In off-season nursery superior R-lines will be crossed with A.Segaolane to produced hybrids for evaluations. Additionally, a test of red seeded entries from both nurseries will be planted to evaluate the entries from the good malting qualities that are needed for the opaque beer industry.

West Africa – Eastern Region (Niger, Nigeria, Burkina Faso)

Bruce Hamaker
Purdue University

Coordinators

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Collaborative Program

Beginning in the 2004-2005 fiscal year, the INTSORMIL program in West Africa will change from two regional programs, representing the eastern and western regions, to one merged six-country program. Thus, this is the last separate reporting of the eastern (and western) regions. The eastern region of West Africa includes a long-standing collaborative research effort in Niger, and, since 2000, the initiation of programs in Burkina Faso and Nigeria. All are multidisciplinary efforts that focus on sorghum and millet improvement in the region, however Niger has the only full range of research activities spanning various production agriculture disciplines, utilization, and economics. Programs in Burkina Faso and Nigeria are positioned with breeding/agronomy and utilization projects to address market-driven issues. Burkina Faso also has plant protection activities. ICRISAT has been an institutional collaborator in the region, as well as, in the past, the regional millet and sorghum networks of ROCEFREMI and ROCARS. The regional networks, however, did not significantly function in this reporting year. It is hoped and expected that a network covering sorghum and millet activities in the region will be revitalized. INTSORMIL looks to become an active partner in such regional network, as it sees the network as vital in realizing a coordinated effort towards regional sorghum and millet research and engagement.

At the programmatic level, a workshop was held in Ouagadougou, Burkina Faso in April 2004 to plan and implement the merger of the two regional programs into one six-country regional INTSORMIL program. A majority of INTSORMIL PIs from the region attended, as well as eight U.S. PIs. Progress reports were given for each of the West Africa country programs comprising Niger, Mali, Senegal, Burkina Faso, Nigeria, and Ghana. Work plans were discussed in terms of the INTSORMIL strategic plan and regional priorities. Two new integrated, regional projects were identified in crop utilization and technology transfer with a goal of developing concept notes/proposals to seek additional funds for these areas of activity.

List of Disciplines and PI Collaborators

Genetic Enhancement – Sorghum and Millet

Sorghum: INRAN, Niger - I. Kapran; KSU - M. Tuinstra, PU – G. Ejeta; IAR, Nigeria - P. Marley; TAM – D. Rosenow

Millet: Lake Chad Research Institute, Nigeria – I. Angarawai; ARS – J. Wilson

Sustainable Plant Protection Systems

Entomology: INRAN, Niger - H. Kadi Kadi; TAM – B. Pendleton

Plant Pathology: INRAN, Niger – A. Kollo (on leave) INERA, Burkina Faso – A. Neya, H. Traore; TAM – D. Rosenow, C. Magill

Sustainable Crop Production Systems

Agronomy: INRAN, Niger – S. Sirifi, N. Mamane; UNL – S. Mason; INERA, Burkina Faso - J.B. Taonda, P. Siebou

Economics: INRAN, Niger – T. Abdoulaye; PU – J. Sanders

Utilization and Marketing

Cereal Processing: INRAN, Niger – K. Saley, M. Moussa; PU – B. Hamaker; University of Maiduguri, Nigeria – I. Nkama; IRSAT, Burkina Faso – B. Bougouma; ITA, Senegal – A. N'Doye

Poultry: INRAN, Niger – S. Issa; KSU – J. Hancock

Marketing: INRAN, Niger - A. Tahirou; Purdue – J. Sanders

Sorghum/Millet Constraints Researched

Sorghum and pearl millet are staple food crops of Niger, Burkina Faso, and northern Nigeria. In Niger, sorghum acreage increased from less than half a million hectares in 1961 to more than two million hectares in 2000. Grain yield declined from 0.6 t/ha to 0.2 t/ha during the same period. Sorghum and millet production in the eastern Sahelian region of West Africa is severely limited by biotic and abiotic stresses including drought, poor soils, insect pests (especially midge and headbugs), and diseases including long smut and *Striga*. In the 1998 strategic plan for sorghum and millet prepared by the Institut National de Recherches Agronomiques du Niger (INRAN), emphasis was placed on technology transfer, development of varieties with better yield stability, and plant protection. Improved utilization of these cereals, such as through commercial processing to products or animal feed use, is also key to expanding demand and markets to generate income at the farmer and entrepreneurial levels.

INTSORMIL's support for sorghum and millet improvement has been significant in terms of human resource enhancement and vision for technologies that can be transferred and adopted by farmers and other end-users. For example, sorghum and millet breeders and food technologists work together to demonstrate feasibility of the use of improved seeds to increase food production, diversify uses for local consumers, and stimulate entrepreneurial processing businesses. New projects in breeding and poultry nutrition aim to encourage poultry producers to use sorghum and millet for feed.

Institution Building

Expendable supplies for field and office uses were purchased for the programs, as well as laptop computers and software for some project areas. All PI's listed above had regional support funding through INTSORMIL. INTSORMIL regional and ME programs also sponsored the April 2004 planning workshop held in Ouagadougou, Burkina Faso.

Tahirou Abdoulaye, INRAN/Niger, completed post-doctoral studies with Dr. John Sanders at Purdue University and returned to Niger in December 2003

Research Progress

Niger

Sorghum Breeding and Seed Production
I. Kapran, INRAN; M. Tuinstra, KSU ; G. Ejeta, Purdue

Objective

To evaluate various germplasms to identify highly productive and well-adapted, open-pollinated varieties and hybrids to be increased for food and feed uses.

Efforts focused on fieldwork as well outreach activities with other partners:

- Breeding nurseries and trials were designed to evaluate germplasm from various origins based on INRAN request for material with acceptable maturity and grain quality, resistance to drought, and/or *Striga*,
- Seed production was organized to provide foundation seed in support of the INRAN seed unit which is in charge of all seed production activity for INRAN,
- Finally the results of this collaborative breeding program were used for outreach to other groups through training of university students or presentations at workshops and seminars.

Collaborative Breeding Nurseries

The project allowed us to identify well-adapted lines that may be released for cultivation and/or used in our hybrid-breeding program. More than 3,000 entries were evaluated in 2003 as given in Table 1 below. Some highlights of the activities include:

Development of new germplasm for drought/sandy soil adaptation. Farming in Niger is practiced essentially on highly drained sandy soils poor in nutrients, the so-called dune soils where farmers intercrop cereals with cereals, cereals with legumes, or more complex schemes of cereals/legumes/cereals. Landraces are well adapted to this environment but have poor yield potential. On the other hand, we have developed through this collaborative effort a number of improved varieties and hybrids, most of which do not have enough adaptation to achieve a larger diffusion and more significant contribution to food security. Therefore we crossed a well adapted sorghum landrace (MDK) to a breeding line (L153-5, itself derived from a cross involving *Striga* resistant SRN39 with landrace ABH) to develop a population for genetic studies of yield/adaptation traits and selection of lines that may be released to farmers or used in the synthesis of widely adapted F1 hybrids. A preliminary characterization work showed that the parents are different for emergence, maturity, height and yield. MDK has an excellent germination, is very late in maturity, but relatively better yielding than the early parent. Progeny average is usually intermediate but the range of distribution is wide for these traits so as to indicate good feasibility of selection.

Development of midge resistant cultivars. After testing midge resistant lines we introduced from TAMU and ICRISAT, we developed a population (MMxICSV88032) which was characterized as part of a university student research (Amadou Mahaman Bassirou: 1999. Comportement agronomique et résistance à la cécidomye des descendances non sélectionnées de sorgho –*Evaluation of the agronomic performance and midge resistance of single seed descent lines*). The best of these lines were further tested in our breeding/entomology nursery (see entomology report) which confirmed their resistance. We selected entry 35 (SSD35) as the most promising for re-

Table 1. Collaborative sorghum breeding nurseries in Niger, 2003

Description	Number of entries	Source	Observation
Single Seed Descent lines (F8)for sandy soil adaptation	995	INRAN	Derived from local cultivar MDK
Single Seed Descent lines (F10) for midge resistance	30	INRAN	Derived from local cutivar MM
Hybrid observation nursery	482	INRAN	Between 60 A lines (PU,TAMU, NE) and 74 R lines (INRAN, PU, TAMU)
New experimental hybrids	396	Purdue	
Tan food grain hybrids	100	Purdue	
Drought tolerant hybrids	66	Purdue	
Advanced hybrid trial	24	INRAN	
Large seeded experimental hybrids	18	Kansas State	
International striga testing	25	Purdue	
Striga introgression lines	300	Purdue	Using landrace El Mota from Niger
Striga introgression F2 population	1	Purdue	Using improved SEPON82 from Niger
High digestibility lines	108	Purdue	
Elite R line observation nursery	86	Kansas State	
MACIA derivatives	351	Kansas State	
BRON nursery	82	TAMU	
IFSAT	40	TAMU	
Selected lines from Lubbock nurseries	139	TAMU	
Total	3243	4	

lease, based on its high resistance to midge, apparent good grain quality, and a maturity and height very close to those of the local parent MM. SSD35 seed was increased in isolation to produce enough quality seed for on farm testing during the 2004 crop season.

Introgression of *Striga* resistance into landrace El Mota (EM). EM is a favorite of farmers in the Maggia valley of Niger for its early maturity associated with rapid grain-fill. Although it may escape *Striga* damage, it is highly susceptible as seen in controlled studies. On the other hand, improved *Striga* resistant cultivars are less accepted in this environment, because of problems of grain deterioration, despite their higher yield potential. A project was started to transfer *Striga* resistance genes from a well-characterized source of resistance to *Striga* (SRN39) to EM through a bioassay-mediated and/or molecular marker assisted introgression. As part of this on going effort, an advanced backcross population made of 103 BC2F3 progeny between EM and SRN39 was evaluated for *Striga* resistance in a *Striga* sick plot at the Konni station during 2002 and 2003. Overall our results show that important genetic variation was present in the parental lines and was largely transmitted to the progeny especially for broad sorghum phenotypes. There is also indication of *Striga* resistance being introgressed in this second-generation backcross population. This suggests that these lines may be the best candidates for the next stage of backcrossing whereby *Striga* resistance will be further incorporated into EM background. This project was initiated with financial support from the Rockefeller Foundation to the Ejeta lab at Purdue University.

Hybrid Program

There is sustained interest in hybrid cultivars in farming communities of Niger following the large number of convincing demonstrations with NAD-1, the first hybrid released. In 2003, we evaluated around 1,000 testcross hybrids largely to evaluate best inbreds for further experimentation. Out of 60 A lines and 74 potential R lines, we have identified the most promising to be used as testers for hybrid combinations in the Sahelian environment of Niger. They include 7 A lines (NE223, P9504, P9511, P9512, P9521, P9526, HF8) and 9 R lines (MR732, ST9007-5-3-1, MACIA, P9401, P9403, N7112R, 97M7642, 97M10522, 91BE7414). In the end, this activity aims at identification of best-adapted, high yielding food grain combinations for commercial cultivation in Niger.

Seed Production Activities

Seed production including hybrid seed was conducted in support of the INRAN seed unit which took off from the INRAN/INTSORMIL hybrid seed project. Nearly six tons of seed of various sorghum cultivars and lines were produced. The seed unit increased foundation seed for varieties MM, IRAT 204, SEPON82 and 90SN7. The last two are direct products of the INTSORMIL collaboration.

NAD-1 and F1-223 hybrids were produced at the Gabagoura station near Niamey. Production environment is at least as important as the genetics of maturity, which explains our agronomic trial to determine the best interaction of soil fertility level with planting density for optimal seed yields.

Another partner, the West and Central Africa Sorghum Research Network (WCASRN) helped with NAD-1 seed production.

In addition to breeding for open pollinated varieties, a strong focus is placed on hybrid breeding. Hybrids synthesized at INRAN or coming from Purdue go through nurseries and the best will reach advanced testing. In the preliminary hybrid trial, a yield average of about two tons per ha was obtained, which was also the yield of checks NAD-1 and Mota Maradi (MM). The best three hybrids yielded, however, over three tons per ha each. The best hybrid was P9526AxST9007-5-3-1 which yielded around 3.6 tons per ha while being early maturing. It is a cross between two tan plant parents belonging to the same maturity group, which will ease seed production and provide improved grain quality for food uses. Such early hybrids have the potential for adaptation over a wide area in Niger.

Sorghum/Millet Quality and Utilization
K. Saley, M. Moussa, I. Kapran, INRAN; B. Hamaker and A. Aboubacar, Purdue

Primary Objective

Processing and commercialization of value-added sorghum and millet products with particular emphasis on utilization of locally and regionally fabricated food processing equipments

Specific Objectives

- Identify and implement a form of contractual agreement between farmers and processors that could help to support a reliable and sustainable supply of quality grains needed to produce high quality sorghum/millet foods.
- Optimize the couscous agglomerator and solar dryer.
- Monitor product stability under different packaging materials and define a shelf life for both couscous and flour.

Findings

A partnership was initiated among sorghum/millet breeders, food technologists, food processors, and grains producers to identify potential grains producers and production sites to create consistent and reliable sources of high quality sorghum and millet grains for food processors. The optimized couscous agglomerator designed by CIRAD was locally reproduced with the collaboration of the national institute of mechanical engineering of Niger and the financial assistance of IFAD Regional project (Sorghum-Millet Initiative). The new equipment is in the process of being tested by a group of private processors under the supervision of INRAN food technologist. The existing solar dryer was optimized and repaired and discussion and planning is going on to construct a large-scale (50 kg/h) couscous steamer (estimated to cost $6000).

Entomology
H. Kadi Kadi and I. Kapran, INRAN; B. Pendleton, WTAMU

Primary Objective

To determine the sorghum lines or varieties that are resistant to sorghum midge under field conditions.

Specific Objectives

- Identify the sorghum lines with stable resistance against sorghum midge.
- Determine if variation in the flowering of sorghum lines affects sorghum midge incidence and day-to-day variation in midge population abundance.

The sorghum midge is the most encountered insect pest in Niger on sorghum causing damage to the flowering panicles. Caging sorghum midge with sorghum panicles is an important method for avoiding escape, and permits screening for midge resistance under uniform insect pressure. Six lines (99 SSD F9-3, 99 SSD F9-4, 99 SSD F9-24, 99 SSD F-31, 99 SSD F-32 and IRAT 204) had highest damaged spikelets (20-40%). The percentages of grain loss recorded on these lines were 20-30%. Sorghum lines 99 SSD F9-18, 99 SSD F9-21, 99 SSD F9-33, 99 SSD F9-35 and ICSV 745 were identified as resistant to midge. These lines had the lowest grain loss (10-20%), even though some had high damaged spikelets. After three years of screening, we confirm that the lines 99 SSD F9-21, 99 SSD F9-33, 99 SSD F9-35 and ICSV 745 are resistant to sorghum midge.

Agronomic Studies for Producing Hybrid Sorghum Seed
N. Maman, S. Sirifi, I. Kapran, INRAN; S. Mason, UNL

Objectives

- To determine recommendations for microdose fertilizer application in combination with N and P application on pearl millet.
- To find the best combination of plant population and fertilizer rate in hybrid sorghum seed production.

Activities

Results from a three year study on microdose of N and P application showed that use of a combination of microdose with 20 units of P and 30 units of N gave better millet grain yield than seven other treatments (Table 2). Experiments on plant population and fertilizer rate on hybrid sorghum seed production, however, failed due to environmental problems in two years of the study out of three. In one year of the trial, the greatest seed yield was from the combination of plant density of 31,250 plants/ha with 100 kg/ha^{-1} urea application.

Table 2. Mean grain yields from on-station pearl millet trials in 2001, 2002, and 2003 at Kalapaté, Niger. Treatments (8) consisted of check (T1), Microdose (T2), Microdose + 20 P (T3), Microdose + 30 N (T4), Microdose + 40 P (T5), Microdose + 60 N (T6), Microdose + 20 P + 30 N (T7), and Microdose + 40 P + 60 N (T8), on millet genotype (Zatib).

Treatments (T)	2001 yields (kg/ha^{-1})	2002 yields (kg/ha^{-1})	2003 yields (kg/ha^{-1})	Average (kg/ha^{-1})
1	526	250	195	322
2	643	570	391	535
3	765	961	521	749
4	456	1026	399	627
5	944	570	317	610
6	977	449	415	614
7	903	1335	651	963
8	977	1171	627	925
Average	773	791	439	668

Nigeria

Pearl Millet Breeding

Angarawai I. I., W. B. Ndahi,
Z.G.S. Turaki, M. Is, LCRI; J. Wilson, USDA-ARS

Objective

Pearl millet improvement especially regarding hybrid development.

Activities

Improvement of adapted A4 cytoplasm male sterile (B) lines for multi-line resistance to Downy mildew. This project was initiated in October 2000. A4 cytoplasm male sterile (B) were composited from diverse maintainer lines during December 2000-April 2001 and December 2002-April 2003 dry seasons at Lake Chad Research Institute (LCRI) experimental station under irrigation. Seed was harvested and planted during the 2003 main season to screen for stable sterility and fertility restoration. Multi-location evaluation at both on-station and on-farm of A4 cytoplasm male sterile-based pearl millet hybrids from 2001-2002 seasons across millet growing zones of Nigeria, revealed increased yield more than the improved OPVs varieties with the hybrids having yield potential of 4.5-5.0t/ha.

Adapted male sterile (B) lines were used for the development of new male sterile maintainer lines. During December 2000-April 2001 dry season, 65 plant-to-plant crosses were made between SOSAT-C88 (pearl millet variety) and 75A-2/75B-2 (male sterile pairs). Each set of 75A-2 X SOSAT-C88 and 75B-2 X SOSAT-C88 were planted for BC1 in 2001 main season. 17BC1A and 26BC1B obtained were bulked separately as SOSAT-75A-2 and SOSAT-75B-2 pair. During December 2002-April 2003 two diverse A/B pairs were developed; LC0475A-3/LC0375B-3 and LC044A-2/LC034B-2 were composited from six diverse adapted maintainer lines. Each pair was screened for sterility in the 2003 main season. During the December 2003-April 2004 the newly constituted A-lines were each crossed to LCICDMR15. This material will be evaluated for sterility and fertility restoration in 2004 main season.

Genotype, environment and diseases effect on grain quality of pearl millet. This project was initiated in 2002. Forty pearl millet lines made up of West African landraces, and improved cultivars and hybrids, were centrally collected and distributed by Jeff Wilson to collaborating scientists in West Africa. The long-term goal of the research is to develop top-cross hybrids for West Africa that will be acceptable by farmers, local markets, and consumers. As a step toward that goal, selection must be carried out in the target areas to ensure adequate adaptation and disease resistance. Results from this year indicate that line 086R could be exploited as a maintainer on male sterile (A) lines, since its hybrid produced sterile heads. NKOXTCI a medium maturing material can be explored for downy mildew resistance (1%).

Effect of population density and N-Fertilizer application on growth and yield of pearl millet hybrid. This project was initiated in 2002. Although the optimum plant population and nutritional requirement of OPV's have been determined there is a need to establish the requirement of newly developed millet hybrids. A combination of two factors: 4 intra-row spacing of 15, 30, 45 and 60 cm between stands, and 4 levels of N (0, 30, 60 and 90 kgN/ha) were applied as treatment, and planted on 6 row plot of 5m long and 75cm apart. The experiment was conducted at LCRI during the 2003 main season. Data was taken for days to flower, plant height, stalk weight and grain yield. Result showed application of 60 kgN/ha at 45cm intra-row spacing as the optimum for maximum yield since increasing the N rate to 90 kgN/ha at 30cm intra row spacing only lead to luxury consumption. This will be confirmed during 2004 main season experiment.

Seeds of a newly developed hybrid, which document for release is being prepared, were sent to Dr Iro Nkama for nutritional quality evaluation at the University of Maiduguri. Seeds of evaluated millet lines at LCRI were sent to Kaka Saley, INRAN/Niger for grain quality analysis.

Millet Utilization
I. Nkama, M. Badau, A. Jato, U. Maiduguri; I. Angarawai, C. Uga, LCRI; B. Hamaker, Purdue

Objective

To characterize new pearl millet lines and local cultivars for physical, chemical, rheological and sensory properties, and food processing qualities

Grain and Food Quality

Studies on the physical, chemical, and sensory characteristics of the 10 multi-location millet hybrid lines developed by LCRI were continued for the 2003/2004 cropping season. There were variations in 1000 kernel weight (8.1 - 10.2 g), 1000 kernel volume (6.8 - 8.8 ml), density (1.1 - 1.4 g/ml), and grain hardness (36.8 - 52.9 N). Also, the proximate composition varied considerably. Protein ranged from 9.5 – 11.7%, fat 3.7 - 7.4%, and ash 1.5 - 1.9%. The *in vitro* carbohydrate digestibility varied significantly ranging from 29.5% for LCICMH99-39 to 64.1% for LCICMH99-12. LCICMH99-1 and LCICMH99-10 had digestibilities of 62.3% and 61.7%, respectively. The protein, fat, and ash contents of all the hybrids were within the normal range of values reported for pearl millet and also in comparison with the farmers' local. Studies on the acceptability of these hybrids for the preparation of kunun zaki, ogi and couscous showed that all the hybrid lines could be used to produce acceptable kunun zaki, ogi, tuwon tsari and couscous. These hybrids can be considered as good materials for food processing. *However, based on yields and downy mildew resistance LCICMH99-10 was selected as the best hybrid line.*

Studies on the malting characteristics of 10 pearl millet cultivars

The malting characteristics of 10 pearl millet cultivars with negligible tannin content, low mold count, and good germination properties were investigated. During steeping, the pearl millet cultivars Zango and Gwagwa absorbed more water per temperature rise and were more heat sensitive. Peleg's equation was found satisfactory in modeling the water absorption characteristics of these cultivars. GB 8735 had the lowest total malting loss of 21.1% and Zango had the highest of 35.6%. á– and â– amylase activities and diastatic power of samples varied significantly during mating (Table 3). SOSAT–C88, G.1-14.9, Zango, G.1-297.1 and Gwagwa had higher amylase activities. Diastatic power increased with germination period. SOSAT–C88 had the highest diastatic power after 72 hr steeping. Addition of 5% malt from SOSAT-C88, Zango, Ex Borno, ICMV-IS-94206, Gwagwa and GB 8735 to weaning foods prepared from mixtures of pearl millet, cowpea and groundnut (65:20:10) considerably reduced the hot paste viscosities of the weaning foods and improved taste and texture of the weaning foods. Gruels prepared from the weaning foods generally exhibited pseudoplastic behavior.

Germination of the pearl millet cultivars considerably reduced the phytic acid content by 85–90 % in all cultivars. The HCl extractability of calcium, iron, zinc and phosphorous, iodine, copper, and manganese increased progressively with germination up to the 72 hr germination.

Studies on couscous from the pearl millet hybrids lines

In 2002/2003 season the physical and proximate composition of 10 pearl millet hybrids developed by LCRI were investigated. During the 2003/2004 season, the couscous production potentials of these cultivars were evaluated. The proximate composition of the couscous from the 10 hybrids varied significantly. Sensory evaluation of the couscous using 30 panelists showed that any of the hybrids could be considered as a good material for couscous production. The *in vitro* carbohydrate digestibility of the couscous from the hybrids varied significantly for all samples and ranged from 56.5 – 82.5%.

Dissertation and Theses

Mamudu Badau a Ph.D. student is at the final stages of his study on the malting characteristics of pearl millet cultivars and their food application.

In this year, 12 undergraduate students participated in the INTSORMIL project. The main thrust was on couscous and its production from tsari flour. Marketing studies on couscous will be conducted this year. Work is continuing on the protein and carbohydrate digestibilities of the pearl millet hybrids and couscous from them. About 10 sorghum cultivars, both local and improved, are being characterized for their tannin contents and their malting characteristics.

Collaborative Sorghum Breeding Trials
P. Marley, IAR; D. Rosenow, TAMU

Activities

Regional trials were conducted for early, medium, and late maturing sorghum lines. All the countries involved made contributions of elite lines into each of the cycles for distribution to each country for evaluation.

Early maturing variety trial. Fifteen newly developed lines of sorghum were evaluated for yield, plant height, and days to flowering in the 2003 wet season. Three local checks

Table 3. α– and β-amylase activities (unit/mg protein/min) and diastatic power (%) of some pearl millet cultivars as affected by germination time[1,2,3]

Samples	α – amylase activity		β- amylase activity		diastatic power	
	0 hr	72 hr	0hr	72 hr	0 hr	72 hr
SOSAT-C88	6.32	85.0xy	55.0x	80.5v	22.0w	45.4x
ZANGO	6.01	80.2xy	53.0x	78.4vw	20.5w	42.3xy
EX BORNO	6.03	82.0xy	49.4x	66.0vwxy	18.7wx	38.4xy
LCIC-IC-9701	5.54	39.5z	40.3y	57.8y	12.1z	27.0z
ICMV-IS-94206	5.47	36.5z	48.3xy	71.7vwxy	15.3xyz	36.9xyz
ICMV-IS-94208	5.38	36.2z	46.5xy	58.0xy	12.8z	30.1yz
GWAGWA	6.00	80.9xy	42.8y	61.3vwxy	15.1xyz	26.8z
G.1-14.9	6.19	82.1xy	47.9xy	76.0vwx	13.5yz	27.9z
GB 8735	5.57	36.1z	46.6xy	71.0vwx	13.9xyz	29..7yz
G.I-297-1	6.04	81.0xy	48.4xy	77.2vw	17.1wxyz	45.0x
ICSV III(SORGHUM)	6.45	86.4x	32.5z	45.1z	17.1wxz	45.9x

[1]0 hr is time after steeping and before germination; [2]Mean of triplicate determinations
[3]Means in each column not followed by the same letter are significantly different ($p < 0.05$)

were used – ICSV III, Samsorg 16, and KSV 4. Line 98-BE-F5P-74-1 gave the best yield of 1333.4 kg/ha followed by the check Samsorg 16 with 1200 kg/ha^{-1}. Lowest yields came from line 98-BE-F5P-58 and the check variety ICSV III with 533.4 kg/ha^{-1}. Plant height ranged from 120 cm for Seguifa to 272.5 cm for 98-BE-F5P-54-1. The days to 50% flowering ranged from 65.5 for 98-CZ-F5P-83 to 89 for 98-BE-F5DT-128-1. Lines 98-BE-F5P-74-1 and Seguifa were more promising in terms of their yields.

Medium maturing variety trial. The medium maturing trial was made up of twelve (12) entries, which were evaluated for yield, plant height and days to maturity. This trial showed more promise as most of the entries yielded above 1000 kg ha^{-1} The best line yielded 2072 kg/ha^{-1} compared to the local Faradawa 2020 kg/ha. Only three lines did not do well giving yields of less than 1000 kg/ha^{-1} (10-SB-F5DOT-210, 00-SB-F5DOT-427, AND 98-SB-F5D0T-170-1). Lines 12-G1-1—100-SB-F5DT-19 and 00-SB-F4DT-275-282 have been selected for multi-locational trials for their adaptability. Days to 50% flowering ranged from 71 for lines 00-SB-F5DT-427 and E2-B02-108 to 95cm for the local Faradawa.

Burkina Faso

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

J.B. Taonda, S. Pale, INERA; S. Mason, UNL
***Collaborators:* B. Albert, I. Ilboudo, B. Bougouma, INERA**

Objectives

- Conduct multi-year research on microdose, N and P fertilizer application on pearl millet grain yield, nutrient removal, and changes in soil nutrient levels.
- Conduct research on mechanized (i.e., animal traction) Zaï production system for pearl millet, production practices for traditional beer production.
- Collaborate with national extension services and NGO/PVOs in transferring improved pearl millet and grain sorghum agronomy practices.

Activities

Microdose fertilizer study. Three-year central studies were initiated on-station. A randomized complete designed study was used with four replications. Treatments consisted of zero, microdose (cap-full of complete fertilizer in the seed hill at planting), Microdose + 20 kg/ha^{-1} P, microdose + 40 kg ha^{-1} P, microdose + 30 kg ha^{-1} N, microdose + 60 kg ha^{-1}, microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N, and microdose + 40 kg ha^{-1} P + 60 kg ha^{-1} N. In addition, satellite studies were conducted on farms using zero, microdose and microdose + 20 kg ha^{-1} P or 20 kg ha^{-1} P + 40 kg ha^{-1} N treatments. One replication was planted per farm, and in the data analysis farms were considered to be replications. Analysis of variance indicated that grain and stover yields to fertilizer treatments varied by country and year. However, on the average, microdose fertilizer application increased grain and stover yield by 62% increase. Clearly the microdose application is a low cost investment that has a high probability to increase grain yields across the West Africa pearl millet production area. Yield responses were greater for P application than N application, but application of microdose plus 40 kg ha^{-1} P and 60 kg ha^{-1} N was required to maximize yields of grain and stover.

Zaï and other fertilizer treatments on grain. A study conducted at SARIA in 2002 and 2003 compared a no fertilizer check (farmer practice), microdose fertilizer application at planting, Zaï with compost 300 g hill^{-1} compost application, and the recommended fertilizer rate of 75 kg ha^{-1} of 15-15-15 complete fertilizer at planting and 24 kg ha^{-1} N 45 days after planting. Microdose and recommended fertilizer rates increased grain yield by approximately 600 kg ha^{-1} stover yield by approximately 1000 kg ha^{-1} (Table 2). The Zaï plus compost increased grain yield over the control by 1200 kg/ha^{-1}, and stover yield increased by 2000 kg ha^{-1}. The water conservation and nutrient supplying of the Zai plus compost system clearly increases yields greater than the other systems in the study.

Sorghum production practices for *dolo* (traditional beer). Previous research showed that the red grain sorghum varieties - IRAT 9 and ICSV 1001(Framida) - to be superior for *dolo* (traditional beer) production. A study was initiated in 2003 to develop production practice recommendations for grain yield and *dolo* quality. The study is being conducted with a randomized complete block and split plot treatment arrangement. The whole plot includes water management (shallow cultivation control, tied ridges, manual Zai), mechanized (animal traction Zai, and dry soil tillage) and split plots of fertilizer levels (zero, microdose with 4 g 15-15-15 per hill, recommended rate of 75 kg ha-1 15-15-15 plus 50 kg ha^{-1} urea, and microdose plus 20 kg ha^{-1} P and 30 kg ha^{-1} N). Grain yield and quality tests associated with *dolo* production are being collected. In 2003, tied ridges and mechanized Zai resulted in the highest yields for Framida, while tied ridges and dry soil tillage produced the highest yields for IR12. Also, the microdose plus 20 kg ha^{-1} and 30 kg ha^{-1} produced yields that were more than 50% higher than all the other fertilizer treatments.

Sorghum Disease Nursery
A. Neya, INERA; D. Rosenow, C. Magill TAMU

Objective

To identify resistance to multiple diseases in selected breeding lines assembled by NARS in West Africa.

Activities

The West Africa Sorghum Diseases Nursery (WASDON) comprised of 13 sorghum-breeding lines replicated two times in randomised complete block design. The materials were from Mali (3 entries), Nigeria (5 entries) and Burkina Faso (5 entries, including the local check). In order to increase the overall incidence and severity of leaf anthracnose, a mixture of three susceptible sorghum genotypes (i.e., IS 18442, IS 4585, IS 905) was planted prior to test genotypes, alternately every fifth row and as border rows on both sides. The field experiments were conducted at two locations at Farako-Ba (latitude 11° 11' N; longitude 4° 18'; altitude 432 m, and Niangoloko (latitude 10° 16' N; longitude 4° 55' W; altitude 320 m). Scorings were made for leaf anthracnose (*Colletotrichum graminicola*), sooty stripe (*Ramulispora sorghi*), grey leaf spot (*Cercospora sorghi*), zonate spot (*Gloeocercospora sorghi*), stalk red rot (*Colletotrichum graminicola*) and grain mold (complex of fungi) on 10 plants randomly tagged on the row next to the infector row.

Grain yield ranged up to 2506 kg ha^{-1} with a test mean of 1523 kg ha $^{-1}$. When days to 50 % flowering were considered, the earliest entry was BES-SAMSORG 4 (67 days), and the latest was SAMSORG 17 (109 days). Data show that plants height ranged from 139 – 357 cm with a test mean of 226 cm. Leaf anthracnose severity ranged from 1.6 to 4.5, the entry EPII-2002-19 from Burkina Faso being the most susceptible with a rating of 4.5. Grey leaf spot severity was low, ranging from 1.0 to 1.2. The severity of stalk red rot also was low with a test mean of 1.2. Mean severity of stalk red rot ranged from 0.4 to 2.2 (scale 0-5). Under the condition of Farako-Ba, symptoms of sooty stripe and zonate leaf spot were recorded in a few cases on lower leaves but they were observed on the four upper leaves. Grain mold severity ranged from 1.2 to 3.2 with test mean of 2.3 (scale 1-9). Considering the reaction of the genotypes to all diseases, the following entries exhibited field tolerance to multiple diseases: 02KIF-5T-22 and 99 SB-F-5DT-196 from Mali, SAMSORG 14 and SAMSORG 17 from Nigeria, and Sariaso 01 from Burkina Faso. These entries showed low leaf anthracnose severity (less than 2.0) and low grain mold severity (less than 2). The severities of different diseases were variable and none had multiple disease resistance.

***Striga* Control**
H. Traore, INERA; G. Ejeta, Purdue

This project was new and trials were planted in 2004. They include using: 1) water conservation, cultivar tolerance, fertilizer to control *Striga* in sorghum and millet in farmers' fields in eastern Burkina Faso, and 2) evaluation of sorghum cultivars for *Striga hermonthica* resistance in eastern Burkina Faso.

Sorghum and Millet Utilization
B. Bougouma, L. Ouattara, K. Zida,
B. Diawara, IRSAT; B. Hamaker, Purdue

Objectives

- To determine the nutritional and technological qualities of five sorghum varieties and five millet varieties used in Burkina Faso.
- To determine the impact of packaging in polyethylene sachets with thickness of 150 and 200 µm on the shelf life of three market products containing millet.

Activities

Characterization of sorghum and millet varieties for specific end uses. Three local varieties and seven selected varieties introduced recently into the central area of Burkina Faso for their high agronomic potential were characterized on the nutritional level. The varieties Sariaso 11, tan Nazongala, ICSV 1049, and Fibmega had comparably high protein contents of at least 12.3% db. Sarisao 14 had low protein content of 8.0%. Tests of suitability for local dishes and market products must be conducted to identify the suited varieties.

Conservation and packaging tests of millet-based products. The impact of polyethylene packaging thickness on shelf live of three millet-based products was studied. Polyethylene sachets with thickness of 150 and 200 μm were used to package millet rolled flour, millet simple flour and millet weaning food. Quality was evaluated by evolution of fatty acids and water content at room temperature. There was no significant difference in fatty acid contents between samples stored within the two thicknesses of packaging ($p = 0.15$), as well over times ($p = 0.83$). Water content also did not change among samples stored in different package thicknesses or over time. The three products kept good characteristics in the four months of storage; also the 150 μm thickness packaging material was found to be adequate and is economically profitable.

A survey is also being conducted on traditional malting and brewing processes in western Burkina Faso, and is a collaboration with the above agronomic study on production of sorghum for *dolo*.

Senegal

Cereal Technology Project (new)
A. N'Doye, ITA; B. Hamaker, Purdue

Characterization of the millet variety "Thialack". A local landrace millet cultivar "Thialack" has been found to be superior in making composite flour bread ("pan riche") compared to other cultivars. In this study, cv. Thialack is being characterized to understand the basis of its better bread-making quality so that tools can be developed to breed for improved millet varieties. Three millet varieties were tested in preliminary testing – Thialack, Sossat C, and Souna III. Electrophoresis of proteins showed little discernable differences among the three varieties. Starch and simple sugar analyses showed a higher level of total sugars in Thialack (4.3%) compared to Sossat C (3.5%) and Souna III (2.5%); starch analyses showed little differences, although there was a discrepancy in amylose values among three laboratories. Amylose content and starch structural characterization is being done.

Networking

Discussions were ongoing in West Africa for formation of a joint millet and sorghum network in the 2003-2004 year. ROCARS had some minimal activity in the region during this period. INTSORMIL supports the concept of a new network in the region, and looks to play an active role when renewed. Networking occurred with the Millet-Sorghum Initiative coordinated by Global 2000 involving contracting between farmers and processors, and farmer warrantage/contracting conducted by Ouendeba Botorou and John Sanders. World Vision supported seed activities in the Maradi region of Niger. Rockefeller Foundation, through Gebisa Ejeta, is supporting research to introduce *Striga* resistance into adaptable varieties.

West Africa - Western Region (Mali, Ghana, Senegal)

Darrell T. Rosenow
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Collaborative Program

The initial INTSORMIL collaborative program in this area was established in Mali which now has a large multidisciplinary research program. The program centers around Malian scientists and each Malian scientist develops research plans cooperatively with a U.S. counterpart which provides for effective research planning, communication, and coordination. Each year INTSORMIL collaborators travel to Mali or other host countries, or to PI conferences or workshops as appropriate, to observe field trials, consult, review progress and plan future activities with host country scientists. Occasionally, host country scientists also travel to the U.S. for research review, planning, and coordination.

The Mali program includes all aspects of sorghum/millet improvement with major emphasis on breeding or germplasm enhancement, utilization and quality, nutrient use efficiency, soil management, insect pests, disease control strategies, and *Striga* control. In Ghana, the program includes breeding, entomology, pathology, agronomy, and economics, while in Senegal it includes sorghum and millet breeding, entomology, pathology, and commercialization/transformation/marketing of grain.

In 2000-2001 a new thrust to the program previously centered in Mali began with the initiation of collaborative INTSORMIL research in Ghana and Senegal. An MOU between INTSORMIL and ISRA (Institute of Agricultural Research) in Senegal was signed in early 2001. An existing MOU with SARI (Savanna Agricultural Research Institute) in Ghana which involved agronomic research between Dr. S.S. Buah and Dr. J.W. Maranville was utilized and expanded to include the new collaborative efforts in Ghana. In 2002 a new MOU was signed between INTSORMIL and ITA (Institut de Technologic Alimentaire) in Dakar, Senegal which deals with commercialization of grain in Senegal.

Collaborative research was initiated in the 2001 crop season in both countries in breeding, pathology, entomology, and *Striga*, and also in agronomy in Ghana, continuing some of the research initiated in collaboration with Dr. Maranville. Breeding, disease, insect, drought, and *Striga* trials were developed collaboratively with Malian and U.S. INTSORMIL scientists and grown in Ghana and Senegal as well as in Mali. Some of these were also offered to scientists in Niger, Burkina Faso, and Nigeria, and scientists there requested seed of specific nurseries according to their interests and needs. Also, an elite sorghum germplasm nursery from worldwide sources was sent to Ghana and Senegal to broaden the genetic base of their breeding program. The mechanism for developing collaborative research plans is evolving as new INTSORMIL PIs initiate their programs, and PIs are able to interact and /or travel to these new countries. The PI Conference in Ethiopia in November 2002 served as the initial broad based planning conference for collaborative research efforts among Mali, Ghana, and Senegal as well as with the Eastern Region (Niger, Nigeria, and Burkina Faso) scientists. In April 2004, an INTSORMIL West African Regional Conference was held in Ouagadougou, Burkina Faso to finalize the merger of the Western and Eastern West African Regions into one overall West African Regional Program. The new structure became effective July 1, 2004.

Other Collaboration

Previous collaboration involving germplasm exchange, workshops, monitoring tours, and specific research projects with the regional networks ROCARS (WCASRN), and ROCAFREMI essentially ended in 2003. Unfortunately, ROCAFREMI ceased operation prior to the 2002 crop season, and ROCARS funding for the 2003 crop season was greatly reduced, effectively ceasing operation. Collaboration with ICRISAT at Samanko outside Bamako has continued, although on a more limited scale than in the past. There also was cooperation with NGOs such as World Vision, Winrock, AMEDD, FDS, GRADECOM, and other small NGOs in evaluation and seed increase of potential new cultivars as well as with the Soil Management CRSP and the SYNGENTA Foundation.

Financial Input

The USAID Mission has in the past provided significant financial support to Mali IER research program through the SPARC Project which ended in June 1997. In addition to the Malian Government, the Syngenta Foundation and World Bank support the IER research program.

Sorghum/Millet Constraints Researched

Plant Production Constraints

Grain yield level and stability in sorghum and millet production is of major importance in all the countries. Drought is a serious constraint to production over much of the area. Diseases, insect infestations and *Striga* significantly affect both sorghum and millet production. Head bugs and associated grain molds adversely affect sorghum yield and grain quality of sorghum. Anthracnose is a very severe sorghum disease in the more humid areas and long smut is severe in the drier regions. Sooty stripe can be a severe leaf disease problem. *Striga* is a major constraint for both sorghum and millet. Downey mildew is a serious problem on pearl millet as well as the head miner.

Land Production Constraints

Low soil fertility combined with the low yield and unstable yields of local cultivars affect sorghum and millet production. Major soil related constraints to production are phosphorus and nitrogen deficiency, and water stress. The population increase and increased demand for food has impacted the traditional multi-year land rotation system and contributed to reduced soil fertility and productivity.

Technological and Socioeconomic Constraints

There is a lack of farm credit policy which would encourage adoption of improved sorghum and millet new cultivars. In addition, the prices of these two predominantly subsistence cereals are low and unstable. New shelf-stable foods, industrial sorghum and millet based products, and enhanced use for animal feed are needed to encourage production. Effective supply chain management systems are needed to assure a consistent supply of good quality identity-preserved grain which is required for increased commercialization and transformation of sorghum and millet into value-enhanced products.

Research Methods

The collaborative program in the Western Region of West

Africa emphasizes research in breeding (germplasm enhancement), entomology, pathology, agronomy (soil, water, fertility relationships), weed science (*Striga*), cereal technology (quality and utilization), marketing, and technology transfer. An effort to develop new food products from sorghum and millet is emphasized along with the development of new cultivars with improved food quality traits. Major breeding activities involve the use of new genetic materials to develop cultivars to increase or stabilize yields of grain with enhanced food quality traits. Research methods appropriate for each of these are used in this research program.

Research Results

Details of some of the research in the area are presented in individual PI project reports in this publication. This host country annual report will emphasize research done by IER in Mali, SARI in Ghana, and ISRA in Senegal.

Sorghum Breeding - Mali

The sorghum-breeding program in IER in Mali is a large and diverse program. The program utilizes extensive crossing and intercrossing among elite introductions, improved non-guinea and guinea derived breeding lines, and elite local cultivars. It utilizes genetically diverse germplasm from around the world resulting in much genetic diversity in the breeding program. Use is made of elite lines from the U.S. and previously developed ICRISAT lines. Emphasis in the program centers on developing tan-plant true guinea cultivars, and on improving the head bug/grain mold resistance of high yielding tan-plant non-guinea breeding lines and guinea non-guinea intergrades. Essentially 100% of the breeding effort is directed toward white-seeded, tan-plant genotypes. Breeding for the dry northern areas also involves crosses with local Durras and good yielding Bicolor derivatives from the area and early Caudatum derivatives from Senegal.

A standard system of moving progenies along at the different locations is in place and understood by the technicians. The F_2, progenies are separated into early, medium, and late maturing groups and then selected and advanced at appropriate sites. Early materials are selected at the lower rainfall, more northern sites of Bema and Cinzana, while medium maturity materials are grown at Sotuba, Kolombada, and Cinzana. Late maturing progenies are evaluated mainly in the more southern, high rainfall sites of Farako (Sikasso), Finkolo, and Kita. Yield trials of advanced breeding lines also are divided into these three general maturity groups and corresponding sites.

New breeding crosses are made annually to assure the gradual improvement of new breeding materials through recombination of the best materials. In the 2003 rainy season, 79 new crosses were made at Sotuba, and the F_1s grown during the 2003-04 off-season nursery to produce F_2 seeds.

From the multilocation evaluation of 135 F_2 families in the 2003 rainy season, 366 single-plant selections were made at Samanko, 162 at Cinzana and 158 at Finkolo. These selections will be advanced by the pedigree method. The 866 F_3 progenies evaluated were mostly derived from tan guinea cultivars. The F3 families were grown at Samanko, Cinzana, Finkolo, Bema, and Kite, and selected were 183 single heads at Sotuba, 106 at Cinzana and 223 at Béma, and 48 at Finkolo and Kita. The F_4 and F_5 generations were evaluated according to the maturity group. The early and medium F_4 progenies were evaluated at Sotuba, Kolombada, Béma and Cinzana. Selected were 199 panicles at Kolombada, and 168 at Cinzana, and 246 at Bema. The late F_4 progenies were evaluated at Finkolo and Kita with 61 and 38 panicles selected, respectively, at Kita and Finkolo. In the early F_5s 18 lines at Béma and four at Cinzana were selected. The medium F_5 progenies were evaluated and we selected 43 lines (38 at Sotuba and 28 at Kolombada). A total of 38 lines were selected from late F_5 progenies at Finkolo and Kita. The F_5 selections move to the off-season for seed increase for entry into Group I yield trials the following year. Yield trials of new breeding lines and improved varieties in 2003 were divided into three maturity groups, Early, Medium, and Late with three groups (GI, GII, GIII) within each maturity corresponding to the years in tests (I - first year, II - second year, III - third year). Evaluation was for maturity, yield, agronomic desirability, and food quality.

Advanced Early Maturity Variety Trials

Three advanced elite early varieties groups (GI, GII and GIII) were evaluated at two locations, Bema and Cinzana. In GI (first year evaluation) at Cinzana and at Bema the analysis showed significant difference among entries for grain yield, plant height and flowering date. At Bema the highest yielding variety was 02-CZ-F5P-100 with 3278 kg/ha^{-1}, while the local check produced 1555 kg/ha^{-1}. At Cinzana the grain yield varied between 3671 and 1224 kg/ha^{-1} with thirteen varieties showed a yield gain of 20 to 27% compared to the local check.

In the GII (two year evaluation) at Cinzana and Bema there are no significant differences among lines for grain yield with the average yield at Cinzana 2354 kg/ha^{-1} compared to 1500 at Bema.

After three years of evaluation in the two locations (GIII), five lines 00-BE-F5P-15 (1766 kg/ha^{-1}), 00-BE-F5P-22 (1963 kg/ha^{-1}), 00-BE-F5P-23 (1773 kg/ha^{-1}), 00-BE-F5P-135 (1986 kg/ha^{-1}) and 00-BE-F5P-245 (1970 kg/ha^{-1}) were retained for grain yield and grain quality and will be in on-farm tests in 2004 (Table 1).

Advanced Medium Variety Trials

In the GI trial at Sotuba, with an average yield of 2688 kg/ha^{-1}, there were no significant differences among entries for grain yield. However, some entries 02-SB-F4DT-298, 02-SB-F4DT-275-282, 02-SB-F5DT-144, 02-SB-F5DT-142, 02-SB-F5DT-94, 02-SB-F5DT-12, 02-SB-F5DT-60, and 02-SB-F5DT-63 showed high grain quality and good plant architecture.

At Kolombada the average grain yield was 1463kg/ha^{-1} with significant differences among entries. The combined analysis of Sotuba and Kolombada indicated a good performance of 02-SB-F5DT-144 and 02-SB-F5DT-169. The local check with a grain yield of 2858 and 2500 kg/ha^{-1}. The variety 02-SB-F5DT-141 was most stable in the two trials with an average grain yield of 2369 kg/ha^{-1}.

In GII at Sotuba, the highest yielding variety 01-SB-F5DT-221 produced 3389 kg/ha $^{-1}$ and showed a yield gain of 16% compared to the check. The average yield was 2089 kg/ha^{-1}. At Kolombada, there were no significant differences among entries for grain yield with an average yield of 1984 kg/ha^{-1}.

In the combined analysis, the varieties 01-SB-F5DT-14 (2639 kg/ha^{-1}), 01-SB-F5DT-21 (2417 kg/ha^{-1}), 01-SB-F5DT-46 (2551 kg/ha^{-1}), 01-SB-F5DT-184 (2070 kg/ha^{-1}), 01-SB-F5DT-216 (2389 kg/ha^{-1}), 01-SB-F5DT-144 (2692 kg/ha^{-1}) and 01-SB-F5DT-221 (2709 kg/ha^{-1}) showed good performance compared to the average yield of 20033 kg/ha^{-1}.

After three years of evaluation at the two locations (GIII), with a mean grain yield of 2134 kg/ha^{-1}. The varieties 00-KO-F5DT-18 and 00-KO-F5DT-30 gave more than 2500 kg/ha^{-1} and performed well in the two localities during the three years of evaluation (Table 1).

Advanced Late Variety Trials

Elite varieties were yield tested agronomically along with Foulatiéba and local check at two locations in North Guinea Zone of Mali in a randomized complete bloc design. Each plot

Table 1. Mean performance data of selected improved breeding varieties from sorghum yield trials, 2001-2003, Mali.

Designation	Pedigree	Days to 50% flowering	Plant height (m)	Grain yield (kg/ha^{-1})
Early GIII - (3 years - 2 locations)				
00-BE-F5P-15*	((M84-7*Nagawhite)*M84-7)	80	1.7	1766
00-CZ-F5P-22*	((M84-7*Nagawhite)*M84-7)	81	1.6	1963
00-CZ-F5P-23*	((M84-7*Nagawhite)*M84-7)	81	1.5	1773
00-BE-F5P-135*	((M84-7*Nagawhite)*CEM326/11-5-1-1)	75	1.7	1986
00-BE-F5P-245-2GR*	(M84-5*(CSM388*Sureno))	80	2.1	1970
Malisor 92-1 (check)		74	1.9	1853
CSM-63 (check)	Improved Local	73	2.4	1478
Local Check	Local Cultivar	73	2.7	1629
(Test Mean)		77	1.85	1664
Medium GIII - (3 years - 2 locations)				
00-KO-F5DT-18*	((M84-7*Nagawhite)*CEM326/11-5-1-1)	92	1.8	2682
00-DO-F5DT-30*	((M84-7*Nagawhite)*CEM326/11-5-1-1)	95	2.0	2575
00-DO-F5DT-386	(CGM-19/9/1-1*(M84-7*CSM-388)	95	2.7	2266
CSM-388 (check)	Improved Local	93	3.6	2270
Local Check		80	3.8	2310
(Test Mean)		89	2.6	2134

*Entries to be advanced to on-farm trials in 2004.

Table 2. New Malian white-seeded, tan-plant sorghum breeding lines recently released and named in Mali.[1/]

Name	Designation	Pedigree	Days to flower
Wassa	97-SB-F5DT-63	(N'Tenimissa*Tiemarfing)	77
Kénikédiè	97-SB-F5DT-64	(N'Tenimissa*Tiemarfing)	78
Darrellken	99-BE-F5P-128-1	(N'Tenimissa*Seguetana CZ)	79
Niéta	97-SB-F5DT-74-2	(N'Tenimissa*Tiemarfing)	83
Zarra-blè	96-CZ-F4P-98	(N'Tenimissa*Tiemarfing)	94
Zarra-djé	96-CZ-F4P-99	(N'Tenimissa*Tiemarfing)	90
Niétichama	97-SB-F5DT-150	(92-SB-F4-14*92-SB-F4-97)	89

[1/]The top six cultivars are all true guinea types, but with tan plant. The last cultivar is an intermediate caudatum-guinea type. Tiemarfing is a Malian local landrace guinea type sorghum.

consisted of four rows, 0.75 m apart and five m long. Cultivars were evaluated for maturity, yield, agronomic desirability and food quality.

In the G1 at Kita significant differences were observed among entries with an average grain yield of 2207 kg/ha^{-1}. Entries 02-F1-F5T-38 (3000 kg/ha^{-1}) Foulatiéba (3611 kg/ha^{-1}), and Zarra (3056 kg/ha^{-1}) performed well. At Finkolo there was no significant difference in grain yield. In GII, no significant differences were observed among varieties. There was no GIII trial in 2003.

On-Farm Trials

Six farmers were selected in each of two locations, Cinzana and Sirakorola where 15 new early maturing breeding varieties were compared to the local of the farm. At both locations, there were no significant differences for grain yield, indicating equal to, but not greater than, the farmers local. In the second year on-farm trials with six farmers at two locations, there was no significant difference among entries for grain yield, but one line, 98-BE-F5P-84, had superior grain quality compared to the local.

For medium maturity varieties, six farmers each at Ouéléssébougou and Bancoumana evaluated nine new varieties compared to the local check. At Ouéléssébougou there were significant differences among entries for grain yield with the line 98-BE-F5DT-82 ranked first with 1400 kg/ha^{-1}, followed by 98-SB-F5DT-52 and 98-SB-F5DT-19-3. The entry 98-SB-F5DT-52 was appreciated by farmers for both forage and grain quality.

For late maturing on-farm trials, four new tan-plant varieties were compared to the local check by six farmers each at two sites, Kita and Kébila. At Kébila, three of the new varieties produced yields equal to the local check, Zarra, Kénikéba, and 98-SB-F4P-98. In an on-farm large adoption trial at Kébila, Zarra yielded 960 kg/ha^{-1} compared to the local with 810 kg/ha^{-1}, and Zarra had superior grain and food quality.

New Developed Cultivars

Six new N'Tenimissa derivative tan-plant IER developed breeding guinea lines and one intermediate caudatum-guinea line have been named and released in Mali, or distributed thru on-farm trials, demonstrations, or NGOs. Their names, pedigrees, previous designations and days to flower are given in Table 2. The guinea cultivars have superior grain quality and less stalk breakage than N'Tenimissa.

Seed Multiplication

Listed below are some improved cultivars and new breeding lines for which seed was increased by the Mali IER sorghum breeding program in 2003 for distribution, NGOs, on-farm trials and demonstrations, and future seed increase.

Varieties	Localities	Area (ha)	Quantity (kg)
CSM-63 E	Béma	1	1000
Malisor-92-1	Béma	1	600
CSM-388	Kolombada	1/2	400
Kinikeba	Sotuba	1/4	100
N'TENIMISSA	Kolombada/Tamala	1/2	600
Wassa	Cinzana/Kafara	3/4	800
Darrelken	Cinzana	1/4	300
Niéta	Tamale	1/2	587
98-BE-F5P-84	Cinzana	1/4	400
98-BE-F5P-84	Kolombada	1/2	700
96-CZ-F4P-98 (Zarra-blé)	Kita/Kebila/Tamale	1 1/2	1800
96-CZ-F4P-99 (Zarra-bjé)	Kita	1/4	100

Hybrid Development

In a cooperative IER/ICRISAT project supported by the Rockefeller Foundation some hybrids involving newly sterilized A-lines (BC4) were planted for observation in 2003. Some tan-plant Guinea0Caudatum intermediate lines of short stature and sterilized by IER (97-SB-F5DT-150, 154, and 160) produced good hybrids but their sterility was poor, resulting in numerous female selfs, thus these lines are probably not useable as females. One female from Burkina Faso, Sariaso9, a purple plant Guinea type cultivar was fine on sterility, but possessed the dominant B1 gene and produced very tall, brown, high tannin hybrids.

The white, tan-plant guinea cultivar, N'Tenimissa, has good sterility as an A-line, and makes good, but very tall, hybrids, and has the recessive b_1 gene. New N'Tenimissa derivative with shorter stature should be good candidates for new B-lines to sterilize N'Tenimissa produced higher yielding hybrids than true guinea A-line such as CSM-219 or Seriaso 9. Two IER breeding guinea type lines produced good hybrids (and have the recessive b_1 gene), 96-CZ-F4P-98 and 02-SB-F4DT-57.

Four IER tan-plant guinea-breeding lines introduced into the U.S. showed a good B-line reaction in Puerto Rico, and are recessive b_1. The BC2 of the A and the B0line were sent to Mali for further sterilization and evaluation in 2004. The four are: 99-CZ-F5-131 (N'Tenimissa*Seguetana CZ); 98-SB-F5DT-17 ((M84-7*N'Tenimissa)*N'Tenimissa); 98-SB-F5DT-52 (N'Tenimissa*CSM-388); and 99-SB-F5DT-169/98-SB-F4DT-164-1 (N'Tenimissa*CSM-388). It appears that the Caudatum derivatives involved in at least part of the hybrid significantly increases heterosis compared to true Guinea hybrids.

In another study, 35 diverse Mali indigenous cultivars from the Mali Sorghum Collection and 30 Guinea-Caudatum derivative exotics from southern Sudan were evaluated as potential breeding germplasm to use in a hybrid-breeding program. They were evaluated in Puerto Rico and Mali for hybrid vigor, B/R fertility reaction, and pressure of the dominant B1 gene (gives test with U.S. Females). Data is presented on page 88 (TAM 222) of the 2003 INTSORMIL annual report. Most Malian cultivars were restorers except for a few Guinea types, especially Margarita ferum types. Essentially all the Guinea-Caudatum cultivars from southern Sudan were strong restorers and had the dominant B1 gene. The B1 gene was absent in most Durra and Durra-Bicolor Malian lines, and some of them showed promising heterosis. Thus, they could be useful in breeding non-guinea cultivars for northern Mali.

Sorghum Breeding - Senegal

At Bambey, two yield trials were grown involving selected lines from previous INTSORMIL observational nurseries. Based on agronomic performance, the genotypes 97-CZ-F5-28; 96-CZ-F5P-12; KSV111; 99-EA-P102 and ISCV 401*S34 were chosen for inclusion in multi location tests in 2004. In another trail involving lines developed in Burkina Faso and received frmo CIRAD three lines were selected, CEF418-/1-3-2; Cirad 439, and Cirad 440 for use in the 2004 field trials at several locations. Highly performing lines were observed for the new INTSORMIL observation Nursery; namely 98-CZ-F5P-83 and Seguifa. From the dwarf guinea population originally obtained for ICRISAT, 6 families were selected with plant height ranging between 168 and 190 cm., and grain yield of 180 to 2350 kg/ha^{-1}.

F_2 segregating populations involved crosses between Sorvato1, a high yielding line with good grain qualities identified from the ROCARS trials and the local varieties CE151-262, CD145-66 and 180-33 were grown. Segregating populations of those same three lines with very earliness sources were also grown with the F2 and BC1F1. The objective is to develop very early materials (about 80 days from planting to maturity) for the northern zones.

At Kolda, two observation nurseries from ICRISAT were grown with eight lines selected from the 25 entries, IS3443, IS22680, ICSV902, ICSV2N, S8135, Sariasso-10, ICSV1063, and ICSV1079. From the dwarf S1.2 guinea population, 139 plants were selected based on agronomic performance.

From the INTSORMIL collaborative West African yield trial, which was comprised of medium maturity lines, it was observed that the highest performing were CSM-388 and SSV 20031, producing 2462 and 2084 kg/ha^{-1} compared to 1421 kg/ha^{-1} for the local check F2-20.

Sorghum Breeding - Ghana

The nation-wide sorghum germplasm collection continued in October-December, 2003 in the whole Upper West Region and six districts in the Northern Region. In all, 467 accessions have been collected so far. Visually, the collections show a wide range of seed size, grain color, and panicle shape. Agro-morphological evaluations at two locations in 2002 and 2003 were carried out on the 2001 and 2002 collections. Maturity and grain yield varied considerably among entries and from year to year. Most accessions appear genetically low yielding, but they do possess good food quality according to the farmers. All accessions will be evaluated in 2004 and the nutritional and functional properties of some of the promising accessions as well as advanced breeding lines will be determined in collaboration with the Ford Research Institute.

One hundred and ten INTSORMIL breeding and germplasm lines were planted for observation, selection, and subsequent use. However, poor stands and excessive midge damage made the plantings useless. New seeds will be replanted in 2004.

Millet Breeding

Mali

The 40-entry Regional Millet variety trial developed cooperatively among West African millet breeders and Dr. Jeff Wilson was evaluated. There was a great range in days to flowering, from 38 to 90 days. Panicle length also varied greatly, from 5 cm to 80 cm. Most of the long panicle varieties were from Niger. The trial was also scored for head miner incidence and downy mildew, the most miner susceptible lines being 99-72, DMR72, PT7328, Tongo Yellow, and Sosat. The varieties 3/4 Souna, 99-72, ICMVIS90311, and IBMV8401 had no downy mildew. There also were significant differences for grain yield, with Indiana 05 and ICMVIS89305 having the highest grain yield with 2000 kg/ha^{-1}.

On a trial involving a hybrid, the hybrid grain yield was not better than the original parents, and was less than other millet varieties (Table 3). During the off-season, crosses were made with eleven male parents onto the male sterile Civarex 9105_{A4} for future hybrid evaluation.

Senegal

A 40-entry yield trial was conducted collaboratively with the University of Georgia. The objective was to evaluate the productivity and the grain quality of 40 genotypes of West Africa and USA origin and to identify parents to be included in the breeding process. The genotypes consisted of open pollinated varieties, hybrids and lines. With a mean yield of 930 kg/ha^{-1}, the best performing were ICMV IS 89305 (2331 kg ha^{-1}), Sosank (2163 kg ha^{-1}). (Table 4) Four entries, 99-72, P1449-2, 3/4 EX Bornu and 99M59043Mw x 68 A4R4, were free of smut while T99B, 01 Miso NCD23-NE, 68A x 086, 3/4 Souna, and Kapelga were highly susceptible to mildew. The SOSANK, SOSAT C88, Taram, Gwagawa and ICMB IS 89305 cultivars will be further evaluated.

On-farm test were conducted with the varieties BGB 8735 and ICTP 8203 in the direr northern zones. They were highly appreciated for their earliness, but have short panicles. Seed multiplication of the new synthetics; ISMI 9301, ISMI 9506 and ISMI 9404 was carried out at Bambey, Simthiou, and Kolda. The quantity of seed obtained (ISMI 9304:45 kg, ISMI 9506:13 kg, ISMI 9404:1.6 kg) will be used in the 2004 on-farm trials.

Table 3. Hybrid Civarex 9105A$_4$ x TrombedieR$_4$ performance evaluation, 2003, Cinzana, Mali.

Varieties	Plant height (cm)	Days to flower	Panicle length (cm)	Number heads harvested	Grain yield (kg/ha^{-1})
Civ 9105A$_4$ x TrombedieR$_4$	232	61	31	90	2470
Civarex 9105	223	40	30	92	3750
Trombedie	254	64	31	70	2470
NKO x TC1	335	75	34	66	3720
TC1	344	71	34	71	3750
Boboni (loca)	357	79	33	66	3720
CV (%)	4.2	19.4	5.8	15.5	8.5
Significance	HS	S	NS	NS	HS

Table 4. Results from the collaborative millet trial, 2003, Bambey, Senegal.

Variety	Grain yield (kg/ha^{-1})	Days to 50% flower	Plant height (cm)	Head length (cm)	Panicle diameter (cm)	Panicle length (cm)	Number plants	Number heads	Head weight (g)	1000 grain (g)
Sadoré local	1039	60	244	55.5	2.3	-5.0	12	56	2685	10.5
Kapelga	266	70	256	29.4	2.1	6.5	14	35	827	10.6
Torinio	755	62	279	40.1	2.4	5.9	14	64	1960	9.8
Zatib	1624	50	239	53.9	2.6	-3.9	14	134	3283	10.2
Zongo	555	63	248	76.7	2.3	-10.4	8	26	1325	8.5
HKP	1661	53	235	56.5	2.1	-0.6	10	69	3211	8.3
CIVT	2128	44	244	58.3	2.3	-2.3	14	77	4093	10.1
SOSAT C88	2028	48	202	28.3	3.1	5.5	14	90	3563	8.4
Taram	1472	55	229	66.7	2.6	-7.0	13	69	3133	8.6
SOSANK	2163	49	188	27.1	3.4	4.9	15	99	4051	7.6
ICMV IS 89305	2331	53	226	51.2	2.3	1.2	13	92	4208	8.4
ICMV IS 90311	1342	53	235	42.5	2.5	0.1	13	76	2709	9.4
Synthetic 1-2000	677	65	245	38.1	3	0.1	13	51	1850	9.5
NKO x TC1	375	60	240	36.3	2.3	4.1	9	34	923	7.7
Guéfoué16	593	67	291	38.7	2.3	6.3	12	70	1801	9.4
Indiana 05	782	64	270	42.6	2.5	1.7	13	77	2407	8.6
NKK	794	63	262	46.0	2.7	3.9	15	78	2371	9.3
Bongo Short Head	952	43	158	8.8	3.6	5.3	12	95	1796	8.2
Manga Nara	987	42	181	20.7	3.0	5.9	12	81	1791	9.3
Arrow	1023	44	215	33.1	2.1	4.1	15	57	1888	8.6
Tongo Yellow	702	45	192	22.9	3.3	9.4	10	75	1310	10
PT 732B	702	52	152	31.5	2.2	1.7	9	88	1588	8.9
P1449-2	865	51	158	28.1	2.3	-1.7	11	51	1685	10.4
3/4 Ex Bornu	687	47	168	42.1	2.7	0.7	12	78	1667	8.8
3/4 HK	601	59	138	40.6	2.3	-1.1	9	58	1446	9.6
3/4 Souna	450	55	106	33.9	2.3	-0.2	10	47	957	9
Gwagawa	2085	49	232	26.2	2.6	7.3	14	112	3748	7.6
LCIC 9702	691	47	140	24.1	2.6	3.7	9	54	1422	9.1
DMR 15	872	58	181	25.1	2.7	-3.6	13	68	1951	9.2
DMR 68	533	58	211	27.4	2.6	-1.1	11	46	1328	7.9
DMR 72	418	64	212	29.2	2.4	-0.3	10	56	924	9.6
GB 8735	1120	39	160	23.9	2.9	4.7	11	111	2186	8.9
99-72	166	53	118	16.3	2.4	2.1	10	45	560	8.3
TG102	851	36	115	26.1	2.7	10.7	14	69	1934	9.6
T99B	497	52	153	3.8	2.1	2.5	9	59	1527	10.2
T454	94	52	101	27.5	2.5	5.8	10	52	320	8.3
IBMV8401Mx 68A4R4w	574	45	126	33.3	2.6	9.5	12	86	1307	8.7
01 Miso NCD2-NE	672	46	97	28.2	1.8	5.5	10	91	1458	10.8
68A x 086R	498	34	112	21.9	1.7	17.1	13	85	989	9.7
99M5904Mw x 68A4R4	466	38	104	24.8	3.8	934	13	88	1148	8

The 40 genotypes in the collaborative yield trial were also tested for reaction to *Striga* in a screen house. *Striga* emergence was very early on GB8735, and IBMV8401M X 68A4R4@ and occurred 38 days after planting while it was late with Sadore local, Zongo, Guefoue, and Tongo yellow (62 days after planting). On four genotypes, emergence was not observed, these being HKP, NKO x TCI, Indiana 05, and NKK. Sosat C88, Arrow, DM$68 and ICMVIS 89305 have shown high susceptibility to *Striga* . The *Striga plants* that emerged on PT732B, Guefoue 16 and T99B died 10 days dater and did not complete their biological cycle.

Striga

Mali

Thirty-three early, thirty-two medium and fifteen late maturing breeding lines selected from the breeding program were evaluated for *Striga* in field trials in 2003 at Sotuba. *Striga* infestation level was low in all three trials and the results showed no significant differences among entries.

A 20-entry collaborative nursery with varieties from Nigeria, Burkina Faso and Mali was planted at Sotuba and Cinzana for *Striga* evaluation. *Striga* infestation was low, with no significant difference among entries on *Striga* counts at 75 and 95 days. Grain yield differences were significant at Sotuba with SSV200123, Sequetana, Komo Farfara, KL3, CEF 322/35-1-2, and EPII-2002-17 producing well with over 2000 kg/ha^{-1}.

Senegal

Field and screen house trials were conducted to evaluate the reaction to *Striga hermonthica* of genotypes from Mali, Nigeria, Burkina Faso and Senegal. The field trials had no *Striga* emergence while in the screen house, pots were infested with *Striga* harvested from a sorghum field. *Striga* emergence was low but Seguetana showed some resistance. *Striga* emergence was significantly delayed in CMDT-38 (111 days after planting) compared to Kamo Farafara (58 days) and Twin secdeel (65 days) both from Nigeria. Improved varieties from Senegal showed high susceptibility.

Ghana

Fourteen lines and cultivars contributed by INTSORMIL, Mali, Nigeria, and Burkina Faso were evaluated in a *Striga* infested field (on-farm) in 2203 at Yendi. *Striga* infestations were higher in 2003 than in 2002. The 14 lines screen showed varied levels of *Striga* infection/resistance (Table 5). In 2003 the lines 97-SB-F5DT-63, 97-SB-F5DT-64, and SRN 39 showed quite a high level of resistance to *Striga* but had very low yields. Conversely, CMDT-45 was quite tolerant to *Striga* as it combined high yield (1156 kg/ha^{-1}) with high *Striga* infection. SAMSORG 14, CMDT-39 appeared to be the most susceptible and N'Tenimissa being moderately susceptible. There didn't appear to be distinct correlations between the *Striga* infestations and their corresponding yields for the two years.

Pathology

Mali

For anthracnose, out of 88 breeding lines screened artificially at Sotuba, 02-SB-F5DT-9, 02-BE-F5P-90, 02-CZ-F5P-96 (02-CSM409C*N'Tenimissa)-2, 02-SB-F4DT-275-282, 02-SB-F5DT-12, 02-SB-F5DT-26, 02-SB-F5DT-93, 02-SB-F5DT-149, 02-SB-F5DT-180, 02-KI-F5T-44 and F2-78 showed a good level of resistance to the disease.

In the West African Disease Observation Nursery (WASDON), SAMSORG14 from Nigeria, OUEDZOURE from Burkina Faso and CSM660, Sakoika02, 00/ISO-CSM335 from ICRISAT/Samanko screened for the third year were considered resistant to anthracnose.

Table 5. Performance of selected sorghum varieties in *Striga* infested field at Yendi, Ghana in 2002 and 2003.

	Grain yield (kg/ha^{-1})		*Striga* count at maturity (No/ha)	
Line	2002	2003	2002	2003
CMDT-38	568	568	7	46
CMDT-39	578	578	8	179
SEGUETANA	472	472	9	54
CMDT-45	711	711	32	163
97-SB-F5DT-63	395	395	28	7
97-SB-F5DT-64	2232	2232	6	40
N'TENIMISSA	474	474	47	86
97-SB-F5DT-65	690	690	2	60
MALISOR-92-1	1011	1011	12	42
MALISOR-8401	627	627	2	66
CD-151-202-A1	341	341	39	58
SRN 39	-	-	-	30
SAMSORG 41	-	-	-	47
SAMSORG 14	-	-	-	225
Grand Mean	736	736	18	79
CV (%)	57	57	24	107
LSD	717	605	7	141

Table 6. Field reaction[1] of sorghum genotypes in WASDON trial, Nyankpala, Ghana, 2003.

Entry	Grey leaf spot[1]	Leaf blight	Long smut[1]	Zonate leaf spot[1]	Shootfly infestation (%)
BES-SAMSORG 4	2.0	6.0	1.0	3.0	85
NR-71168	3.0	1.0	1.0	2.0	19
99-SB-F5DT-154	4.5	1.0	1.0	4.0	47
97-SB-F5DT-154	3.0	1.0	1.0	3.0	19
EP 11 2002-1	2.0	2.0	1.0	2.0	65
TEMOIN DELA ZONE	3.5	2.0	1.0	3.0	29
SAMSORG 14	1.0	1.0	2.2	1.0	27
EP 11 2002-3	2.0	1.0	1.0	3.0	26
SP 11 2002-9	1.0	1.0	1.0	1.0	36
SAMSORG 17	1.0	6.5	2.2	1.0	12
EP 11 2002-19	3.0	2.0	1.0	3.0	22
02-K1-F5T-22	1.0	2.5	1.0	2.0	30
SAMSORG 40	1.0	3.0	1.0	3.0	19
CV (%)	35	51	15	26	54

[1]Based on rating scale 1-9: 1 = no disease; 2 = 1-5%, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 41=50%, 8 = 51=-75%, and 9 = > 75% of leaf area of the plant or panicle parts damaged by the disease.

Three years results indicated that covered smut incidence can be reduced by dressing sorghum seeds with 20 g of (Diro+Nguo+Nere) powder/kg of seed while grain yield can be increased to 56%. This plant pesticide can replace conventional fungicides such as Apron Stars in the future.

Senegal

From WASDON nursery, it was found that the lines 99-SBF5DT-196, 97-SBF5DT-154, and 02-KIF5-22 were highly resistant to grain mold, while Samsorg 14 and Samsorg 17 were resistant to *Ramulospora*, and EP 11 2002-19 and 02-KIF5T-22 were resistant to anthracnose.

Ghana

The 13 entry WASDON was rated for several diseases in 2003 with several showing good resistance to each of the four diseases (Table 6). The 60 entry ADIN was evaluated at Nyankpala in 2003 for gray leaf spot, leaf blight and zonate leave spot, with leaf blight, infestation being very light. ADIN entries which scored the most resistant to gray and zonate, with either no disease of no more than 5% leaf area infested included: SC414-12E, 86EO361, 90EO328, 96CD635, 96CD677, 92BD1982-4, 99GW092, B.HF14, 95BRON155, 96GCP124, 96GCPOB143, 96GCPOB160, 97BRON179, 91BE7414, BTx2928, RTx2925, RTx2914, RTx2919, RTx2916, BTx2923, Sureno, Tx 436, and BTx631.

The 40 entry collaborative INTSORMIL/ARS 206 regional West Arica pearl millet trial was evaluated for disease and agronomic traits (Table 7). Downey mildew was quite severe, but several entries showed good resistance. Ten entries yielded over 1,000 kg/ha^{-1} which is considerably above the traditional system yields of 200-700 kg/ha^{-1}.

Entomology

Senegal

A trial was conducted at Nioro to evaluate the effect on several species of head bugs of botanical (neem extract) and insecticide (decis) on different varieties. Eight different pest species were observed with *Eurystylus immaculatus, Ceontiades pallidus* and *Spilostethus sp* being dominant, with respectively 66%, 21%, and 6% of the total number of insects observed. The insect populations were reduced by 40% and 52% respectively with the neem and decis treatment compared to the untreated plots. The reductions were 43% and 58% for *Eurystylus immaculatus*. CE151-262, F2-20 and Malisor 84-7 were less infested by *Eurystylus*_with 6, 7, and 7.3 insects/panicle respectively while CE180-33 had the highest infestation with 14.8 insects/head. The amount of grain loss varied between 36.7% and 43.3% for F2-20 and CE 151-262 to 77% for CE245-66. For CE196-7, CD183-333 and Malisor-84-7, the loss was 50-52%.

Ghana

Seventy-five sorghum lines from the local breeding, ICRISAT, and other NARS in West Africa were planted for evaluation for multiple insect resistance (shootfly, head bugs, grain mold, and midge) at Manga. Poor germination and lateness due to photoperiod sensitivity rendered the results unreliable. The study will hopefully be repeated with earlier lines.

Table 7. INTSORMIL ARS 206 Multilocation West Africa Pearl Millet Trial, Ghana, 2003.

Entry	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle diameter (cm)	Downy mildew incidence (%)[1]	Yield (kg/ha⁻¹)
Sadore local	64.0	259.0	49.7	1.9	7.3	355
Kapielga (Burkina local)	94.7	251.3	23.0	1.6	40.3	133
Toronio (Mali local)	75.3	289.7	33.0	2.1	22.0	178
Zatib	49.7	202.7	52.3	2.2	0.0	645
Zongo	55.3	260.7	70.7	2.1	0.0	556
HKP (GMS)	50.0	242.7	56.3	2.1	2.7	911
CIVT	50.0	229.0	55.3	2.0	0.0	1156
Sosat C-88	52.0	201.3	22.0	2.8	3.0	1022
Taram	50.3	232.3	70.3	2.2	1.3	600
SoSant	52.0	201.7	26.3	3.0	0.0	600
ICMV IS 89305	53.3	236.0	50.0	2.0	0.0	644
ICMV IS 90311	53.7	207.0	41.3	1.8	0.0	555
Synthetic 1-2000	81.0	236.3	30.0	2.3	8.3	222
NKO x TC1	84.0	233.0	30.7	1.3	13.3	178
Guefoue 16	87.3	206.0	25.7	1.6	5.3	156
Indiana 05	86.7	225.7	32.7	2.2	1.3	142
NKK	79.3	268.0	38.0	2.2	18.0	178
Bongo short head	43.7	164.7	10.7	3.3	32.0	1205
Manga nara	40.7	163.3	17.7	2.7	33.3	1200
Arrow	44.3	200.0	28.3	1.9	13.0	1089
Tongo Yellow	42.3	173.7	31.3	2.7	31.7	1044
PT732B	52.0	103.3	23.0	1.9	51.0	467
P1449-2	53.7	191.0	30.0	1.8	11.3	600
3/4 Ex Bornu	48.0	119.3	40.7	1.6	0.0	533
3/4 HK	56.7	144.7	49.3	2.0	5.3	400
3/4 Souna	53.0	142.0	38.7	1.8	1.7	200
Gwagwa	57.7	238.3	24.3	2.3	0.0	600
LCIC 9702	43.3	148.3	23.7	2.5	30.0	667
DMR 15	56.0	170.7	20.7	2.5	1.3	204
DMR 68	54.3	193.3	27.7	2.2	12.0	356
DMR 72	51.7	212.0	33.0	2.2	2.7	400
GB 8735	39.0	144.0	20.3	2.4	38.3	1245
99-72	50.0	118.3	23.7	2.5	4.0	111
TG102	37.7	90.3	23.7	1.9	66.3	711
T99B	44.7	61.7	39.3	1.5	96.3	222
T454	44.3	53.7	18.3	1.5	91.3	356
IBMV8401Mx68A-4R4w	42.3	117.0	25.0	2.1	29.7	1111
01Miso NCD2-NE	45.7	105.3	35.7	1.7	16.3	822
68A x 086R	37.3	109.7	19.3	1.8	55.0	1045
99M59043Mw x 68A4R4	37.7	96.7	21.0	2.1	75.0	1156
LSD	3.6	32.9	14.0	0.3	11.6	575

[1]Percentage of plants infected by downy mildew at 70 (soft dough stage) days after planting.

In a study on the effect of planting date and host plant resistance on sorghum IPM, three varieties, Malisor 84-7 (head bug resistant), Kobori (local guinea) and Kapaala (ICSV 111-N) were planted on three dates, early-June, late-June, and mid-July. Head bug (*Eurystylus oldi*) populations increased on all three varieties with delayed planting with Malisor 84-7 showing the lowest infestations in the early planting. Grain yield of all three declined with later plantings, with the local being affected the least. Yield reductions in the mid-July planting ranged from 43% to 72%.

Mali

Several entomology trials were conducted in Mali in 2003. Three preliminary head bug (*Eurystylus*) screening nurseries of primarily IER new breeding lines were conducted at Sotuba in 2003. They were evaluated using natural infestation and cages and pollinating bags to cover panicles at their emergence. At the hard dough stage head bug counts were made. At maturity, visual head bug damage ratings and grain mold ratings were made on the grain. The head bug rating scale ranged from 1, where all grain was well developed with only a few feeding punctures visible to 9 where most grain were brown and/or withered and barely visible through the glumes due to feeding damage. The grain mold rating scale was from 1 to 5. Also, in the laboratory, grain was evaluated for hardness, grain weight, and germination. In Nursery No. 8, 113 lines were evaluated for their third year, and forty-six were resistant to both head bugs and grain mold. In Nursery No. 9 with 109 entries (second year), there were 28 with head bug ratings of 1.0. In nursery No. 10 (first year of evaluation), 17 out of 77 were resistant to head bug damage.

Table 8. Damage assessment of sorghum midge, head bug, grain mold, and seed weight of S34 treated with local plant extracts and Dursban, 2003, Mali.

Treatments	Mean midge damage rating	Mean head bug damage rating	Mean grain mold rating	Mean grain weight of central row panicles(g)
T1: unsprayed check	3.63 a	5.06 a	2.66 ab	633.3 bc
T2: neem seed jelly 80 g/liter	3.20 ab	5.40 a	2.86 a	733.3 bc
T3: neem seed jelly 160 g/liter	2.26 bc	5.00 a	2.60 b	766.6 bc
T4: *C. procera* leaves juice 25 kg/301	2.63 abc	5.33 a	2.70 ab	500.0 c
T5: dursban	1.83 cd	3.30 b	2.53 b	966.6 ab
T6: protected panicle	1.00 d	1.00 b	1.00 c	1200 a
C.V. (%)	36.73	14.96	6.77	22.72
Probability	0.048	0.00	0.00	0.005
Significance	S	HS	HS	HS

Means followed by the same letter for damage score or weight within the column are not significantly different at 5% (Duncan range test).

Of two Advanced Trials, one was lost due to flooding. In the other, five breeding lines were evaluated for head bug resistance under artificial screening, with 20 pairs of bugs per caged panicle. The five advanced breeding lines, 99-CA-F5P-136-2, 99-CZ-F5P-131-2, 99-CZ-F5P-97-2, 99-SB-F5DT-170-1, and 99-SB-F5DT-49-2 all showed excellent head bug resistance, equal to Malisor 87-7, based on number of bugs and larvae per panicle, weight of 200 seed, and grain mold and head bug damage ratings. All entries had head bug and grain mold ratings of essentially 1.0, indicating no damage. In all cases, the infested panicles gave similar results to the cage and pollinating bag-protected panicles.

The effectiveness of local plant extracts (neem seed jelly and *Calotropis procera* leaf juice) and Dursban on midge and head bug damage was studied on a head bug susceptible cultivar (S34) under natural infestations. Bug counts were made a week after treatment. At maturity, head bug and midge damage and grain mold ratings were made along with grain weights. There were significant differences among treatments for traits with data presented in Table 8. Protected panicles showed no damage or insect pests and the best grain yield, and in most cases Dursban was not significantly different from protected. Meanwhile, the untreated check had high ratings and was statistically different in most cases from the low neem jelly or the *C. procera* juice treatments. The high rate of neem jelly was consistently superior to the low dose in insect damage and grain mold ratings. Overall, Dursban gave better insect and grain mold control than the local plant extracts.

In another study, the effect of various crop residue management treatments involving sorghum, millet, and maize on control of stem borers was investigated. Treatments were sole sorghum, sorghum + maize, and sorghum + millet, each with two residue management treatments; (1) Residues removed after harvest and (2) Residues left in field and chopped and buried at planting date. Leaves and stems of subsequent crops were checked for stem borers from the seedling stage to maturity. High numbers of borers were found in the sorghum + millet regardless of the residue management scheme used, but with '2' above the highest. *Coniesta ignifusalis* was the dominant species. Millet was more susceptible to *Coniesta* than either sorghum or maize. Removal of residue after harvest reduced stem borer population in all treatments.

In on-farm trials in the Segou region, four seed treatments were evaluated in three farmer fields in each of three villages (Cinzana, Boussin, Banankoro) on mono-crop millet and on intercropped millet/cowpea. The four treatments were: (1) untreated seed (check) on mono millet; (2) mono millet with seed treated with Apron Star, (3) millet/cowpea - seed treated with neem extract, and (4) millet/cowpea-seed treated with insecticide Dursban. Data was taken on downy mildew, *Striga,* millet head miner, and millet stem borer incidence and grain yield (Table 9). For downy mildew, all three treatments equally reduced (about 50%) downy mildew incidence significantly over the untreated check at Cinzana and Banankoro. *Striga* infestation varied among locations, but with no significant differences among treatments at all locations. For the millet head miner, differences occurred only at Bonankoro where both the monocrop treatments had a much higher incidence over the intercropping millet/cowpea treatments, with 37.5%, 22.5%, and 7.5%, and 5% for treatments 1 though 4, respectively. For the millet stem borer, treatments were significantly different only at Banankoro, with intercrop + Dursban with the lowest incidence followed by mono millet + Apron. Grain yield showed differences at all locations with mono millet giving the highest yield, however, cowpea grain in addition to millet in intercropping compensates for the reduced millet yields.

Food Technology

Mali

Grain from improved breeding lines from the sorghum breeding IER program Medium Maturity GIII and Early Matu-

Table 9. Data on IPM strategies to reduce pest damage on pearl millet at three villages, Mali, 2003.

	D. Mildew incidence %	*Striga* number	MHM incidence %	MSB incidence %	Millet yield kg/ha^{-1}	Cowpea yield kg/ha^{-1}
Cinzana						
T1	24.3	3.7	2.7	8.7	1533ab	0
T2	10.7	2	2	5.7	1739a	0
T3	10.0	2.7	1.7	6.7	1241b	458
T4	11.3	1.0	2	4.7	1303b	499
Significance	*	NS	NS	NS	*	**
Banankoro						
T1	9.5	6	37.5	11	1442ab	0
T2	4.5	5	22.5	6	1657a	0
T3	5.0	5	7.5	7.5	594c	92
T4	4.5	5	5.0	3.5	842c	68
Significance	*	NS	**	*	*	*
Boussin						
T1	6.7	11	10	5	750ab	0
T2	4.7	11.3	10	8.3	818a	0
T3	2.3	10.7	8.3	6.7	484c	375
T4	2.0	10.7	10	6.7	411c	344
Significance	NS	NS	NS	NS	**	**

MHM = Millet Head Miner: MSB = Millet Stem Borer

rity GIII were evaluated for physical-chemical properties and food traits. Several entries in each trial had similar decortication yield, flotation, and vitrosity to the local Guinea checks. All the lines evaluated showed good tô consistency and acceptable tô color. Data on selected entries with the best grain quality traits from both trials are presented in Table 10.

In diversification of sorghum end-use activities, 15 women each from three villages (Kafara, Dafara, and Marako) were trained on processing techniques of diverse sorghum based products including producing quality flour. Products processed included biscuits, cakes, dégué, and drinks. Techniques of preservation and safety issues were also addressed.

Agronomy

Mali - Sorghum

A rotation/previous crop experiment was planned for four years and included in rotation three legumes, three cereals, and six fertility treatments. The proposed scheme is presented below:

Year 1	Year 2	Year 3	Year 4
Cowpea (C)	Sorghum	C	S
Peanut (P)	Sorghum	P	S
Dolichos (D)	Sorghum	D	S
Maize (M)	Sorghum	M	S
Millet (Mlt)	Sorghum	Mlt	S
Sorghum (S)	Sorghum	S	S

Fertilizer inputs included a check treatment (F1) with no fertilizer, a natural rock phosphate treatment with 200 kg ha^{-1} (F2), alternating with variable rates of N (0, 20, 40, and 60 kg ha^{-1} for F2, F3, F4, and F5 respectively) and manure at 1000 kg ha^{-1} every other year F6. Rock phosphate was applied years one and three to previous crops, while N fertilizer and manure were applied years two and four on sorghum. Three genotypes were used at each fertilizer level: CSM 388, Zarra, and N'Tenimissa (V1, V2, V3). A split-split-plot was used as experimental design, with previous crops (PC) as main plots, fertilizer (K) levels as sub-plots, and varieties (V) as sub-sub-plots. Data were collected during the 2003 rainy season.

In evaluation previous crop effects, none of the interactions observed (PC*F PC*V FC*V PC*F*V) were significant for grain, stover, or biomass yields. The previous crops effect upon sorghum was significant for stover only with dolichos, cowpea, with cowpea the best previous crop. Fertilizer effect and varieties effects were highly significant for grain, stover, and biomass. In evaluation of the main effect only of previous crops, legumes were better previous crops than cereals in this study. Peanut was the best, followed by dolichos and then cowpea with respectively 625, 519, and 450 kg/ha^{-1} of grain sorghum.

Rock phosphate applied biannually at 200 kg/ha^{-1} significantly affected sorghum grain, stover and biomass yields, with respectively 21, 27 and 23% of increase compared to the check treatment (Table 11). Manure applied biannually at 1000 kg/ha^{-1} in combination with rock phosphate did not influence sorghum grain, stover, and biomass yields. Increasing N rate from 0 to 60 hg/ha did improve grain, stover, and biomass yields,

Table 10. Physical-chemical characteristics of grain from selected lines from the Advanced Medium Maturity GIII Trial and Advanced Early Maturity GIII Trial, Mali, 2003.

Variety designation	Decortication yield (%)	1000 Grain weight (g)	Vitrosity [1/] rating	Flotation %	Tô [2/] stability rating	Tô [2/] color rating
Medium Maturity GIII						
00-SB-F5DT-123	77.7	21.0	1.0	2.7	1	1
00-SB-F5DT-133	78.7	20.7	1.0	2.0	1	1
00-SB-F5DT-356	76.0	19.0	1.7	2.0	1	1
00-SB-F5DT-366	81.0	18.0	1.3	0.0	1	1
00-SB-F5DT-427	79.3	16.0	1.7	2.0	1	1
00-SB-F5DT-382	76.3	19.7	1.0	1.3	1	1
00-SB-F5DT-386	78.7	19.3	1.0	4.0	1	1
CSM 388 (check)	85.0	20.3	1.0	2.7	1	1
Local check	81.0	23.0	1.0	2.0	1	1
Early Maturity GIII						
00-BE-F5P-1	71.0	18.7	1.3	8.7	1.5	1
00-BE-F5P-25	72.7	17.0	2.0	6.0	1	1
00-BE-F5P-29	75.3	21.0	2.0	4.7	1.5	1
00-BE-F5P-38	72.0	21.0	2.0	12.0	1	1
00-CZ-F5P-61-2DT	72.7	15.0	2.0	14.7	1	1
00-BE-F5P-93	77.0	20.0	2.0	8.7	2	1
00-BE-F5P-245-2	76.0	20.0	2.0	23.3	1	1
Malisor 92-1	71.0	29.7	2.0	18.0	1	1
CSM-63	87.0	23.0	1.7	3.3	1	1
Local check	70.0	23.0	2.0	8.0	1	1

[1/]Rating 1 = hardest to 3 = soft
[2/]Rating 1 = best to 3 = poor

Table 11. Fertilizer effects on sorghum yield components at Sotuba, Mali, 2003.

Fertilizer treatments		Grain yield (kg/ha^{-1})		Stover yield (kg/ha^{-1})		Total biomass (kg/ha^{-1})	
F1	No fertilizer	967	c	3836	d	5255	d
F2	200 kg/ha of PNT	1172	b	4876	c	6477	c
F3	200 kg/ha of PNT + 20 N	1284	b	5682	bc	7517	bc
F4	200 kg/ha of PNT + 40 N	1484	a	6417	ab	8451	a
F5	200 kg/ha of PNT + 60 N	1521	a	6781	a	8850	ab
F6	F2 + 1000 kg/ha manure	1187	b	5179	c	6887	c
Mean		70		5466		7245	
Significance		**		**		**	

PNT stands for tricalcic rock phosphate.
Split-split-plot in RCBD with PC as main plot, fertilizer as sub-plot and varieties as sub-sub-plots.
Means with the same letters are not different at P = 5%.

with yield increase following a significant linear curve. The significant effect of rock phosphate on grain, stover, and biomass yields indicates a serious lack of available P in the soil, over all crops systems involved in this study.

Yield differences observed between CSM 388 (a local variety) (1542 kg/ha^{-1}), Zarra (new tan plant guinea (1184 kg ha^{-1}), and 97-SB-F5DT-154 (short, intermediate type) (1086 kg/ha^{-1}) were significant for grain, stover, and biomass. CSM 399 was higher than only F5-DT-SB-154 for the three parameters. Zarra was intermediate in all these parameters, but not significantly different from either CSM399 or -154. The lower level of yield in 97-SB-DT-F5-154 compared to CSM388 may be due to it needing a higher population to catch solar radiation.

Mali-Acid Soil-Sorghum

A field screening experiment in plot F9, an acid soil plot (millet soil) on Cinzana Station, was designed to identify tolerant or susceptible sorghum genotypes to acid soils. These genotypes will be used for subsequent experiments on understanding mechanisms of sorghum tolerance to acid soil conditions and developing technology packages needed for sustainable sorghum production in acid soils of West Africa.

Several (13) exotic sorghum genotypes, promising breeding lines, local cultivars, and improved varieties were tested for tolerance. Severe flooding of the experiment during August seemed to bias the performance of the genotypes. Only the local check and Malisor 92-1 were able to develop to physiological maturity 53 and 31%, respectively, of their germinated planting hills. All other entries had no healthy plants at maturity, whereas some had shown promise in previous years with about 50% of hills producing healthy plants. Improved local sorghum genotypes from the breeding program (Programme Sorgho of I.E.R.) failed to confirm their past performance under the waterlogged conditions of the 2003 rainy season.

Mali-Millet

Low soil fertility is one of the most important factors limiting millet yield in Sahelian countries. Millet grain yields were over 1200 kg/ha^{-1} except for the control treatment (Table 12). All the treatments produced more grain (P<05) and more straw (P<0.01) than the control. This indicates that the soil used had a low soil fertility level. The application of 50 kg/ha^{-1} complementary P alone resulted in greater millet grain production compared to the application of complementary N alone. The application of complementary P and N did no significantly increase pearl millet yield. This was probably due to the low clay content of the soil and the subsequent low CEC where excess nutrients were probably lost by lixiviation.

The efficacy of chemical fertilizers on crop production is obvious and doesn't need any more demonstration. However, the inadequacies between the price of chemical fertilizers and that of rain fed crops like millet and sorghum doesn't favor the application of recommended rates of mineral fertilizers (41-46-0) N-P-K on these crops. Considering the small amount of chemical fertilizer needed in micro-dose fertilization (about 30 kg/ha^{-1}) applied at the rate of two grams per hill at planting, it becomes important to evaluate the performance of this alternative way to improve millet production in the Sahelian zones of Mali. To evaluate the performance of micro-dose with and without complementary fertilizer application on millet grain and stover production, a trial was conducted on a leached sandy soil at the Cinzana Agricultural Research Station. The two grams of DAP (Di-Ammonium Phosphate) fertilizer were applied at planting per hill. Complementary N and P were applied after plant emergence. The 2003 rainy season was characterized by a relatively good rainfall quantities and distribution.

Plant height did not differ among treatments that received mineral fertilizer, but were taller than the ones that did not receive fertilizer application. The application of micro-dose alone was sufficient to significantly increase pearl millet height compared to the control. This indicates that on sandy soils were pearl millet is mostly grown, small amounts of fertilizer as little as two grams per hill are sufficient to significantly increase crop productivity in the Sahel. Plant population at harvest did not significantly differ among treatments. However, there was strong tendency for treatments that received mineral fertilizer application to produce more tillers than the control. The number of panicles produced was significantly lower for the control and the micro-dose than the other treatments that received mineral fertilizer application. This is largely due to the differences in effective tiller production.

In low fertility sandy soils of Mali, adding a small amount (micro-dose) of chemical fertilizers on millet at planting increased millet yield. Adding complementary P and N to micro-dose sometimes, but not always, gave higher yield compared to micro-dose alone.

Ghana-Sorghum

In a study at the Wa Station, the effectiveness of phosphorus application rates and timing (current on succeeding crop) on a sorghum/cowpea rotation was studied. Most data was reported in the 2003 INTSORMIL Annual Report in Table 14. The application of P direct to the sorghum crop was significantly better than applying P only to the cowpea, and as good as applying to both crops. Sorghum grain yields showed an increase, but not statistically significant, beyond the 30 kg P/ha level. Cowpea yields and components were not significantly affected by application methods or amounts of P fertilizer, but there was a trend toward lower yield when P was applied only to preceding sorghum. In this study, fertilizer P resulted in significant yield increases on a savanna soil very low in plant-available P. Cowpea response to frequency of P application was negligible; therefore, P application (not more than 60 kg P/ha) to sorghum in a two-yr sorghum-cowpea rotation on such a soil seems to be adequate. Moreover, net returns for sorghum were greater than those for cowpea. The succeeding cowpea could benefit from the residual fertilizer.

In another agronomy trial at Wa the previous crop (sorghum, groundnut, cowpea, soybean) effects on sorghum response to four N rates (0, 40, 80, 120) was studied. Again, some data were presented in the previous annual report. The previous crop had no significant effect on grain yield or other yield components, except for stover yield which was lowest in sorghum after sorghum (Table 13). However, sorghum following groundnut tended to have the highest yields. Previous crop and rates of N did not interact significantly. Averaging over previous crops, grain and stover production were significantly increased by N application of 40 kg/ha^{-1} of N with no further increase at higher N rates. With no added fertilizer, sorghum following legumes produced greater yields than sorghum following itself.

Another trial at Wa studied the effects of plant density (50, 75, 100, and 125% of recommended density of 66,600 plants/ha) and within row spacing in sole and intercrop (sole sorghum and cowpea and soybean intercrops) methods were studied on

Table 12. Effects of micro-doses of chemical fertilizers on the development and grain production of millet, Cinzana, Mali.

Treatments	Plant height (cm)	Plant population harvest/ha	Number panicles/ ha	Panicle weight kg/ha^{-1}	Grain weight kg/ha^{-1}	Straw weight kg/ha^{-1}
T1	255	40972	40833	1354	917	1736
T2	293	44444	40000	1924	1361	2639
T3	288	47361	43056	1847	1299	2639
T4	297	51806	46806	2278	1632	3368
T5	283	46944	46667	1951	1347	2500
T6	276	51528	45000	1757	1215	2778
T7	287	50972	43333	1972	1313	3056
T8	288	52778	49861	2000	1347	3263
Significance	HS	NS	S	S	S	HS
LSD	16.67	9313	422	422	338	9313
CV (%)	4.0	13.1	15	15	18	13

T1: Control (no fertilizer added)
T2: 2 grams of DAP
T3: 2 grams DAP + 20 kg/ha^{-1} of TSP
T4: 2 grams DAP+40 kg/ha^{-1} TSP
T5: 2 grams DAP + 30 kg/ha^{-1} Urea
T6: 2 grams DAP + 60 kg/ha^{-1} Urea
T7: 2 grams DAP + 20 kg/ha^{-1} of TSP + 30 kg/ha^{-1} Urea
T8: 2 grams DAP + 40 kg/ha^{-1} TSP + 60 kg/ha^{-1} Urea
NS: Non Significant at 5% level
HS: Significant at 1% level.
S: Significant at 5% level

Table 13. Sorghum grain yield and yield components as affected by previous crops and fertilizer N, Wa, Ghana, 2002.

Previous crop	Days to 50% flowering	Stover yield at maturity (kg/ha^{-1})	100-seed weight (g)	Kernels m^{-2}	Grain yield (kg/ha^{-1})
Cowpea	68	3033	2.08	8147	1954
Groundnut	68	3192	2.14	8710	2151
Soybean	68	3313	2.06	7131	1721
Sorghum	70	2563	2.19	6515	1627
LSD (0.05)	NS	391	NS	NS	NS
N rate (kg/ha^{-1})					
0	71	2597	2.27	4673	1240
40	68	3058	2.03	7969	1883
80	68	3150	2.03	8874	2129
120	67	3297	2.13	8987	2200
N linear	**	**	NS	**	**
N quadratic	**	Ns	*	**	*
CV (%)	1.8	15.3	12.7	18.6	22.5

*, **, and NS = significant at 1 and 5% probability levels and not significant, respectively.

new sorghum varieties. Sole sorghum planted at one plant/hill produced greater grain yields even when the recommended plant population of 66,600 plants/ha was either reduced to 50,000 or increased to 80,000 plants/ha. With one plant/hill, sorghum planted at 80,000 plants/ha whether sole or intercropped with either legume crop as well as sole sorghum planted at the recommended density or 50,000 plants/ha produced similar yields. At the recommended density, intercropping sorghum with either legume reduced grain yields. Having 1 plant/hill produced greater grain yields than leaving two plants/hill, irrespective of the plant population density. Consequently, it may be better to sow three-four seeds of sorghum per hill and later thin to one seedling/hill in order to achieve the respective optimum plant population density. Grain yield was drastically reduced when planting was done at 33,300 plants/ha. When sorghum was intercropped with cowpea, lower grain yields were produced compared with sorghum planted sole or intercropped with soybean.

Another trial studied the effect of fertilizer (four levels of N (0, 40, 80, 120 kg/ha^{-1}), two levels each of P_2O_5 (0 and 40 kg/ha^{-1}) and K_2O (0 and 40 kg/ha^{-1}) on a new sorghum cultivar Kapaala. The sources of N, P, and K were Urea, triple super phosphate (TSP), and muriate of potash (KCl). For one season only, there were no significant interactions among the rates of N, P, and K. Potassium (K) had no significant effect on grain yield or components. N and P increased grain yield, and when averaged across P and K rates, yield related to N rates in a quadratic manner. Grain yield was not increased significantly beyond the 80 kg N/ha rate. The addition of 40 kg P_2O_5/ha increased grain yield by 16.5% over no P.

Economic Analysis - Ghana Agronomy

When sorghum is grown in rotation with cowpea, the optimal, considering both crops, is a P rate of 60 kg/ha^{-1} to sorghum directly with cowpea benefiting from the residual. If P is applied annually to sorghum, the optimum level is 30 kg P/ha. Direct application of P to cowpea at any level is not cost effective considering only cowpea.

Partial budget analysis on the effect of proceeding crop on response of sorghum to N application shows that maximum net benefits are obtained with 40 kg N/ha when cowpea or soybean precedes sorghum. With groundnut preceding, maximum benefits are with 80 kg N/ha. When sorghum follows sorghum, 120 kg N/ha is the best.

In analysis of the effect of residue removal, net returns decline with increasing rate of residue removal. Maximum net benefit was obtained with no residue removal plus fertilizer applications.

Economics/Marketing

The acceptance of white-seeded, tan-plant improved Guinea type sorghum cultivars, developed in the IER/INTSORMIL collaborative breeding program in Mali, by both farmers and in the marketplace has been excellent. The interest of farmers in three villages (Marako, Dafara, and Kafara) involved in the flawed 2002 contract with a local grain/market entrepreneur to produce identity preserved grain of N'Tenimissa was very encouraging following visits there in October, 2003. All farmers visited were interested in another such venture, providing it was not with the grain trader that defaulted on the 2002 contact production. This agreed with comments made by Ouendeba Botorou who visited all the five areas of Mali where the 2002 contracts were made.

To emphasize this observation, the following statement is a quote from the project TAM 226 2004 annual report of Dr. L.W. Rooney: "New more efficient higher yielding white tan varieties are near release from the IER breeding program in Mali. The photosensitive types escape significant weathering/molding that adversely affects earlier insensitive white tan sorghums and led to their failure. These photosensitive value-enhanced sorghums provide improved grain quality for identity-preserved (IP) marketing of sorghums. The grain produced excellent food products because it was not discolored by insects and molds. Farmers were very excited with these white tan plant sorghum varieties because they liked the agronomics and grain yields. They were pleased with the grain quality for their own food consumption and appreciated the opportunity to sell the grain at a potential premium. This was especially significant in view of the fact that some of them had a bad experience the previous year with a grain trader who defaulted on a promised premium price. The principle of supply chain management from seed to food products had been demonstrated; however, a great deal of work to obtain wide-spread participation is required".

Even though the grain trader defaulted on the 2002 contract, the farmers were able to sell the grain at a premium of 15-20 CFA/kg, while some sold in bulk quantities at the market price to other grain traders for resale in Bamako. An emerging organization among farmers in the three villages is a very promising and necessary step in establishing a functioning supply chain management from seed to food.

The other encouraging aspect was that these three villages were very involved in growing on-farm trials and larger scale demonstrations of new sorghum breeding cultivars from IER and liked the new cultivars for their own food use.

Institution Building

The collaborative host country programs in Mali, Senegal, and Ghana were each supplied a computer along with various field and laboratory research equipment and breeding supplies.

Many Malian scientists trained at INTSORMIL institutions are senior staff making important contributions in sorghum and millet research within the IER including:

Dr. Aboubacar Touré (Texas A&M) - Currently Sorghum Breeder, Mali National Coordinator for sorghum, Mali INTSORMIL Coordinator and will be Regional sub-coordinator effective July 2004.
Dr. Ndiaga Cisse (Purdue) - Currently Sorghum Breeder, ISRA, and Co-Country INTSORMIL Coordinator, Senegal.
Dr. Mamourou Diourté (Texas A&M and Kansas State) - Currently Head Sorghum Pathologist, IER, Mali
Dr. Samba Traoré (Nebraska) - Currently Agronomist and Mali National Coordinator for Millet, IER, Mali
Dr. Niamoye Yaro Diarisso (Texas A&M) - Currently sorghum entomologist, and head of Vegetable Research in IER, Mali
Dr. Mamadou Doumbia (Texas A&M) - Currently Director of Soil Laboratory and soil scientist with IER, Mali.
Mr. Abdoul W. Touré (Nebraska) - Currently sorghum agronomist, IER, Mali.
Dr. Samuel Saaka Buah (M.S. - Nebraska) - Currently agronomist and Co-Country INTSORMIL Coordinator, SARI, Ghana.
Dr. Sidi Bekaye Coulibaly (Nebraska and Texas Tech/Texas A&M) - Previously sorghum physiology/agronomy and sorghum breeding and INTSORMIL Coordinator. Currently Sorghum Breeder, Cinzana, IER, Mali.

Students currently in training include Niaba Témé (Mali) who successfully completed his B.S. and M.S. at Texas Tech University and is currently a Ph.D. student at Texas Tech University. Karim Troaré, former Mali millet and sorghum breeder with a M.S. from Nebraksa is now a Ph.D. student at Texas A&M University. Mr. Tiecoura Traore (Mali) has initiated a M.S. program in sorghum entomology at West Texas A&M University. Mr. Seriba Katile has initiated a Ph.D. program in pathology/biotechnology at Texas A&M University.

Bocar Sidibé, Niaba Teme, Abocar Toure, Kissima Traore, Seriba Katile, Sibène Déna, and Moussa Sanogo received short-term training in the U.S. provided by INTSORMIL in breeding and plant pathology.

Dr. Aboubacar Touré, Malian sorghum breeder, is serving as acting Coordinator of the West and Central Africa Sorghum Research Network, WCASRN (ROCARS).

U.S. scientists traveling to the region in October 2003 included Dr. Bonnie Pendleton (Mali and Ghana), Dr. Bruce Hamaker (Senegal and Mali), Dr. Darrell Rosenow (Senegal and Mali), Dr. Lloyd Rooney (Mali), and Dr. Mitch Tuinstra (Mali). Other travel included Drs. L. Rooney and B. Hamaker (Senegal - January, 2004), Drs. John Sanders and Ouendeba Botorou (Mali - January, 2004), and Dr. Tom Crawford (Mali-October, 2003).

Mali and Senegal hosted the INTSORMIL External Evaluation Panel in October 2003 and also provided for EEP interaction with the above-mentioned scientists in Mali and Senegal. Drs. Ibrahim Atokple and Samuel Buah from Ghana traveled to Bamako, Mali to meet with the EEP in evaluating research activities in Ghana.

A major INTSORMIL West Africa Regional meeting was held in Ouagadougou, Burkina Faso, April 18-21, 2004 with host country scientists form Mali, Ghana, Senegal, Niger, Nigeria, and Burkina Faso, and collaborating U.S. INTSORMIL scientists. The purpose of the meeting was to discuss and formalize the proposed restructuring of the INTSORMIL collaborative programs in the six West African countries into one overall regional program and establish a working administrative structure to the program. The meeting also provided the forum to develop and strengthen collaborative ties and collaborative research between host country and U.S. scientists, among host-country researchers in the region, and among disciplines. U.S. scientists participating included: Drs. Darrell Rosenow, Bruce Hamaker, Bonnie Pendleton, Mitch Tuinstra, Steve Mason, Jeff Wilson, Joe Hancock, and Clint Magill, as well as Dr. John Yohe, INTSORMIL Program Director. Scientists from Mali participating included Drs. Aboubacar Touré, Bourema Dembele, Mamourou Diourte, Mamadou Doumbia, and Niamoye Diarisso, as well as Mrs. Fatim Cisse, Mr. Moutaga Kayentao, Mr. Abdoul W. Toure, and Mr. Moussa Sanogo. Senegalese scientists attending included Drs. Ndiaga Cisse, Demba Farba M'Baye, Ababacar N'doye, and Mr. Amadou Fotana. Attending scientists from Ghana included Drs. Ibrahim Atokple, Samuel Saaka Buah, Steven Nutsugah, and Paul Tanzubil.

Networking

A useful research and technology transfer mechanism was lost with the demise of the West African regional sorghum and millet networks, WCASRN (ROCARS) and ROCAFREMI. The direction and scientist losses in ICRISAT has reduced, but not eliminated, collaborative efforts with ICRISAT in both sorghum and millet. Technologies developed in Mali on sorghum are transferable to most countries in West Africa particularly in areas where head bugs, drought, and grain mold are common and grain quality is a high priority trait. Exchange of elite new breeding germplasm with useful traits is ongoing among scientists in the region. The improved white-seeded, tan-plant Guinea types (N'Tenimissa and its derivatives) developed in Mali hold potential in other Guinea-type sorghum growing areas of West Africa. The increased use of NGOs, farm organizations, and extension in on-farm trials, seed increase and distribution is a positive in the region. The new regional approach for the West African INTSORMIL programs should contribute to movement of technologies throughout the region, and foster increased collaboration among scientists from different countries.

New Ghana and Senegal Collaboration

Plans to initiate INTSORMIL collaborative research in Ghana and Senegal began in November 2000, with arrangements to bring two scientists each from Ghana (Drs. S. Buah, Agronomist and I. Atokple, Sorghum Breeder) and Senegal (Ndiaga Cissé, Sorghum Breeder and Demba M'Baye, Pathologist) to Bamako to meet with Darrell Rosenow, Aboubacar Touré, and other key Malian IER scientists. Dr. Buah already had previously initiated a collaborative program in agronomy with Dr. Maranville. The discussions were all fruitful and positive with three initial areas of collaboration among Malian, Ghana, Senegal, and U.S. scientists agreed upon: 1) sorghum breeding with one aspect being the establishment of a germplasm exchange program centering on a West African Regional Breeding Nursery to which all breeders would contribute new breeding germplasm or cultivars annually, and would be assembled and distributed by Dr. Touré in Mali; 2) sorghum pathology centered initially on a West African Disease Nursery to which all pathologists and breeders would contribute entries annually and would be assembled and distributed by M. Diourte in Mali; and 3) *Striga* research with initially a *Striga* nursery of known or suspected *Striga* resistant local cultivars and selected lines from Dr. Gebisa Ejeta evaluated at several sites. The lines will be assembled in Mali and distributed by Dr. A. Touré. Also, Dr. Ejeta will evaluate some of the sources for types of resistance involved. In addition, INTSORMIL scientists in the U.S. will provide breeding germplasm for midge resistance, drought resistance, grain mold resistance, other disease resistance, and elite sources of worldwide germplasm for the new breeding programs in Ghana and Senegal. Requests were made by scientists in Ghana and Senegal for the future development of collaboration in millet breeding, entomology (head bugs and midge), cereal technology and utilization, and agronomy. Dr. Buah has continued his collaborative activities in Ghana based on previously developed work plans with Dr. Maranville.

In 2002, a new INTSORMIL initiative in Senegal began with the ITA (Institute de Technologic Alimentaire) to work on commercialization and supply chain management of grain in Senegal. An established system in Senegal involving an Austria NGO (EWA) on pearl millet is being looked at as a model for development in other countries of West Africa.

West Africa Regional Program

In 2003, the INTSORMIL Technical Committee and Board of Directors mandated that the West Africa-Western Region (Mali, Senegal, Ghana) and Eastern Region (Niger, Burkina Faso, and Nigeria) be merged into one overall regional program. This led to many discussions on the logistics of such a merging and a possible administrative structure of such as program. To discuss this merger with host country PIs and to provide a forum for strengthening collaboration between U.S. and host country scientists as well as among host country PIs, a large meeting was held in April in Ouagadougou, Burkina Faso with all the key scientists from the six West African countries and U.S. present. The meeting was productive an initial structure of one overall U.S. coordinator (Bruce Hamaker) and two sub-regional host country coordinators (Aboubacar Touré - Mali, Ghana, Senegal) (Issoufou Kapran - Niger, Burkina Faso, Nigeria) named. Essentially, currently funded scientists and projects would be maintained through the end of the grant period ending in June 2006. Two new multi-country and disciplinary thrusts (possibly resulting in future projects) were identified (and coordinators named) for project and proposal development to seek outside funding. The two areas were utilization and technology transfer. Another area, biotechnology, was identified as a third area for possible project development.

Research Accomplishments - Summary

The most significant impact of INTSORMIL has been the strengthening of the IER both through staff training and research capacity building. Interdisciplinary and cooperative research in sorghum and millet which are in place at the IER are mainly due to INTSORMIL/IER collaborations. The multidisciplinary approach to solving technical problems have been promoted by the INTSORMIL, and is functioning well in Mali.

Breeding

- Six new N'Tenimissa derivative tan-plant, guinea type improved breeding lines developed by IER, plus one intermediate caudatum-guinea line have been named and released in Mali thru 2003. They were distributed thru on-farm trials and demonstration or thru NGO's and are being well accepted by farmers. The guinea cultivars have superior grain quality and less stalk breakage than N'Tenimissa.
- From on-farm trials, the Guinea-type cultivar 97-SB-F5-DT-63 (N'Tenimissa*Tiemarfing) has been selected, seed saved, and grown by local farmers and has been released and named "Wassa" which mean 'satisfaction' in Bambara. Farmers like it over N'Tenimissa because of its whiter, higher quality grain.
- Two other new breeding lines, true Guinea cultivars (N'Tenimissa*Tiemarfing) were widely tested and given the names Zarra and Keninkedie, and will be increased for use in value-added products. All three of these new cultivars have superior grain quality and less stem breakage then N'Tenimissa.
- Eight local photosensitive sorghum cultivars have been improved through mass selection and are grown by farmers on a significant area in Mali (CSM 388, CSM 219E, CSM 63E, Foulatiéba, Séguétana CZ, CMDT 45 , CMDT 39).
- The white-seeded, tan-plant Guinea type breeding cultivar, N'tenimissa, was released. It's yield is equal to or slightly superior to local checks. It has good farmer acceptance regarding yield and food use. Flour from N'tenimissa is currently being marketed commercially (20% N'tenimissa and 80% wheat flour) in a cookie called Deli-Ken by the private company, GAM, in Bamako.
- A local entrepreneur in Mali successfully produced , in 2001, over 11 tons of grain of the white, tan plant guinea cultivar, N'Tenimissa, under identity preserved (IP marketing procedures. This grain trader also developed a new market by packaging and selling one-kilo bags of flour (Sorgho Phar) in Bamako markets, with a demand so strong he was having trouble keeping the product on the shelf. In 2002, his contracted production for 200 tons was derailed due to financial and other problems in his company unrelated to the N'Tenimissa effort.
- Varieties of millet selected for the tallest expression of the D2 dwarfing complex (1.7 to 1.9 m) have given good performance in millet/legume intercropping studies.
- Testing in Texas and Mali has demonstrated that the drought response in Mali is similar to the drought response in West Texas, increasing the probability of success in breeding for enhanced drought tolerance.
- The Mali Sorghum Collection of indigenous cultivars from Mali was successfully grown in 1997 was characterized and seed increased and distributed. A small working collection has been identified. There was greater diversity in the collection than anticipated. Approximately one-third of the collection was grown in St. Croix in spring 2000 with seed increased and characterization completed. The remaining two-thirds was grown in a St. Croix quarantine grow out in winter, 2000-2001, and seed increased and characterization completed. A tentative working collection was identified.

Entomology

- The adverse effect of head bugs on the grain food quality of introduced sorghum across West Africa was first recognized and documented in Mali.

- The INTSORMIL collaborative sorghum entomology research program in Mali has discovered the best source of genetic resistance to head bug (*Eurystylus marginatus*) in a non-Guinea type sorghum, a major constraint to the quality of grain sorghum in Mali, in an IER Malian developed cultivar, Malisor 84-7.
- An easy, efficient technique for screening for head bug resistance using bagged vs. non-bagged heads has been developed and is used cooperatively by the breeders and the entomologists.
- Observations indicate that head bug infestations in on-farm trials is much lower than in station nurseries. This means that sorghum with somewhat lower levels of head bug resistance may well work at the farm level, even though they may show significant damage under certain station infestations.
- Sorghum selfing bags work equally well with cages in head bug evaluations and are much more cost and labor efficient.
- Natural infestation appears superior to infested cages for head bug screening.

Pathology

- Grain yield increase of 20% can be obtained by treating millet seed with Apron plus.
- Protection from head bugs will be a requirement for evaluation of grain mold resistance.
- Long smut (*Tolyposporium ehrenbergii*) is severe in the drier regions of Mali. Anthracnose (*Collectostrichum graminicola*) is a very serious sorghum disease in Mali.
- Studies were conducted on covered kernel smut (*Sphacelotheca sorghi*) by using traditional fungicides and the results showed that "Gon" (*Canavalia ensiloformis*) used in seed treatment had the same effects as Apron Plus 50DS and Oftanol.

Agronomy

- Micro-dose fertilizer application increases the grain and stover yield of millet on sandy soils. Its effect on sorghum and on heavier soils is highly variable.
- INTSORMIL/IER research has demonstrated that millet or sorghum planted after peanut or cowpea results in 36-63% yield increases.
- INTSORMIL collaborative research has shown an increase in pearl millet grain yield and biomass production due to previous cowpea crops and equivalent to the application of 30 to 40 kg/ha^{-1} N.
- The joint INTSORMIL/Soil Management CRSP collaborative program has addressed soil chemical properties associated with nutrient deficiencies toxicities in sandy soils of the Cinzana Station. Some Durra varieties from Niger and northern Mali show tolerance to soil toxicity (Bagoba, Babadia Fara, and Gadiaba)
- A method of screening large numbers of sorghum and millet lines for early generation and selection for seedling stage drought resistance using a charcoal pit has been adapted and is used.
- Nitrogen use efficiency (NUE) of improved sorghum cultivars has been better than that of local cultivars at higher N rates, while local cultivars had better NUE at zero and very low N rates.
- Without fertilizer application all tested cropping systems (including legume rotations) mine the soil of nutrients.
- Crop rotation with cowpea and leaving crop residues in the field (either incorporated or on the surface) increases the unstainability and productivity of pearl millet cropping systems.
- New IER developed sorghum cultivars show moderate levels of acid soil tolerance.

Weed Science

- Wassa and some other improved breeding lines have been identified to have a high level of field *Striga* resistance.
- Several *Striga* resistant lines from Purdue evaluated in Mali showed good *Striga* resistance, but had inferior grain quality compared to local cultivars.
- *Striga* resistance using lab screening to *Striga asiatica* in the U.S. works under field conditions to *S. hermonthica* in Mali.
- New sources of resistance to *Striga* were identified: Séguétana CZ, CMDT 45, CMDT 30, and CMDT 39.
- Several new Guinea breeding line/cultivars such as Wassa show good *Striga* tolerance.

Grain Quality and Utilization

- Mini tests for evaluating milling and tô properties were developed and currently are used in the laboratory. Sorghum with hard endosperm and thick pericarps was definitely required for efficient traditional hand pounding. The size and shape of the pearl millet kernels affects dehulling properties significantly.
- Head bugs damage reduced sorghum milling yields and produced tô with unacceptable texture and keeping properties.
- Parboiling can convert sorghum and millet into acceptable products. It improves dehulling yields, especially for soft grains. The cooked milled products can be eaten like rice.
- The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children. This technology has been transferred to many villages especially in the Cinzana area.
- 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.
- 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 posses excellent guinea traits and yield potential.
- Deli-ken, a cookie using 20% N'Tenimissa flour and 80% wheat flour has been developed by private enterprise GAM and marketed in stores in Mali.
- A new market for N'Tenimissa flour has been developed with the successful marketing of 1 kg bags of N'Tenimissa flour in Bamako by a local entrepreneur.

Economics/Marketing

- The principle of supply chain management from seed to commercial food products has been demonstrated in Mali, utilizing new sorghum cultivars with improved grains/food quality traits.
- In Mali, a local entrepreneur successfully produced grain from the white-seeded, tan-plant Guinea cultivar, N'Tenimissa, under identity preserved (IP) marketing procedures, involving 38 ha and 50 farms in 4 villages. From 38 tons harvested, over 11 tons were sold to the grain trader. When the demand for sorghum flour by GAM for cookies dropped due to reduced tariff on wheat imports, a new market for the N'Tenimissa flour was developed with the marketing of one-kilo bags of N'Tenimissa flour (Sorgho Phar) in markets in Bamako. Demand was so strong, there were problems keeping the product on the shelf. A portion of the grain was also sold directly in local Bamako markets, and sold well at a premium price.
- An economics study on the benefits of new technology in Mali suggests that new technology in the traditional cereals of sorghum and pearl millet would provide a greater increase in benefits compared to new technology introduction in the new cereals, maize and rice.
- The domestic cereal economy has been helped by devaluation with the increased relative price of sorghum and millet to rice. A future devaluation is expected to result in much more substitution of traditional cereals now that there is only a minimal rice tariff.
- In spite of substantial introduction of new sorghum and millet cultivars, there has been minimum aggregate impact on yields. Only where inorganic fertilizers and improved water retention or irrigation were combined with new cultivars, have there been large yield increases. Given the low soil fertility and irregular rainfall in semi-arid regions, both increased water availability and higher levels of principal nutrients will be necessary for substantial yield increases. Improved cultivars alone are unlikely to have a significant effect upon yield.
- 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.

Educational Activities

Year 25 Educational Activities

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, 49 students from 19 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 71% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

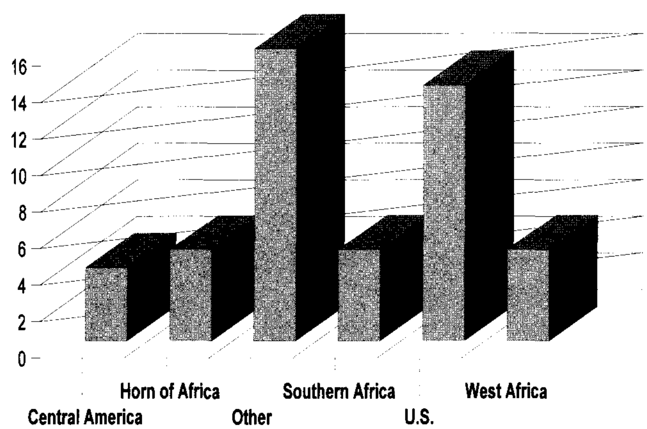

Figure 1. Degree Participants by Region

INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 2003-2004, 18% of all INTSORMIL graduate participants were female. Ten of the total 49 students received full INTSORMIL scholarships. An additional 35 students received partial INTSORMIL funding and the remaining four students were funded from other sources as shown in Figure 3.

All 49 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in eight disciplinary areas, agronomy, animal nutrition, breeding, pathology, entomology, food quality, economics, and molecular biology.

The number of INTSORMIL funded students has decreased gradually over the years. This is related to decreases in program budget and lower numbers of U.S. principal investigators. In 1993-94 there were 25 U.S. PIs with the program and in 2003-2004 there were 18.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case

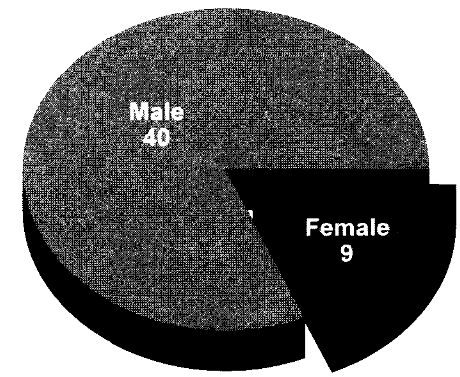

Figure 2. Degree Participants by Gender

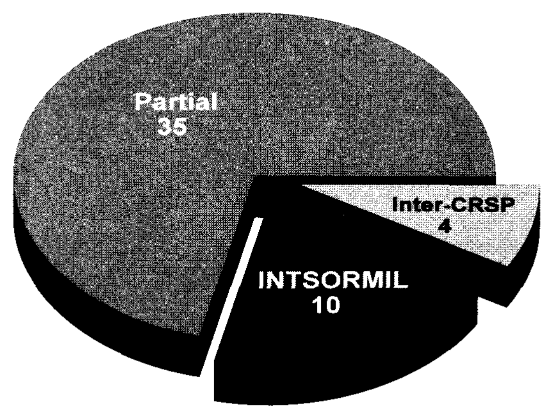

Figure 3. Degree Participants Funding

basis to suit the needs of host country scientists. Six post doctoral scientists and 14 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during 2003-2004.

Figure 4 is a compilation of all INTSORMIL training activities by discipline for the period July 1, 2003 through June 30, 2004.

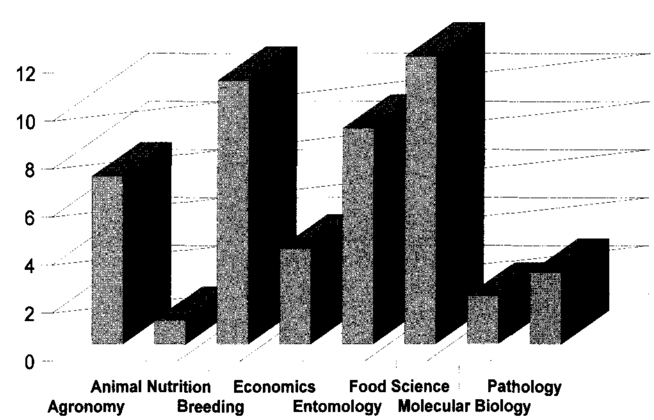

Figure 4. Degree Participants by Discipline

Year 25 INTSORMIL Degree Training Participants July 1, 2003 - June 30, 2004

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding
Garcia, Juan Pablo	Colombia	UNL	Agronomy	Wortmann/Mamo	MSC	M	P
Kathol, Delon	U.S.	UNL	Agronomy	Mason	MSC	M	P
Kaye Mady, Nanga	Chad	UNL	Agronomy	Mason	MSC	M	P
Miller, Greg	U.S.	UNL	Agronomy	Wortmann/Mamo	MSC	M	P
Tesfahungen, G.B.	Ethiopia	UNL	Agronomy	Wortmann/Mamo	MSC	M	P
Xerinda, Soares	Mozambique	UNL	Agronomy	Wortmann/Mamo	MSC	M	IC
Quincke, Andreas	Uruguay	UNL	Agronomy	Wortmann/Mamo	PHD	M	P
Baudon, Edouard	France	KSU	Animal Nutrition	Hancock	MSC	M	P
Kaufman, Rhett	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
McCartor, Kayla	U.S.	TTU	Breeding	Rosenow	MSC	F	P
Mutaliano, Joaquim	Mozambique	TAM	Breeding	W. Rooney	MSC	M	IC
Pandravada, S.	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
Stamm, Michael	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
Teme, Niaba	Mali	TTU	Breeding	Peterson/Rosenow	MSC	M	P
Franks, Cleve	U.S.	TAM	Breeding	W. Rooney/Rosenow	PHD	M	P
Knoll, Joseph	U.S.	PRF	Breeding	Ejeta	PHD	M	I
Krishnamorthy, G.	India	TAM	Breeding	W. Rooney/Rosenow	PHD	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	PHD	M	I
Wordoffa, Zenbaba	Ethiopia	PRF	Breeding	Ejeta	PHD	M	P
Baquedano, Felix	Nicaragua	PRF	Economics	Sanders	MSC	M	P
Uaiene, Rafael	Mozambique	PRF	Economics	Sanders	PHD	M	IC
Wubeneh, Nega	Ethiopia	PRF	Economics	Sanders	PHD	M	I
Yigezu, Yigezu	Ethiopia	PRF	Economics	Sanders	PHD	M	I
Ayyanath, M.	India	WTU	Entomology	Pendleton	MSC	M	P
Chitio, Fernando	Mozambique	WTU	Entomology	Pendleton	MSC	M	IC
Sambaraju, Kishan	India	WTU	Entomology	Pendleton	MSC	M	P
Traore, Tiecoura	Mali	WTU	Entomology	Pendleton	MSC	M	I
Veerabomma, Suresh	India	WTU	Entomology	Pendleton	MSC	M	P
Gorena, Roberto	U.S.	TAM	Entomology	Peterson	PHD	M	P
Johnson, Zeledon	Nicaragua	MSU	Entomology	Pitre	PHD	M	I
Parado Jaco, Mario	El Salvador	MSU	Entomology	Pitre	PHD	M	I
Pichard, Sergio	Nicaragua	MSU	Entomology	Pitre/Claflin	PHD	M	P
Acosta, David	Mexico	TAM	Food Science	L. Rooney	MSC	M	P
Barron, Marc	U.S.	TAM	Food Science	L. Rooney/M. Riaz	MSC	M	P
Barth, Alison	U.S.	PRF	Food Science	Hamaker	MSC	F	P
Cedillo, Guisselle	Mexico	TAM	Food Science	L. Rooney	MSC	F	P
de Castro, Angelina	Mexico	TAM	Food Science	L. Rooney	MSC	F	P
Gutierrez, Arturo	Mexico	TAM	Food Science	L. Rooney	MSC	M	P
Perez, Alejandro	Mexico	TAM	Food Science	L. Rooney	MSC	M	P
Turner, Duane	U.S.	TAM	Food Science	L. Rooney	MSC	M	P
Wortham, Lindsay	U.S.	TAM	Food Science	L. Rooney	MSC	F	P
Xu, Lisha	China	TAM	Food Science	L. Rooney	MSC	F	P
Bugusu, Betty	Kenya	PRF	Food Science	Hamaker	PHD	F	I
Dykes, Linda	U.S.	TAM	Food Science	L. Rooney/R. Waniska	PHD	F	P
Cho, Jae-Min	Korea	TAM	Molecular Biology	Magill	PHD	M	P
Katile, Seibe	Mali	TAM	Molecular Biology	Magill	PHD	M	I
Ditshipi, Phoebe	Botswana	UFS	Pathology	McLaren/Swart	PHD	F	I
Lee, Jin-Kwan	S. Korea	KSU	Pathology	Leslie	PHD	M	P
Salah, Amgad	Egypt	KSU	Pathology	Leslie	PHD	M	P

I = Completely funded by INTSORMIL P = Partially funded by INTSORMIL IC = InterCRSP funding

KSU = Kansas State Univ.
MSU = Mississippi State Univ.
PRF = Purdue Univ.
TAM = Texas A&M Univ.
TTU = Texas Tech Univ.
UNL = Univ. of Nebraska, Lincoln
USDA = Tifton, Georgia
WTU = W. Texas A&M Univ.

Year 25 INTSORMIL Non-Degree Training Participants July 1, 2003 - June 30, 2004

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Hess, Dale	U.S.	PRF	Breeding	Ejeta	PD	M	I
Tesso, Tesfaye	Ethiopia	PRF	Breeding	Ejeta	PD	M	P
Botorou, Ouendeba	Niger	USDA	Breeding	Wilson	VS	M	P
Kapran, Issoufou	Niger	PRF	Breeding	Ejeta	VS	M	I
Soumana, Souley	Niger	KSU	Breeding	Tuinstra	VS	M	I
Botorou, Ouendeba	Niger	PRF	Economics	Sanders	VS	M	I
Badiane, Djibril	Senegal	WTAMU	Entomology	Pendleton	VS	M	I
Baldé, Mamadou	Senegal	WTAMU	Entomology	Pendleton	VS	M	I
Diarisso, Niamoye	Mali	WTAMU	Entomology	Pendleton	VS	F	I
du Plessis, Hannalene	South Africa	WTAMU	Entomology	Pendleton	VS	F	I
Kadi Kadi, Hamé	Niger	WTAMU	Entomology	Pendleton	VS	M	I
Munthali, D.C.	Malawi	WTAMU	Entomology	Pendleton	VS	M	I
van den Berg, Johnnie	South Africa	WTAMU	Entomology	Pendleton	VS	M	I
Aboubacar, Adam	Niger	PRF	Food Science	Hamaker	PD	M	P
Benmoussa, Mustapha	Indonesia	PRF	Food Science	Hamaker	PD	M	P
Chandrashekar, A.	India	PRF	Food Science	Hamaker	VS	M	P
Taylor, John	South Africa	PRF	Food Science	Hamaker	VS	M	P
Saleh, Amgad	Egypt	KSU	Pathology	Leslie	PD	M	P
Zeller, Kurt	U.S.	KSU	Pathology	Leslie	PD	M	P
Jurgenson, Jim	U.S.	KSU	Pathology	Leslie	VS	M	P

VS = Visiting Scientist **PD = Post Doctoral**

Year 25 INTSORMIL Conference/Workshop Activities July 1, 2003 - June 30, 2004

Name	Location	Date	Participants Male	Participants Female	Participants Total
PCCMCA Annual Meeting	San Salvador, El Salvador	April 16-20, 2004	13	1	14
West Africa Regional Meeting	Ougagdougou, Burkina Faso	April 18 - 21, 2004	55	5	60
African Sorghum & Millet Entomology	Ougagdougou, Burkina Faso	April, 2004	5	3	8
Scientific Workshop	Pretoria, South Africa	Nov. 5, 2003	25	20	45
Scientific Workshop	Stellenbosch, South Africa	Nov. 17, 2003	50	45	95
Scientific Workshop	Kota Baru, Malaysia	April 26, 2004	60	100	160
Scientific Workshop	Penang, Malaysia	April 28, 2004	130	160	290
Scientific Workshop	Butterworth, Malaysia	April 29, 2004	105	95	200
Scientific Workshop	Seoul, Korea	May 4, 2004	32	48	80
Scientific Workshop	Beijing, China	May 12, 2004	51	71	122
Scientific Workshop	Cotonou, Benin	May 31, 2004	40	4	44
TOTAL			553	551	1104

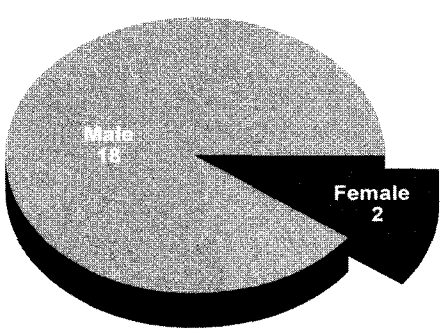

Figure 5. Total Non-Degree Participants by Gender

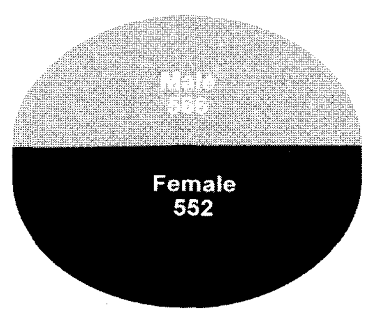

Figure 6. Total Conference/Workshop Participants by Gender

Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 2004

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. Agrimetorology 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 80's	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	2/84
22. Evaluation 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. INTSORMIL PI Conference	Kansas City, Missouri	1/87
31. Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
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. ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
36. Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
37. Sorghum for the Future Workshop	Cali, Colombia	1/91
38. INTSORMIL PI Conference	Corpus Christi, Texas	7/91
39. Workshop on Social Science Research and the CRSPs	Lexington, Kentucky	2/92
40. Workshop on Adaptation of Plants to Soil Stresses	Lincoln, Nebraska	8/93
41. International Conference on Genetic Improvement of Sorghum and Millet	Lubbock, Texas	9/96
42. Conference on Ergot of Sorghum in the Americas	Sete Lagos, Brazil	6/97
43. Ethiopia Sorghum and Millet Traveling Workshop	Ethiopia	9/97
44. Mali Sorghum Characterization Workshop	Cinzana, Mali	11/97
45. INTSORMIL PI Conference	Corpus Christi, Texas	6/98
46. Impact Assessment Workshop	Corpus Christi, Texas	6/98
47. Conference on the Status of Sorghum Ergot in North America	Corpus Christi, Texas	6/98
48. Regional Hybrid Sorghum and Pearl Millet Seed Workshop	Niamey, Niger	9/98
49. CRSP Symposium/Annual Meeting of the American Society of Agronomy	Baltimore, Maryland	10/98
50. Global 2000 Sorghum and Pearl Millet Diseases III	Guanajuato, Mexico	9/00
51. INTSORMIL PI Conference	Addis Ababa, Ethiopia	11/02
52. West Africa Regional Meeting	Ougagdougou, Burkina Faso	04/04

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
AFLP	Amplified Fragment Length Polymorphisms
AID	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
AMEDD	Association Malienne d'Eveil Au Développement
ANOVA	Analysis of Variance
ANPROSOR	Nicaraguan Grain Sorghum Producers Association
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARC	Agriculture Research Council, South Africa
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
AVES	Associación de Avicultores de El Salvador
BAMB	Botswana Agricultural Marketing Board
BIFAD	Board for International Food and Agricultural Development
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARO	Chief Agricultural Research Officer
CARS	Central Agricultural Research Station, Kenya

CATIE	Centro Agronómico Tropical de Investigación y EnseZanza, Costa Rica
CEDA	Centro de EnseZanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro Nacional de Technologia Agropecuaria y Forestal, El Salvador
CFTRI	Central Food Technological Research Institute, India
CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands, Mexico
CICP	Consortium for International Crop Protection
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre International en recherche Agronomique pour le Développement
CITESGRAN	Centro Internacional de Tecnologia de Semilla y Granos, EAP in Honduras
CLAIS	Comisión Latinoamericana de Investigadores en Sorgho
CMS	Cytoplasmic Male-Sterility System
CNIA	Centro Nacional de Investigaciones Agricoles, Nicaragua
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CORASUR	Consolidated Agrarian Reform in the South, Belgium
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DAR	Department of Agricultural Research, Botswana
DARE	Division of Agricultural Research and Extension, Eritrea
DICTA	Dirección de Ciencia y Tecnologia Agricola, Mexico
DR	Dominican Republic
DRA	Division de la Recherche Agronomique, IER Mali

DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAGA	Extended Agar Gel Assay
EAP	Escuela Agricola Panamericana, Honduras
EARO	Ethiopian Agricultural Research Organization
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
EWA	Austrian NGO
ECARSAM	East Central Africa Regional Sorghum and Millet
ECHO	Educational Concerns for Hunger Organization
EEC	Euorpean 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
ESBESA	Escobar Betancourt S.A.
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
FDS	Fonds de Développement pour la Solidarité
FEDEARROZ	Federación HondureZa de Investigación Agricola, Honduras
FENALCE	Federación Nacional de Cultivadores de Cereales
FHIA	Fundación HondurenZa de Investigación Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
FUNDESYRAM	Fundación Para E Desarrollo Socio-Económico y Restauración Ambiental

FUNPROCOOP	Fundación Promotora de Coopertivas
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GRADECOM	Groupe de Recherche et d'Action pour le Développement Communautaires
GTZ	German Agency for Technical Cooperation
GWT	Uniform Nursery for Grain Mold
HIAH	Honduran Institute of Anthropology and History
HOA	Horn of Africa
HPLC	High Pressur Liquid Chromatography
HR	Hypersensitive Response
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln
IAR	Institute of Agricultural Research, Ethiopia
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFAD	International Fund for Agricultural Development, Rome
IFPRI	International Food Policy Research Institute

IFSAT	International Food Sorghum Adaptation Trial
IGAD	Intergovernmental Authority on Development
IHAH	Instituto HondureZo de Antropologia e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agricultura
ILRA	International Livestock Research Institute, Niger
INCAP	Instituo de Nutrición de Centro America y Panama
INERA	Institut d'Environnement et de Recherche Agricoles
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigaciónes Agricoles, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico
INIPA	National Agricultural Research Institute, Peru
INRAN	Institut National de Recherches Agronomiques du Niger
INTA	Instito Nicaragüense de Tecnologia Agropecuaria, Nicaragua
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronómicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Rsearch Institute, Philippines
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISM	Integrated *Striga* Management
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
LC/MS	Liquid Chromatography/Mass Spectrometry
LCRI	Lake Chad Research Institute
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
MAVS	Ministerio de Agrcultura y Ganadería
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MHM	Millet Head Miner
MIAC	Mid-America International Agricultural Consortium
MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources, Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras

MSU	Mississippi State University
NAARP	Niger Applied Agricultural Research Project
NARO	National Agricultural Research Organization, Uganda
NARP	National Agricultural Research Project
NARS	National Agricultural Research System
NCRP	Niger Cereals Research Project
NGO	Non-Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory, Fort Collins, CO
NU	University of Nebraska
OAS	Organization of American States
OAU	Organization of African Unity
OFDA	Office of Foreign Disaster
OICD	Office of International Cooperation and Development
ORSTOM	L'Institut Français de Recherche Scientifique pour le Développement en Coopération, France
PCCMCA	Programa Cooperative Centroamericano para el Mejoramiento de Cultivos Alimenticios
PI	Principal Investigator
PL480	Public Law No. 480
PNVA	Malien Agricultural Extension Service
PPRI/DRSS	Plant Protection Research Institute/Department of Research and Specialist Services
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains in Central America
PRODAP	Proyecto de Desarrollo Rural en la Región Paracentral
PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Medical Research Council
PROFIT	Productive Rotations on Farms in Texas
PROMESA	Pryecto de Mejoramiento de Semilla - Nicaragua
PSTC	Program in Science and Technology Cooperation

PVO	Provate Volunteer Organization
QTL	Quantitative Trait Loci
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
RADRSN	Regional Advanced Disease Resistance Screening Nursery
RAPD	Random Amplified Polymorphic DNA
RARSN	Regional Anthracnose Resistance Screening Nursery
RFLP	Restriction Fragment Length Polymorphism
RFP	Request for Proposals
RI	Recombinant Inbred
RIIC	Rural Industry Innovation Centre, Botswana
ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Sorgho, Mali
ROCARS	Réseau Ouest et Centre Africain de Recherche sur le Sorgho, Mali
RPDRSN	Regional Preliminary Disease Resistance Screening Nursery
RVL	Royal Veterinary and Agricultural University, Frederiksberg, Denmark
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern Africa Development Community
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SANREM	Sustainable Agriculture and Natural Resource Management CRSP
SARI	Savannah Agricultural Research Institute, Ghana
SAT	Semi-Arid Tropics
SDM	Sorghum Downy Mildew
SDMVN	Sorghum Downy Mildew Virulent Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMIP	Sorghum and Millet Improvement Program
SMINET	Sorghum and Millet Improvement Network
SPARC	Strengthening Research Planning and Research on Commodities Project, Mali
SRVCO	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
TPHT	Tan Plant Hybrid Trial
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UANL	Universidad Autonóma de Nuevo Leon, Mexico
UHSN	Uniform Head Smut Nursery
UNA	Universidad Nacional Agraria, Nicaragua
UNAN	Universidad Nacional Autónoma de Nicaragua, Leon, Nicaragua
UNILLANOS	Universidad Technológica de los Llanos
UNL	University of Nebraska, Lincoln
UPANIC	Union of Agricultural Producers of Nicaragua
USA	United States of America
USAID	United States Agency for International Development
USAID-RAPID	Regional Activity to Promote Integration through Dialogue and Policy Implementation
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
WASDON	West Africa Sorghum Disease Observation Nursery
WASIP	West Africa Sorghum Improvement Program
WCAMRN	West and Central African Millet Research Network (ROCAFREMI), Mali
WCASRN	West and Central African Sorghum Research Network (ROCARS), Mali
WVI	World Vision International

From the left: Ms. Hannalene du Plessis, entomologist with ARC Grain Crops Institute and Dr. Bonnie Pendleton, INTSORMIL PI from West Texas A&M University participating in a field visit with the INTSORMIL External Evaluation Panel during their review of the Southern Africa Regional Program in March 2004.